SPIE. DEFENSE+ COMMERCIAL SENSING

CONNECTING MINDS. ADVANCING LIGHT.

2017 TECHNICAL SUMMARIES

Anaheim Convention Center
Anaheim, California, USA

Conferences & Courses:
9–13 April 2017

Expo:
11–13 April 2017

www.spie.org/DCS

DEFENSE + SECURITY

SYMPOSIUM CHAIR:

Donald A. Reago, Jr.
Director, U.S. Army Night Vision & Electronic Sensors Directorate (USA)

SYMPOSIUM CO-CHAIR:

Arthur A. Morrish
VP, Advanced Concepts & Technology, Raytheon Space and Airborne Systems (USA)

Contents

COMMERCIAL + SCIENTIFIC SENSING AND IMAGING

SYMPOSIUM CHAIR:

Majid Rabbani
Rochester Institute of Technology (USA)

SYMPOSIUM CO-CHAIR:

Robert Fiete
Harris Corp. (USA)

Contents

Conference 10177: Infrared Technology and Applications XLIII

SPIE. DCS DEFENSE+ SECURITY

Sunday - Thursday 9 –13 April 2017

Part of Proceedings of SPIE Vol. 10177 Infrared Technology and Applications XLIII

10177-1, Session 1

Performance estimation for SWIR cameras under OH night airglow illumination

Naoki Oda, Masahiko Sano, Souta Kagami, Yoshihiro Nambu, Tomo Tanaka, Tsuyoshi Yamamoto, NEC Corp. (Japan); Hiroshi Inada, Yasuhiro Iguchi, Tsukuru Katsuyama, Sumitomo Electric Industries, Ltd. (Japan)

In the wavelength region from 1um to 3um, Hydroxyl (OH) radicals in a layer located at ca. 90 km altitude dominate night airglow (NAG) emission whose spectrum shows a dip around 2.4um. It is well known that the intensity of the OH-NAG emission has a zenith angle dependence which is given by the so-called van Rhijn function. Atmospheric transmission also has zenith angle dependence. It is, therefore, not straightforward to estimate performance of SWIR (Short Wavelength Infrared) cameras under illumination of the OH-NAG.

The authors estimate signal-to-noise ratios (SNRs) and contrasts for both InGaAs SWIR camera (cut-off wavelength ~1.7um) and type II superlattice (T2SL) SWIR camera (cut-off wavelength ~2.3um), under a certain situation, e.g. human as a target and vegetation as surroundings. In estimating the number of signal electrons, the brightness of OH-NAG, reflectance spectra of human skin and vegetation, and measured spectral properties of quantum efficiencies for both InGaAs and T2SL detectors are used, while atmospheric transmission spectra are calculated with MODTRAN for several zenith angles. As to noise electrons, shot noise resulting from the dark current of InGaAs or T2SL detector is added to photon noise and ROIC (Read-Out Integrated Circuit) noise.

Finally, the SNR values and contrasts for both cameras will be compared, assuming that the cameras have the same lens with a certain F number, the same array format and the same integration time.

10177-2, Session 1

Development of low-SWaP and low-noise InGaAs detectors

Avraham R. Fraenkel, SCD SemiConductor Devices (Israel)

In recent years SCD has developed InGaAs/InP technology for Short-Wave Infrared (SWIR) imaging. The first product, Cardinal 640, has a 640?512 (VGA) format at 15μm pitch, and more than a thousand units have already been delivered to customers. Recently we have also introduced Cardinal 1280 which is an SXGA array with 10μm pitch aimed for long-range high end platforms [1].

One of the big challenges facing the SWIR technology is its proliferation to widespread low cost and low SWaP applications, specifically Low Light Level (LLL) and Image Intensifier (II) replacements. In order to achieve this goal we have invested and combined efforts in several design and development directions:

1. Optimization of the InGaAs pixel array, reducing the dark current below 1fA at 20? C in order to save TEC cooling power under harsh light and environmental conditions.

2. Design of a new "Low Noise" ROIC with < 15e noise floor and improved active imaging capabilities

3. Design of compact, low SWaP and low cost packages. In that context we have developed 2 types of packages: a non-hermetic package with thermo-electric cooler (TEC) and an hermetic TEC-Less ceramic package.

4. Development of efficient TEC-Less algorithms for optimal imaging at both day-light and low light level conditions.

The result of these combined efforts is a compact low SWaP detector that provides better performance than a Gen III image intensifier. In this paper we will present results from various lab and field experiments that will support this claim.

[1] "High Definition 10μm pitch InGaAs detector with Asynchronous Laser Pulse Detection mode" SPIE - DCS 2016.

10177-3, Session 1

Development of InGaAs/GaAsSb type-II QW SWIR focal plane array with cutoff-wavelength of 2.5 μm

Hiroshi Inada, Kenichi Machinaga, Sundararajan Balasekaran, Kouhei Miura, Takahiko Kawahara, Masaki Migita, Hiroshi Obi, Takuma Fuyuki, Kei Fujii, Takashi Ishizuka, Yasuhiro Iguchi, Sumitomo Electric Industries, Ltd. (Japan)

Short wavelength infrared (SWIR) focal plane array (FPA), has an attractive application such as night vision, chemical sensing, remote monitoring of infrastructure and so on. In spite of the many trials on alternative material, FPA with HgCdTe (MCT) keep predominant position in SWIR region, especially over wavelength of 1.7μm. However, MCT is not suitable for commercial application due to its containing environmentally hazardous substances. For a commercial use, so far, Sumitomo Electric has developed FPA with InGaAs/GaAsSb type-II quantum well structures, which are based on maturity of III-V compound semiconductor epitaxial and device fabrication technology. Recently, we have successfully extended cutoff-wavelength up to 2.5μm, which showed comparable spectral range to MCT. By adopting asymmetrically the thicker layer of InGaAs in quantum wells, we modified spectral response related to the type-II transition in the quantum well. The 250-pair InGaAs/GaAsSb quantum wells structure lattice-matched InP substrates were grown by metal organic vaper phase epitaxy. The p-n junction of each pixel was formed by selective zinc diffusion. Dark current density was less than 1μA/cm2 at 213K, which means comparably to low dark current of MCT. Temperature dependence of dark current density showed diffusion current limited mode. These results means InGaAs/GaAsSb type-II FPA is a promising candidate for commercial applications. In the presentation, we will report the characteristics of InGaAs/GaAsSb type-II quantum well and the operational results of SWIR FPA.

10177-4, Session 1

Recent advances in antimonide-based gap-engineered Type-II superlattices material system for 2 and 3 colors infrared imagers *(Invited Paper)*

Manijeh Razeghi, Northwestern Univ. (United States)

Infrared imagers demand performances for higher detectivity, higher operating temperature, higher resolution, and multi-color detection all accomplished with better yield and lower manufacturing costs. We demonstrated the Antimonide-based gap-engineered Type-II superlattices (T2SLs) material system as a potential alternative for Mercury-Cadmium-Telluride (HgCdTe) technology in all different infrared detection regimes from short to very long wavelengths for the next generation of infrared imagers.

In this talk, I will present the most recent research results on atomic and gap engineered of Antimonite-based Type-II superalattice, multi colors detectors and focal plane arrays for different infrared regimes in my group (the Center for Quantum Devices at northwestern).

10177-5, Session 1

Al/Sb free InGaAs unipolar barrier photodetectors

Fatih Uzgur, Utku Karaca, Ekin Kızılkan, Serdar Kocaman, Middle East Technical Univ. (Turkey)

Barrier structures are known for reducing dark current mechanisms in the infrared detectors leading to higher operation temperatures with the same detector performances. However, obtaining zero valance band offset and pre-aligned fermi levels to form a barrier brings material limitations. Here, novel unipolar barrier photodetectors benefiting from the variable band gap property of InGaAs are proposed for the short wave infrared (SWIR) region. Instead of using Al or Sb based materials; absorber, barrier and contact layers are all obtained with utilizing InGaAs by varying the mole fraction of In and Ga. In order to remove the valance band offset between absorber and barrier, graded composition layers are used at the interfaces and delta doping layers are introduced to cancel the quasi electric field created by graded layers. Numerical simulations are performed in order to insert this barrier optimally into "nBn" and "nBp" type photodetectors. In the nBp case, the barrier is designed to be in the n type absorber side of the depletion region in order to block Shockley-Read-Hall, band to band tunneling and trap assisted tunneling dark current mechanisms as well as surface leakage current. Surface leakage component is particularly important as it is the most significant dark current component in the mesa type photodetectors which are important for multi-color and hyperspectral imaging applications with low cross talk. The proposed barrier structure have been utilized in this study is not limited to SWIR and can be applied to variety of materials operating in various infrared regions.

10177-6, Session 1

Low-noise readout circuit for SWIR focal plane arrays

Oguz Altun, ASELSAN A.S. (Turkey)

This paper reports a 640x512 SWIR ROIC with 15um pixel pitch that is designed and fabricated using 0.18um CMOS process. Main challenge of SWIR ROIC design is related to input circuit due to pixel area and noise limitations. In this design, CTIA with single stage amplifier is utilized as input stage. The pixel design has three pixel gain options; High Gain (HG), Medium Gain (MG), and Low Gain (LG) with corresponding Full-Well-Capacities of 18.7ké, 190ké and 1.56Mé, respectively. According to extracted simulation results, 5,9é noise is achieved at HG mode and 200é is achieved at LG mode of operation. The ROIC can be programmed through an SPI interface. It supports 1, 2 and 4 output modes which enables the user to configure the detector to work at 30, 60 and 120fps frame rates. In the 4 output mode, the total power consumption of the ROIC is less than 120mW. The ROIC is powered from a 3.3V analog supply and allows for an output swing range in excess of 2V. Anti-blooming feature is added to prevent any unwanted blooming effect during readout. Characterization of the ROIC is still on-going and results should be available soon.

10177-7, Session 1

Progress on MCT SWIR modules for passive and active imaging applications

Rainer Breiter, Matthias Benecke, Detlef Eich, Heinrich Figgemeier, Andreas Weber, Joachim C. Wendler, Alexander Sieck, AIM INFRAROT-MODULE GmbH (Germany)

For SWIR imaging applications, based on AIM's state-of-the-art MCT IR technology specific detector designs for either low light level imaging or laser illuminated active imaging are under development.

For imaging under low-light conditions a low-noise 640x512 15µm pitch ROIC with CTIA input stages and correlated double sampling was designed. The ROIC provides rolling shutter and snapshot integration. To reduce size, weight, power and cost (SWaP-C) a 640x512 format detector in a 10µm pitch is been realized. While LPE grown MCT FPAs with extended 2.5µm cut-off have been fabricated and integrated also MBE grown MCT on GaAs is considered for future production. The module makes use of the extended SWIR (eSWIR) spectral cut-off up to 2.5µm to allow combination of emissive and reflective imaging by already detecting thermal radiation in the eSWIR band. A demonstrator imager was built to allow field testing of this concept. A resulting product will be a small, compact clip-on weapon sight.

For active imaging a detector module was designed providing gating capability. SWIR MCT avalanche photodiodes have been implemented and characterized on FPA level in a 640x512 15µm pitch format. The specific ROIC provides also the necessary functions for range gate control and triggering by the laser illumination. The FPAs are integrated in a compact dewar cooler configuration using AIM's split linear cooler. A command and control electronics (CCE) provides supply voltages, biasing, clocks, control and video digitization for easy system interfacing. First lab and field tests of a gated viewing demonstrator have been carried out and the module has been further improved.

The paper will present the development status and performance results including field trials of AIM's MCT based SWIR modules and sights for imaging applications.

10177-8, Session 1

An extended spectrum SWIR camera with a user-accessible dewar for new applications in the SWIR

Brendan W. Benapfl, John L. Miller, Hari Vemuri, Raja Krishnamoorthi, Siva Sivananthan, Episensors, Inc. (United States)

Episensors has developed a series of extended short wave infrared (eSWIR) cameras based on high-Cd concentration $Hg_{1-x}Cd_xTe$ absorbers. The cameras have a band pass extending to 3 microns cutoff wavelength, opening up new applications compared to traditional InGaAs-based cameras. Applications and uses will be discussed and examples given. A liquid nitrogen pour-filled version was initially developed. This was followed by a compact Stirling-cooled version with detectors operating at 200 K. Each camera has unique sensitivity and performance characteristics. The cameras' size, weight and power specifications will be presented along with images captured with band pass filters and eSWIR sources to demonstrate spectral response beyond 1.7 microns. The soft seal dewars of the cameras are designed for accessibility, and can be opened and modified in a standard laboratory environment. This modular approach allows user flexibility for swapping internal components such as cold filters and cold stops. The core electronics of the Stirling-cooled camera are based on a single commercial FPGA that also performs on-board non-uniformity corrections, bad pixel replacement, and directly drives an HDMI display. This work was supported by a DARPA SBIR contract. The views, opinions, and/or findings expressed are those of the authors and should not be interpreted as representing the official views or policies of the Department of Defense or the U.S. Government.

10177-9, Session 2

Numerical modeling of a dark current suppression mechanism in dense detector arrays

Andreu L. Glasmann, Taylor Hubbard, Enrico Bellotti, Boston Univ. (United States)

As material growth and processing has improved, state of the art infrared detector arrays are limited by material properties and not processing or growth quality. In particular, the dark current characteristics as a function of temperature are controlled by intrinsic recombination mechanisms. In this work, we present a unique detector architecture that allows for dark current suppression below the fundamental diffusion limit. We have extensively studied this effect, and report results on dark current reduction as functions of junction depth, area, placement, and geometry.

As the pixel pitch is reduced below the minority carrier diffusion length in a planar array, the carrier profile fails to return to its equilibrium value away from the junction. In fact, the profile reaches a maximum value halfway between neighboring diodes. Since the diffusion current is proportional to the gradient of the minority carrier profile throughout the device, there is no lateral diffusion current at the symmetry planes between neighboring diodes. By inserting additional junctions at these critical positions, we can reduce the dark current. Furthermore, this technique exploits basic semiconductor device physics, and can be applied to any diffusion limited material system. Finally, we offer discussions on the impact on quantum efficiency, modulation transfer function, and insight into practical detector implementation.

10177-10, Session 2

Functionalization of graphene by size and doping control and its optoelectronic applications

Libin Tang, Kunming Institute of Physics (China)

Abstract: Graphene has received intensive attention in recent years because of the special physical and chemical properties. However, up to now graphene has not been widely used in optoelectronic fields yet, which is mainly caused by its semimetal properties. Therefore, changing its properties from semimetal to semiconductor is becoming a focal point. Recently, aiming at tuning the energy band of graphene, we have carried out systematic studies on the preparations of graphene based materials and devices, the CVD growth techniques of monolayer and double layer graphenes have been developed, the large-area doped graphene films have been fabricated to tune the structure-related optical and electrical properties. A novel graphene oxide (GO) preparation method namely "Tang-Lau Method" has been invented, the graphene quantum dots growths by microwave assisted hydrothermal method and "Soft-Template Method" have been developed, the Cl, S and K doped graphene quantum dots preparations by hydrothermal methods have also been invented. Systematic investigations have been carried out for the effect of preparation parameters on the properties of graphene based materials, the effects of size, doping elements on the energy level of graphene based materials have been explored and discussed. Based on the semiconducting graphene based materials, some novel room temperature photodetectors covering detection wavebands from UV, Vis and NIR have been designed and fabricated.

10177-11, Session 2

Military reconnaissance platform for the spectral range from the visible to the MWIR

Martin Gerken, Jörg Fritze, Mario O. Münzberg, Martin Weispfenning, Airbus Defence and Space (Germany)

The reconnaissance capability of a military observation and targeting platform is mainly driven by the performance of the used sensors. In general the MWIR thermal imager is the primary sensor and the use of a visible camera increases the identification capability of the platform during day for very long observation ranges. In addition to the imaging sensors a laser pointer, a Laser rangefinder (LRF), and a combined laser rangefinder/designator (LRF/D) completes the sensor suite. As LRF a single pulse eyesafe rangefinder based on an OPO shifted Nd:YAG transmitter can be used. The alternative LRF/D uses an diode laser pumped dual wavelength OPO/Nd:YAG transmitter and can be operated either at 1570 nm or at 1064 nm with a pulse rate of maximum 25 pps.

A MWIR thermal imager [1] with a 1280x1024 MWIR detector and an optical zoom range between 1.2° and 20° horizontal fields of view provides a HD-SDI video stream in in the 720p or 1080p standard. A camera build in software image stabilizer and a smart tone mapping algorithm improves the reconnaissance tasks for the observer.

A combined camera with one common entrance optics covers the visible, NIR and SWIR spectral range [2]. The resolution of the color camera Si-CMOS chip is 1920x1080 and of the InGaAs focal plane array it is 640x512 detector pixel.

The combined VIS/NIR/SWIR camera provides improved ranging under haze and mist atmospheric conditions and also the detection of laser spots e.g. of the integrated laser designator with high sensitivity in the spectral range between 450 nm up to 1700 nm, whereas most of the military lasers are operating in the NIR and SWIR spectral band [3].

The combination of the sensors in the platform increases significantly the operational use. The main application of the described platform is on military scout vehicles. However the used sensors are also integrated in a targeting platform with similar performances but other environmental demands.

The possibilities, improvements in comparison of existing platforms and potential upgrades are discussed.

[1] J. Fritze, M. Münzberg, "The new megapixel thermal imager family". Proc. SPIE 8012-04 (2011).

[2] M. Gerken, B. Achtner, M. Kraus, T. Neumann, M. Münzberg, "Shortwave infrared camera with extended spectral sensitivity". Proc SPIE 8353-2 (2012).

[3] M. Hübner, M. Gerken , B. Achtner , M. Kraus , M. Münzberg, "Compact multispectral continuous zoom camera for color and SWIR vision with integrated laser range finder", Proc SPIE 9070-64 (2014).

10177-12, Session 2

High-resolution VIS/SWIR low-light-level digital imaging sensors and goggle/camera systems based on EBAPS(R) technology

Michael J. Jurkovic, Kenneth A. Costello, Verle W. Aebi, Intevac Photonics, Inc. (United States)

Recent progress on development efforts to field high-resolution, low-light-level, TE-cooled SWIR & VIS/SWIR imaging sensors, cameras and portable/head-mounted systems that are based on, and improve upon, Intevac's Transferred-Electron InGaAs(P) Photocathode and Electron Bombarded Active Pixel Sensor(EBAPS®) technologies is presented. Using the volume-production ISIE11 CMOS anode (2MP+, 10.8um-pixel, 12-bit, 1600x1200 @60Hz+ as is incorporated into EBAPS that are currently featured in F35 Joint-Strike Fighter Helmets and Apache Helicopters) as a low-cost demonstration vehicle, progress on the advancement of production paths for sensors/systems that extend performance metrics toward the following goals are reported: high resolution (high electron-optics-limited-MTF at Nyquist), high-sensitivity at low-light-level (extremely low dark current and effective read noise less than 1e- near room temperature), blue-enhanced spectral response, and wide extended dynamic range.

10177-13, Session 3

Airborne thermal infrared remote sensing using HyTES *(Invited Paper)*

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

No Abstract Available

10177-14, Session 3

Recent progress of pushbroom infrared hyperspectral imager in SITP *(Invited Paper)*

Yueming Wang, Weida Hu, Shanghai Institute of Technical Physics of the Chinese Academy of Sciences (China)

In the past decades, hyperspectral imaging technologies was well developed in SITP, CAS. Many innovations for system design and key parts of hyperspectral imager were finished. First airborne hyperspectral imager operating from VNIR to TIR in the world was emerged in SITP. It is well known as OMIS. Some new technologies were introduced to improve the performance of hyperspectral imaging system in these years. A high spatial spaceborne hyperspectral imager was launched with Tiangong-1 spacecraft in Sep.29,2011.Thanks for ground motion compensation and prismatic spectrometer, a large amount of hyperspectral imagery with high sensitivity and good quality were acquired in the past years. Some important phenomena were observed. To diminish spectral distortion and expand field of view, new type prismatic imaging spectrometer based spherical prism were proposed . A prototype of hyperspectral imager based curved fused silica prism were manufactured, which can operate from 400nm~2500nm. We also make progress in the development of LWIR hyperspectral imaging technology.Compact and low F number LWIR imageing spectrometer was designed, manufactured and integrated. The spectrometer operated in a cryogenically-cooled vacuum box for background radiation restraint. The system performed well during flight experiment in an airborne platform. Thanks high sensitivity FPA and high performance optics, spatial resolution and spectral resolution and SNR of system are improved enormously. However, more work should be done for high radiometric accuracy in the future.

10177-15, Session 3

Infrared hyperspectral imaging miniaturized for UAV applications *(Invited Paper)*

Michele Hinnrichs, Bradford R. Hinnrichs, Pacific Advanced Technology, Inc. (United States); Manuel Toledo-Quinones, Univ. de Puerto Rico Mayagüez (United States)

This paper is a follow-on paper to two previous paper presented at SPIE in 2012 and 2014 describing a design for a snapshot multi-spectral hyperspectral camera for CBRNE applications. An update on the final sensor development will be given. Under support by the US Army SBIR program and with support from ONR a hyper-spectral MWIR/LWIR camera was developed. The infrared hyperspectral cameras both use a 640 x 512, 15 micron pixel pitch with InSb for the MWIR and SLS for the LWIR focal plane array. The micro-optics (lenslet arrays) are configured in a 2 x 2 array giving 4 simultaneous different spectral images consisting of 256 x 256 pixels each. The lenslet array is translated using piezo motors to cover the full hyperspectral bands of 3 to 5 microns for the MWIR and 8 to 11 microns for the LWIR.

By multiplexing 4 simultaneous spectral images an entire hyperspectral data cube can be collected rapidly and thus eliminate or significantly reduce the temporal variation which reduces motion sensitivity between spectral images and enhances real-time image processing capability.

This paper will describe the design of the electro-optical system and how this is used to collect and perform spectral image processing in real-time using an embedded FPGA processor.

10177-16, Session 3

Remote measurement with imaging spectroscopy: solids, liquids, and gases *(Invited Paper)*

Robert O. Green, Jet Propulsion Lab. (United States)

No Abstract Available

10177-17, Session 3

MWIR hyperspectral imaging with the MIDAS instrument *(Invited Paper)*

Casey I. Honniball, Robert Wright, Paul G. Lucey, Hawai'i Institute of Geophysics and Planetology (United States); Alain S. J. Khayat, Hawai'i Institute of Geophysics and Planetology (United States)

Hyperspectral imaging (HSI) in the Mid-Wave InfraRed (MWIR, 3-5 microns) can provide information on a variety of science applications from NASA applications like the chemical composition of lava lakes on Io, a moon of Jupiter, to the amount of carbon liberated into the Earth's atmosphere during a wildfire. However, the limited signal available in the MWIR presents technical challenges to achieving high signal-to-noise ratio, therefore it is typically necessary to cryogenically cool MWIR instruments. With the recent improvements to microbolometer technology and emerging interferometric techniques we have shown in Hawaii that uncooled microbolometers coupled with a Sagnac interferometer can achieve high signal-to-noise ratios for long-wave infrared HSI. To explore if this technique holds in the MWIR, with funding from NASA, we are building the Miniaturized Infrared Detector of Atmospheric Species (MIDAS). Using standard characterization tests we are comparing MIDAS against a cooled photon detector to evaluate the MIDAS instruments ability to quantify gas concentrations. We are also developing atmospheric modeling codes that will inform us on the science limitations of MIDAS as well as what science objectives MIDAS will excel at. To verify our results from lab characterization and our atmospheric modeling code we will simulate science applications with gas cells filled with varying gas concentrations and varying source temperatures. Results from these tests will be presented.

10177-18, Session 3

CubeSat infrared atmospheric sounder (CIRAS) NASA InVEST technology demonstration *(Invited Paper)*

Thomas S. Pagano, Jet Propulsion Lab. (United States)

The CubeSat Infrared Atmospheric Sounder (CIRAS) will measure upwelling infrared radiation of the Earth in the MWIR region of the spectrum from space on a CubeSat. The observed radiances can be assimilated into weather forecast models and be used to retrieve lower tropospheric temperature and water vapor for climate studies. Multiple units can be flown to improve temporal coverage.

CIRAS incorporates three new instrument technologies. The first is a 2D array of High Operating Temperature Barrier Infrared Detector (HOT-BIRD) material, selected for its high uniformity, low cost, low noise and higher operating temperatures than traditional materials. The detectors are hybridized to a commercial ROIC and commercial camera electronics. The second technology is an MWIR Grating Spectrometer (MGS) designed to provide imaging spectroscopy for atmospheric sounding in a CubeSat volume. The MGS employs an immersion grating or grism, has no moving parts, and is based on heritage spectrometers including the OCO-2. The third technology is a Black Silicon infrared blackbody calibration target. The black silicon offers very low reflectance over a broad spectral range on a flat

surface and is more robust than carbon nanotubes. JPL will also develop the mechanical, electronic and thermal subsystems for CIRAS payload. The spacecraft will be a commercially available CubeSat. The integrated system will be a complete 6U CubeSat capable of measuring temperature and water vapor profiles with good lower tropospheric sensitivity. The CIRAS is the first step towards the development of an Earth Observation Nanosatellite Infrared (EON-IR) operational sounder for the National Oceanic and Atmospheric Administration (NOAA).

10177-19, Session 3

An innovative multispectral EVS *(Invited Paper)*

Ofer Nesher, Avi Noy, Elbit Systems Ltd. (Israel)

Landing below 200ft altitude can be achieved by runway light detection, either by the pilot or by Enhanced Vision System (EVS). EVS today should provide pilots with the ability to safely conduct landing operations in zero-zero conditions. This implies high quality situation awareness and runway light detection (LED and incandescent bulbs) at adverse weather conditions. Elbit systems aerospace has developed and certified a novel EVS which is part of the ClearVisionTM system based on multispectral cameras, real time algorithms and multichannel fusion for early runway light detection.

In this paper we describe the key concepts of the ClearVision EVS. The basic physical model includes runaway light sources modeling, various atmospheric models, multi-spectral detection algorithms and a method for early runway light detection. To support the development, a multi-layer validation and verification approach was developed, including the use of computer simulation, calibrated fog chamber and flight tests. Characterizations and flight tests results of the ClearVision will be presented, validating the physical model and the performance of the ClearVision.

10177-20, Session 3

NASA/ESTO Investments in remote sensing technologies *(Invited Paper)*

Sachidananda R. Babu, NASA Goddard Space Flight Ctr. (United States)

For more then 18 years NASA Earth Science Technology Office has been investing in remote sensing technologies. During this period ESTO has invested in more then 900 tasks. These tasks are managed under multiple programs like Instrument Incubator Program (IIP), Advanced Component Technology (ACT), Advanced Information Systems Technology (AIST), In-Space Validation of Earth Science Technologies (InVEST), Sustainable Land Imaging –Technology (SLI-T) and others. This covers the whole spectrum of technologies from component to full up satellite in space and software. Over the years many of these technologies have been infused into space missions like Aquarius, SMAP, CYGNSS, SWOT, TEMPO and others.

Over the years ESTO is actively investing in Infrared sensor technologies for space applications. Recent investments have been for SLI-T and InVEST program. On these tasks technology development is from simple Bolometers to Advanced Photonic waveguide based spectrometers. Some of the details on these missions and technologies will be presented.

10177-21, Session 4

VISTA video and overview *(Invited Paper)*

Meimei Z. Tidrow, U.S. Army Night Vision & Electronic Sensors Directorate (United States)

No Abstract Available

10177-22, Session 4

Antimonide type-II superlattice barrier infrared detectors *(Invited Paper)*

Sarath D. Gunapala, David Z. Ting, Alexander Soibel, Areqou Khoshakhagh, Linda Höglund, Sam A. Keo, Sir B. Rafol, Cory J. Hill, Anita M. Fisher, Edward M. Luong, John K. Liu, Jason M. Mumolo, Brian J. Pepper, Sarath D. Gunapala, Jet Propulsion Lab. (United States)

The unipolar barrier photodetector architecture provides an effective means for lowering generation-recombination dark current by suppressing Shockley-Read-Hall processes, and for reducing surface leakage dark current. This has been especially beneficial for III-V semiconductor based infrared photodiodes, which traditionally tend to suffer from excess depletion dark current and lack of good surface passivation. The antimonide based type-II superlattices have further beneficial properties such as tunneling and Auger suppression, as well as providing continuously adjustable cutoff wavelength ranging from the SWIR to the VLWIR. In this work we discuss the advances in type-II superlattice unipolar barrier infrared detectors and focal plane arrays at the NASA Jet Propulsion Laboratory in recent years.

10177-23, Session 4

Trusted entity materials analysis under VISTA *(Invited Paper)*

Edward H. Aifer, Nadeem A. Mahadik, Mark E. Twigg, Michael Katz, Sergey I. Maximenko, Jill A. Nolde, Chaffra A. Affouda, Eric M. Jackson, Chadwick L. Canedy, Erin R. Cleveland, Igor Vurgaftman, Jerry R. Meyer, U.S. Naval Research Lab. (United States)

Under the VISTA program, a range of new materials were designed to yield improved infrared sensor performance. Occasionally, however, desired improvements were masked by the influence of material defects in the actual samples. One of the key tasks then for “trusted entities” under the VISTA program, was to identify specific non-idealities occurring in the as-grown material that tended to degrade electronic properties. So, here we review some of the materials analysis techniques that we used as a “trusted Entity” under the VISTA program to measure the structural and electronic properties of type-II superlattice material grown by various institutions. These include the use of X-ray analysis to extract interfacial structure, plan-view and cross-sectional electron beam induced current (EBIC) analysis to identify active defects and to measure minority carrier diffusion length, and transmission electron microscopy (TEM) to identify specific defect structures in type-II superlattices and associated material.

10177-24, Session 4

Production manufacturing of 5” diameter gallium antimonide substrates *(Invited Paper)*

James P. Flint, Gordon Dallas, Annette Bollaert, Galaxy Compound Semiconductors, Inc. (United States)

No Abstract Available

10177-25, Session 4

Large diameter Epi-ready GaSb substrate manufacturing *(Invited Paper)*

Paul R. Pinsukanjana, Intelligent Epitaxy Technology, Inc. (United States)

No Abstract Available

10177-26, Session 4

Multi-wafer production MBE capabilities for Sb-based type-II SLS IR detectors *(Invited Paper)*

Paul R. Pinsukanjana, Intelligent Epitaxy Technology, Inc. (United States)

No Abstract Available

10177-27, Session 4

MBE growth of advanced Sb-based IR photodetector structures for the VISTA Program *(Invited Paper)*

Amy W. K. Liu, Dmitri Lubyshev, Joel M. Fastenau, Michael Kattner, Phillip Frey, Ying Wu, IQE Inc. (United States)

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, with mid-wave and long-wave IR photodetectors progressing toward commercial manufacturing. To succeed, they must move from research laboratory settings to general semiconductor production, where high-quality, large-size GaSb-based epitaxial wafers are highly desirable. Participation in the VISTA programs has accelerated our progress in the development of a manufacturable epitaxial growth technology for this material system in the last 5 years. The program provided a framework of collaboration with various VISTA partners, with strong support in areas of structure design, discussions of growth experience, and timely feedback of materials characterization and diode fabrication and testing. Within this framework, and through our own systematic studies and improved understanding of epiwafer growth requirements, we were able to demonstrate high quality growths of Sb-based IR detector epiwafers. By working closely with GaSb substrate vendors, we have achieved consistent delivery of 4-inch epiwafers with comparable device performance to that of 3-inch materials, and also demonstrated the same performance on 5-inch diameter substrates. Material characterization data including surface morphology, structural and optical quality, and uniformity obtained from Sb-based detector wafers grown under the VISTA program will be discussed.

10177-28, Session 4

Advances in III-V superlattice-based dual-band MWIR/LWIR FPAs at HRL *(Invited Paper)*

Pierre-Yves Delaunay, Brett Z. Nosho, Alexander R. Gurga, Sevag Terterian, Wyatt Strong, Rajesh D. Rajavel, HRL Labs., LLC (United States)

No Abstract Available

10177-29, Session 4

Advances in bulk InAsSb and III-V superlattice-based HOT-MWIR detector technology *(Invited Paper)*

Hasan Sharifi, Mark S. Roebuck, Sevag Terterian, James Jenkins, Bor-An Tu, Wyatt Strong, Terry J. De Lyon, Rajesh D. Rajavel, HRL Labs., LLC (United States); John T. Caulfield, Jon Paul Curzan, Cyan Systems (United States)

No Abstract Available

10177-30, Session 5

III-V strained layer superlattice infrared detector characteristics and FPA performance *(Invited Paper)*

Edward P. Smith, Raytheon Co. (United States)

No Abstract Available

10177-31, Session 5

8um manufacturing for low cost advanced Dewars *(Invited Paper)*

Brendan S. McCay, Lockheed Martin Corp. (United States)

No Abstract Available

10177-32, Session 5

Implementing VISTA technology in a III-V detector foundry *(Invited Paper)*

Dave Forrai, L-3 Cincinnati Electronics (United States)

No Abstract Available

10177-33, Session 5

Current performance of commercial antimony-based midwave and longwave infrared focal plane arrays *(Invited Paper)*

Mani Sundaram, QmagiQ, LLC (United States)

No Abstract Available

10177-34, Session 5

SLS-based camera development at FLIR systems *(Invited Paper)*

Scott Way, FLIR Systems, Inc. (United States)

No Abstract Available

10177-35, Session 5

Digital ROIC developments *(Invited Paper)*

Megan Blackwell, MIT Lincoln Lab. (United States)

No Abstract Available

10177-36, Session 6

Photodetector development at Fraunhofer IAF: From LWIR to SWIR operating from cryogenic close to room temperature

Volker Daumer, Vera Gramich, Raphael Müller, Johannes Schmidt, Frank Rutz, Tim O. Stadelmann, Andreas Wörl, Wolfgang Bronner, Robert Rehm, Fraunhofer-Institut für Angewandte Festkörperphysik (Germany)

Photodetectors in the non-visible region of the electromagnetic spectrum are very important for security, defense and space applications as well as industrial and scientific applications. The research activities at Fraunhofer IAF cover a broad range of III-V material systems. Whereas SWIR detectors are realized by InGaAs/InP structures, InAs/GaSb type-II superlattice (T2SL) infrared detectors are our favorable solutions for the spectral bands from MWIR to LWIR.

This talk will summarize the recent achievements in these research areas. The introduction of heterojunction concepts to our well-established bi-spectral InAs/GaSb T2SL MWIR detector shows a significant reduction in the dark current. For cut-off wavelength near 5 μm a dark current density of 5x10-9 A/cm? has been measured. This allows the operation at increased temperature without any loss in performance. Fraunhofer IAF has recently expanded its capabilities by establishing a packaging technology consisting of indium bump formation and flip-chip bonding. First results will be presented. The highly flexible T2SL detector technology is currently used to develop photoconductive as well as photovoltaic detection devices in the spectral region between 3-12 μm operating near room temperature. We have successfully adapted the superlattice empirical pseudopotential method to calculate band-gap engineered device structures operating at room temperature. In the European pilot line MIRPHAB (Mid InfraRed PHotonics devices fABrication for chemical sensing and spectroscopic application) these T2SL detectors will be integrated with thermoelectric coolers in the detection unit. Finally an outlook on the ongoing development of photodetectors at Fraunhofer IAF will be presented.

10177-37, Session 6

Growth and characterization of InGaAs/InAsSb strained layer superlattice infrared detectors

Gamini Ariyawansa, Charles J. Reyner, Joshua M. Duran, Elizabeth H. Steenbergen, John E. Scheihing, Air Force Research Lab. (United States); Narae Yoon, Univ. of Illinois at Urbana-Champaign (United States); Daniel M. Wasserman, The Univ. of Texas at Austin (United States)

Type-II strained layer superlattices (SLS) are an active research topic in the MBE community, and applications for SLS detectors continue to grow. SLS detector technology has already reached the commercial market because of improvements to material quality, device design, and device fabrication. Despite this progress, the optimal superlattice design has not been agreed upon, and at various times has been believed to be InAs/GaSb, InAs/InGaSb, or InAs/InAsSb. Building on these, in this talk, we investigate the properties of a new mid-wave infrared SLS material: InGaAs/InAsSb SLS. The ternary InGaAs/InAsSb SLS has two main advantages over other SLS designs: greater support for strain compensation and enhanced absorption due to increased electron-hole wavefunction overlap. Here, we compare three ternary SLSs, with approximately the same bandgap (0.240 eV at 150 K), comprised of Ga fractions of 5%, 10%, and 20% to a reference sample with 0% Ga. Enhanced absorption is both theoretically predicted and experimentally realized. Furthermore, the characteristics of ternary SLS infrared detectors based on an nBn architecture are reported and exhibit nearly state-of-the-art dark current performance with minimal growth optimization. Standard material and device characterization information, including photoluminescence, x-ray diffraction, atomic force microscopy, dark current, and external quantum efficiency, are provided.

10177-38, Session 6

T2SL production and development at IRnova: From SWIR to VLWIR detection

Linda Höglund, Rickard Marcks von Würtemberg, Carl Asplund, Himanshu Kataria, Hithesh K. Gatty, Anders Gamfeldt, Eric M. Costard, IRnova AB (Sweden)

IRnova has recently demonstrated excellent manufacturability for 320 x 256 MW type-II FPAs based on InAs/GaSb superlattices. In this paper, development towards higher operating temperature, smaller pitch and larger format arrays will be presented for these MW detectors. Furthermore, MW-MW dual band detectors have been realized by using pixel filters fabricated on top of these FPAs. The pixel filters were designed to transmit infrared radiation in the 3.5 um-4.1 um wavelength region and to completely block light shorter than 3.5 um. By comparing the signals of filtered and unfiltered pixels, excellent contrast between the two bands were obtained. With slight modifications of the MWIR detector structure, SWIR and VLWIR detectors have also been realized and the latest results from this development will be presented.

10177-40, Session 6

Development of Type-II superlattice VLWIR detectors in JAXA

Michito Sakai, Junpei Murooka, Ayaka Kumeta, Toshiyoshi Kimura, Japan Aerospace Exploration Agency (Japan); Hiroshi Inada, Yasuhiro Iguchi, Sumitomo Electric Industries, Ltd. (Japan); Yuta Hiroe, Masafumi Kimata, Ritsumeikan Univ. (Japan)

One of JAXA's future missions, using an imaging Fourier Transform Spectrometer (FTS), requires the focal plane array (FPA) that has high sensitivity and a very long-wavelength infrared (VLWIR) cutoff wavelength. Since a Type-II superlattice (T2SL) is the only known infrared material to have a theoretically predicted performance superior to that of HgCdTe and the cutoff wavelength can be tailored in the wavelength region of 3-30 μm, we started the research and development of the T2SL detector in 2009. In order to confirm our final goal which is to realize an FPA with a cutoff wavelength of 15 μm, we first fabricated the 320 x 256 InAs/GaInSb T2SL FPA with a cutoff wavelength of 15 μm, and the large-format 640 x 512 T2SL FPA is followed because the other missions, using an infrared imager, require the large-format FPA. We show the development status and performance of these T2SL VLWIR detectors including the image taken by these T2SL FPAs with a cutoff wavelength of 15 μm.

10177-99, Session 6

InAs/GaSb type-II superlattice infrared detectors: three decades of development

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

In 1959, Lawson and co-workers publication triggered development of variable band gap Hg1–xCdxTe (HgCdTe) alloys providing an unprecedented degree of freedom in infrared detector design. At present, HgCdTe is the most widely used variable gap semiconductor for infrared (IR) photodetectors. Over the years it has successfully fought off major challenges from other materials, but despite that it has more competitors today than ever before. It is interesting, however, that none of these competitors can compete in terms of fundamental properties. They may promise to be more manufacturable, but never to provide higher performance.

Recently, there has been considerable progress towards III-V antimonide-based low dimensional solids development and device design innovations. From a physics point of view, the type-II InAs/GaSb superlattice is an extremely attractive proposition. Their development results from two primary motivations: the perceived challenges of reproducibly fabricating high-operability HgCdTe FPAs at reasonable cost and theoretical predictions of lower Auger recombination for type-II superlattice (T2SL) detectors compared to HgCdTe. Lower Auger recombination should be translated into a fundamental advantage for T2SL over HgCdTe in terms of lower dark current and/or higher operating temperature, provided other parameters such as Shockley-Read-Hall lifetime are equal.

In fact, investigations of antimonide-based materials began at about the same time as HgCdTe in the 1950's, and the apparent rapid success of their technology, especially low-dimensional solids, depends on the previous five decades of III-V materials and device research. However, the sophisticated physics associated with the antimonide-based bandgap engineering concept started at the beginning of 1990's gave a new impact and interest in development of infrared detector structures within academic and national laboratories. In addition, implementation of barrier in photoconductor structure, in so called barrier detector, prevents current flow in the majority carrier band of detector's absorber but allows unimpeded flow in the minority carrier band. As a result, this concept resurrects the performance of antimonide-based focal plane arrays and give a new perspective in their applications. Apart from barrier structures, a new emerging strategy includes multi-stage/cascade infrared devices.

Based on these promising results it is obvious now that the InAs/GaSb superlattice technology is competing with HgCdTe third generation detector technology with the potential advantage of standard III-V technology to be more competitive in costs and as a consequence series production pricing. Comments to the statement whether the superlattice IR photodetectors can outperform the "bulk" narrow gap HgCdTe detectors is one of the most important questions for the future of IR photodetectors presented by Rogalski at the April 2006 SPIE meeting in Orlando, Florida, are more credible today and are presented in this paper. It concerns the trade-offs between two most competing IR material technologies: InAs/GaSb type-II superlattices and HgCdTe ternary alloy system.

10177-41, Session 7

The development of the infrared technology for meteorological satellites *(Keynote Presentation)*

Wei Lu, Li He, Lei Ding, Xiangyang Li, Jianxin Chen, Xiaoshuang Chen, Shanghai Institute of Technical Physics of the Chinese Academy of Sciences (China)

The requirement of the infrared technology applied on meteorological satellites is the key driving force for the development of infrared technology in Shanghai institute of technical physics (SITP), Chinese Academy of Sciences. The meteorological satellites have become a main detection method for the weather and ocean observation, there are totally 13 meteorological satellites that were launched into both sun synchronous and geostationary orbit and more satellites are under construction to be the second generation ones. The infrared remote sensors are the main payloads on-board on all these satellites. By these infrared remote sensors one can obtaine the remote sensing data for ocean colour, water vapour, weather forecasting, and get the atmospheric temperature profile and humidity profile, etc.

As the key technology in the infrared remote sensor, the infrared detector technology is developed mainly using the HgCdTe material, meanwhile the quantum well infrared photodetector and type II superlattice infrared detector are also developed. As the basic research for the new generation of infrared detector, the 2D and nano wire material is studied.

10177-42, Session 8

Bulk growth and surface characterization of epitaxy ready cadmium zinc telluride substrates for use in IR imaging applications

James P. Flint, Thomas E. M. Betz, Galaxy Compound Semiconductors, Inc. (United States); Jason M. Mackenzie, Francis J. Kumar, Glenn Bindley, Redlen Technologies (Canada)

Cadmium Zinc Telluride (Cd1-xZnxTe or CZT) is a compound semiconductor substrate material that has been used for infrared detector applications for many years. CZT is a perfect substrate for the epitaxial growth of Mercury Cadmium Telluride (Hg1xCdxTe or MCT) epitaxial layers and remains the material of choice for many high performance IR detectors and focal plane arrays that are used to detect across wide IR spectral bands. Critical to the fabrication of high performance MCT IR detectors is a high quality starting CZT substrate, this being a key determinant of epitaxial layer cystallinity, defectivity and ultimately device electro-optical performance. In this work we report on a new source of substrates suitable for IR detector applications, grown using the Travelling Heather Method (THM). This proven method of crystal growth has been used to manufacture high quality IR specification CZT substrates where industry requirements for IR transmission, dislocations, tellurium precipitates and copper impurity levels have been met. Results will be presented for the chemo-mechanical (CMP) polishing of CZT substrates using production tool sets that are identical to those that are used produce epitaxy-ready surface finishes on related IR compound semiconductor materials such as GaSb and InSb. We will also discuss the requirements to scale CZT substrate manufacture and how with a new III-V like approach to both CZT crystal growth and substrate polishing, we can move towards a more standardised product and one that can ultimately deliver a standard round CZT substrate, as is the case for competing IR materials such as GaSb, InSb and InP.

10177-43, Session 8

Large-format multi-wafer production of 5" GaSb-based photodetectors by molecular beam epitaxy

Amy W. K. Liu, Dmitri Loubychev, Joel M. Fastenau, Michael Kattner, Phillip Frey, IQE Inc. (United States); Mark J. Furlong, IQE (United Kingdom)

GaSb and its heterostructures grown by molecular beam epitaxy (MBE) have received much attention given their application in a wide range of mid-wave and long-wave IR photodetector applications. Following an intense period of GaSb IR detector development, the commercialization of this technology is now taking place with R&D specifications transitioning into manufacturing, this placing new requirements on product quality, consistency and throughput at all levels of the IR detector supply chain. Like many other compound semiconductor based technologies, there has been a steady evolution in epitaxial wafer size. From the development of early detector layer structures on 2" diameter GaSb substrates up to today's 3"/4" production standard. However, as detector sizes continue to increase and wafer die yield requirements become ever more demanding, the industry continues to push for a transition to larger diameter substrates, this culminating in a push towards the routine use of a 5" GaSb. In this work we report on the multi-wafer growth of 5" GaSb-based MWIR nBn detector structures by MBE. Using a large format growth platen (5 x 5") we will report on key material characteristics from the perspective of wafer-to-wafer and run-to-run product reproducibility and control, comparing results achieved with smaller batch size MBE reactor formats. Material properties based on AFM, XRD, cross-section TEM and low-temperature photoluminescence characterization will be presented, as well as electrical data from large-area mesa diodes We will also consider these results from the perspective of volume compound semiconductor manufacturing, making reference to the epitaxial growth of GaAs and InP heterostructures, demonstrating that antimonide epitaxy has matured to a level of quality and consistency that can be considered as state-of-the-art for the industry.

10177-44, Session 9

Response time improvement of LWIR HOT MCT detectors

Pawel Madejczyk, Military Univ. of Technology (Poland)

Results presented in this paper show considerable progress in MOCVD-grown HgCdTe HOT photodetectors fabrication. Fully doped HgCdTe heterostructures with acceptor concentration range between 1014 cm–3 and 5?1017cm–3 and donor concentration range between 1014 cm–3 to 1?1018 cm–3 have been reported. Donor and acceptor doping researches in (100) and (111) oriented HgCdTe layers grown by MOCVD have been studied. The electrical and chemical characterization of HgCdTe structures grown at 360°C on GaAs substrates using DIPTe have been described. Infrared photodiodes with different composition x were constructing on the basis of obtained heterostructures enabling signal detection of any wavelength from 1 μm to above 20 μm covering SWIR, MWIR and LWIR spectral ranges.

Particular progress has been achieved in the growth of (100) HgCdTe epilayers for long wavelength infrared photoconductors operated in HOT conditions. The authors report on energy gap engineering solutions to improve the response time of HgCdTe photodiodes.

10177-45, Session 9

Ultra-compact high-performance MCT MWIR engine

Holger Lutz, Rainer Breiter, Heinrich Figgemeier, Reinhard Oelmaier, Stefan Rutzinger, Hans-Thomas Schenk, Wilhelm Schirmacher, Joachim C. Wendler, AIM INFRAROT-MODULE GmbH (Germany)

Size, weight and power (SWaP) reduction is highly desired by applications such as sights for the dismounted soldier or small gimbals for UAVs. But why have high performance and small size of IR systems inevitably exclude each other?

Namely, recent development progress in the fields of miniature cryocoolers, short dewars and high operating temperature (HOT) FPAs combined with pitch size reduction opens the door for very compact MWIR-modules while keeping high electro-optical performance.

Now, AIM has realized first prototypes of an ultra-compact high performance MWIR engine in a total volume of only 18cl (60mm length x 60mm height x 50mm width). Impressive SWaP characteristics are completed by a total weight below 450g and a power consumption of only ~4W in basic imaging mode. The engine consists of a XGA-format (1024x768) MCT detector array with 10μm pitch and a low power consuming ROIC. It is cooled down to a typical operating temperature of ~160K by the miniature linear cryocooler SX020. The dewar uses a short coldfinger and is designed to reduce the heat load as much as possible. The cooler drive electronics is implemented in the CCE layout in order to reduce the required space of the printed boards and to save power. Uncorrected 14bit video data is provided via Camera Link. Optionally, a small image processing board can be stacked on top of the CCE to gain access to basic functions such as BPR, 2- point NUC and dynamic reduction.

This paper will present the design, functionalities and performance data of the ultra-compact MCT MWIR engine operated at HOT.

10177-46, Session 9

Simulation of infrared avalanche photodiodes from first principles

Asta K. Storeboe, Trond Brudevoll, Forsvarets Forsknings Institute (Norway); Dara Goldar, Norwegian Univ. of Science and Technology (Norway)

In the present article we study avalanche photodiodes using material properties data derived directly from first principles electronic structure calculations. By such calculations the use of experimentally measured parameters can be largely avoided, and more detail can be fed into the simulation. Full-band Monte Carlo (MC) device simulation can readily proceed from this kind of detailed information in contrast to other methods which would need an additional intermediate step where materials data are first lumped onto average ensemble-based steady-state/near-equilibrium properties.

We have developed a full-band MC particle simulator for use within the fields of materials technology and semiconductor optoelectronic devices. The simulator takes input data from first principles pseudopotential (ABINIT) or linearized plane wave (Wien2k) calculations. Electric fields are calculated either via finite difference or finite element methods which are fully integrated into the code.

Due to the extremely long penetration depth of IR photons, the thickness of the diode absorption layers is typically quite large. This represents a considerable computational challenge when detailed simulation models are to be used over the whole volume of the device. Different ways of dealing with this problem are considered. We explore planar back-illuminated n on p devices at different reverse bias voltages. The optical signal creates an electronic disturbance which is tracked as it propagates through the device. Strongly non-equilibrium regions, near equilibrium regions, ambipolar transport, impact ionization, dynamic field effects and alloy scattering must all be given proper attention, and the importance of each of these elements are demonstrated and discussed.

10177-47, Session 9

Microstructure characterization of lattice defects induced by As ion implantation in HgCdTe epilayers

Changzhi Shi, Chun Lin, Yanfeng Wei, Lu Chen, Shanghai Institute of Technical Physics of the Chinese Academy of Sciences (China)

The HgCdTe epilayers (xCd~0.24) were grown on CdZnTe and GaAs substrates by LPE and MBE, and then coated with CdTe as barrier cap layers. Before ion implantation, the samples were pre-annealed at 240°C for 48 hrs. Sequentially, arsenic ions were implanted into the samples at different energies and doses. A two-step Hg overpressure annealing (420°C and 240°C) was carried out to activate arsenic ions and eliminate implant damage. The microstructure of lattice defects in arsenic-implanted HgCdTe was characterized by HRTEM, and the arsenic profiles were measured by SIMS. By XRD, the influences of pre-annealing, ion implantation and post-annealing on lattice structure were studied. For the implant energy of 450keV, a residual point defect belt was observed around the previous amorphous/crystal (a/c) interface after annealing, implying that the recrystallization occurs from surface towards a/c interface. By HRTEM, it was discovered that the residual defect is a cluster of vacancies. Also, for the GaAs-based MBE HgCdTe sample without pre-annealing, the ion implantation not only broadens the XRD peak, but also makes the peak deviation. It indicates that the introduction of atomic stress changes the lattice constant, thereby leading to the peak deviation. For the CdZnTe-based LPE sample with pre-annealing, the characteristic peak after ion implantation is considered to be split into two peaks, and the FWHMs of each fitted peak and the combined peak are both broadened. It is noteworthy that the combined peak deviation is likely due to that the pre-annealing significantly decrease lattice constant overwhelming the role of ion implantation.

10177-48, Session 9

General review of multispectral cooled IR development at CEA-Leti, FRANCE

Francois Boulard, CEA-LETI (France); Philippe Ballet, Commissariat à l'Énergie Atomique (France); Jacques P. Baylet, Giacomo Badano, Olivier Gravrand, CEA-LETI (France); Roch Espiau de Lamaestre, MINATEC (France); Sylvette Bisotto, Commissariat à l'Énergie Atomique (France)

Multicolor detection capabilities, which bring information on the thermal and chemical composition of the scene, are desirable for advanced infrared (IR) imaging systems This paper reviews intra and multiband solutions developed at CEA-Leti FRANCE, from dual-band molecular beam epitaxy grown back to back Mercury Cadmium Telluride (MCT) photodiodes to backside pixelated filters and plasmon enhanced multicolors IR detectors.

Spectral responses, quantum efficiency and detector noise performances are discussed in regards to technology maturity, pixel pitch reduction, and affordability. From MWIR-LWIR large band to intra MWIR or LWIR bands peaked detection, results underline the whole MCT possibility developed at CEA-Leti.

10177-49, Session 9

Latest improvements on long wave p on n HgCdTe technology at Sofradir

Laurent Rubaldo, Rachid Taalat, Jocelyn Berthoz, Magalie Maillard, Nicolas Péré-Laperne, Alexandre Brunner, Pierre Guinedor, Loïc Dargent, Alexandre Kerlain, SOFRADIR (France)

SOFRADIR is the worldwide leader on the cooled IR detector market for high-performance space, military and security applications thanks to a well mastered Mercury Cadmium Telluride (MCT) technology, and recently thanks to the acquisition of III-V technology: InSb, InGaAs, and QWIP quantum detectors. As a result, strong and continuous development efforts are deployed to deliver cutting edge products with improved performances in terms of spatial and thermal resolution, dark current, quantum efficiency, low excess noise and high operability.

The actual trend in quantum IR detector development is the design of very small pixel, with the higher achievable operating temperature whatever the spectral band. Maintain the detector operability and image quality at higher temperature moreover for long wavelength is a major issue. This paper presents the recent developments achieved at Sofradir to meet this challenge for MCT extrinsic p on n technology LW band with a cut-off wavelength of 9.3μm at 90K. State of the art performances will be presented in terms of dark current, operability and NETD temperature dependency, quantum efficiency, MTF, RFPN (Residual Fixe Pattern Noise) and its stability up to 100K will be shown.

10177-50, Session 9

A comparative study of carrier lifetimes in ESWIR and MWIR materials: HgCdTe, InGaAs, InAsSb, and GeSn

Enrico Bellotti, Hanqing Wen, Boston Univ. (United States); Stefano Dominici, Politecnico di Torino (Italy); Andreu L. Glasmann, Boston Univ. (United States)

HgCdTe has been the material of choice for MWIR, and LWIR infrared sensing due to its highly tunable band gap and favorable material properties. However, HgCdTe growth and processing for the ESWIR spectral region is less developed, so alternative materials are actively researched. It is important to compare the fundamental limitations of each material to determine which offers optimal device performance. In this article, we investigate the intrinsic recombination mechanisms of ESWIR materials—InGaAs, GeSn, and HgCdTe—with cutoff wavelength near 2.5μm, and MWIR with cutoff of 5μm. First, using an empirical pseudo-potential model, we calculate the full band structure of each alloy using the virtual crystal approximation, modified to include disorder effects and spin-orbit coupling. We then evaluate the Auger and radiative recombination rates using a Green's function based model, applied to the full material band structure, yielding intrinsic carrier lifetimes for each given temperature, carrier injection, doping density, and cutoff wavelength. For example, we show that ESWIR HgCdTe has longer carrier lifetimes than InGaAs when strained or relaxed near room temperature, which is advantageous for high operating temperature photodetectors. We perform similar analyses for varying composition GeSn by comparing the calculated lifetimes with InGaAs and HgCdTe. Finally, we compare HgCdTe, InAsSb and GeSn with a cutoff in the MWIR spectral band.

10177-51, Session 9

Daphnis 10um pixel pitch product: optimized product platforming allowing outstanding on-time delivery

Valery Compain, Bertrand DeMonte, Eric Mazaleyrat, Yves Royer, Pierre Jenouvrier, Bertrand Orlach, Stéphane Vivier, Severin Bonin, Jacques Veyrier, David Lacombe, Florent Panzarella, SOFRADIR (France)

TV format (640x512) products with 15?m pixel pitch are today the most common. They are widely used thanks to a good trade-off between cost and performance. Nevertheless, the market has now switched to higher resolution, compactness and cost reduction. The DAPHNIS 10?m product family is offering a HD TV format (1280x720) or a XGA TV format (1024x768) detectors.

DAPHNIS 10 ?m product family answers on the one hand to fast delivery of standard product on the other hand to easier and anticipated customized products at an acceptable additional cost.

The tradeoff between the 3 main parameters (delivery schedule, customization and reduced cost) is platforming deployment strategy.

The Daphnis 10?m products family is designed for postponement and for performing late-stage product completion as close to demands as possible. Regarding individual building blocks, DAPHNIS generic parts are created during the initial stages of the manufacturing process. In the later stages, these generic parts are customized to create the final product.

This paper discusses postponement strategy including building block early qualification strategy to ease the final product qualification.

10177-52, Session 9

A comparative design tool for HgCdTe detectors

Yigit Özer, Serdar Kocaman, Middle East Technical Univ. (Turkey)

In order to initiate new application areas for the infrared detectors, controlling various dark current mechanisms, which will lead to higher operating temperature (lower cost), is essential. In addition, there is always a focus on HgCdTe detector technology among the alternative material systems due to its unmatched high performance. A well-designed HgCdTe infrared imaging device is desired to have diffusion dominant dark current characteristics at the operating temperature set by the noise level. Nevertheless, due to the non-identical dynamics, generation-recombination (G-R) dark current coming from the Shockley-Read-Hall (SRH) processes usually become the key component here. Shifting the depletion region to the wide bandgap layer or utilizing barrier structures are the methods to suppress this G-R current; however, it is still a design problem for the next generation systems. As improved design tools will be expected to result in higher expected enhancement, the aim of this work is to help this effort with a numerical analysis on one-dimensional heterojunction HgCdTe based P+-n structure. The electrical and optical characteristics are investigated with a detailed analysis on the doping profile and on the distance between electrical junction and hetero-metallurgical interface. A well-known technology computer aided design (TCAD) software and an in-house numerical model, which analytically solves drift-diffusion currents, continuity and Poisson equations under steady state conditions, are utilized to optimize these device architectures. The electron and hole densities, band diagrams and material properties are comparatively presented including the consideration of non-ideal transitions.

10177-86, Session PSTue

Diffusion lengths and dark current analysis in InGaAs focal plane arrays

Alexandre W. Walker, Mike W. Denhoff, Dave Seniuk, Oliver Pitts, National Research Council Canada (Canada)

High material quality is critical in achieving both low dark current and low noise in InP/InGaAs p-i-n focal plane arrays for low light level conditions in short-wave infrared applications. Diffusion length measurements provide insight into the material quality, yet the extraction and methodology of such parameters is not common in the literature. We demonstrate an efficient and simple non-optical method of determining the diffusion lengths based on linear diodes, whereby injection and temperature are controlled in a straightforward manner. Figure 1 illustrates the current collected at a secondary diode due to hole injection from a primary diode as a function of the diode separation. A fit to a one-dimensional analytical equation provides hole diffusion lengths of 65±3 and 89±5 microns at room temperature for two different samples grown in two different MOCVD reactors. These extracted values correlate to the n-type doping level in the n-InGaAs layers according to capacitance-voltage measurements. Furthermore, the simple analytical model allows for the extraction of the minority carrier mobility for both samples. Correlations between the diffusion length and dark current are then investigated for these different samples, whereby higher dark currents are measured and simulated for lower doped InGaAs structures, simply due to an overall increase in Shockley-Read-Hall contribution to the dark current, which is a result of the wider depletion volume. A lower doped InGaAs may then lead to a longer diffusion length, which could be interpreted as a higher material quality, whereas this lower doping is detrimental to the device performance.

10177-87, Session PSTue

Effect of insulator layer in graphene plasmonic metamaterials for infrared detection

Shinpei Ogawa, Daisuke Fujisawa, Masaaki Shimatani, Mitsubishi Electric Corp. (Japan); Kazuhiko Matsumoto, The Institute of Scientific and Industrial Research, Osaka Univ. (Japan)

Graphene is an atomically thin carbon sheet with a two-dimensional hexagonal lattice structure, and exhibits extraordinary electronic and optical properties. There has been growing interest in graphene-based photodetectors due to its fast response and broadband capabilities from the ultraviolet to microwave regions. Absorption by graphene is constant but only about 2.3%, which limits detector performance. If the plasmonic resonance can be localized at the graphene, its absorption can be significantly enhanced. In this study, we investigated the effect of the insulator layer thickness in graphene-covered plasmonic metamaterials (PMs). The PMs consist of top plasmonic antennas, an insulator waveguide layer and a reflector layer. Wavelength-selective absorption occurs due to localized surface plasmon produced by the antennas and the waveguide mode in the insulator layer. Strong electromagnetic field localization was expected at the graphene on the plasmonic antennas.

The graphene was fabricated by chemical vapor deposition and was transferred onto the PMs using a conventional method. Samples with different insulator thicknesses were prepared and their optical properties were compared.

The results of reflectance measurements demonstrated that the insulator thickness had a significant effect on the absorbance of graphene. As the thickness decreased, the absorption wavelength shifted slightly away from the plasmonic resonance wavelength, so that the graphene absorbance became dramatically enhanced rather than suppressed. This indicates that the plasmonic resonance localized at the graphene near the plasmonic antennas was modulated by the waveguide mode in the insulator. These results are expected to contribute to the development of high-performance wavelength-selective graphene-based IR detectors.

10177-88, Session PSTue

Type-II superlattice focal plane arrays detector for mid-wavelength infrared imaging

Xuchang Zhou, Dongsheng Li, Kunming Institute of Physics (China); Jianliang Huang, Key Lab. of Semicoductor Materials Science, Institute of Semiconductors (China); Rongbin Ji, Kunming Institute of Physics (China)

Two type-II superlattice focal plane arrays (FPA) detector with cutoff wavelength of 4.1 μm and 5.6 μm were developed for operating for blue part and red part of the MWIR window of the atmosphere. The T2SL samples with p-i-n structure were grown by molecular beam epitaxy with both GaAs-like and InSb-like interface to balance the strain. The X-ray diffraction (XRD) measurement indicates the average strain is close to zero. The 25 ?m pitch 384x288 pixels detectors were realized by pixel isolation with both dry etching and wet etching method, passsvation with SiNx, and the removal of the substrate. Two FPA devices showed excellent NETD of 18mK and 10 mK respectively. Finally, the T2SL FPA shows high quality imaging capability at the temperature ranging from 80K to 100K which demonstrates the devices' good temperature performance.

10177-89, Session PSTue

Thermal infrared radiometry-based remote pedestrian detection at night

Taehwan Kim, Sungho Kim, Yeungnam Univ. (Korea, Republic of)

This paper proposes a new method to detect remote pedestrians using thermal infrared radiometry data at night. The proposed approach enhances signal to clutter and noise ratio (SCNR) by a z-score based statistical technique using the radiometric temperature information and gaussian filtering to generate a global SCR map. And then, the approach assesses the contrast of thermal image to improve SCNR by sliding multiscale-center surround filter banks (MS-CSFB) as scale-invariant method about remote pedestrian. The contrast saliency maps are normalized from 0 to 1. The contrast saliency maps are used for binarization with low threshold and clustering to select pedestrian candidates. The proposed thermal infrared radiometry-constant false alarm rate (TIR-CFAR) detector can find remote pedestrians with features for the processed MS-CSFB responses such as normalized contrast, average temperature, entropy, etc. The TIR-CFAR is optimized to measure radiometric temperatures of human bodies. Non-maximum suppression is used to eliminate overlapped detection region. Experimental results validate that this method can detect remote pedestrians over 90% of detection rate. The proposed method will be another building block to perform the challenging task detecting remote pedestrian at night. In the future, we will develop a new pedestrian detection technique that can show high performance by combining the TIR-CFAR detector as proposal method with deep learning.

10177-90, Session PSTue

A study on inductively coupled pSasma cryoetching of HgCdTe

Lingfeng Liu, Yiyu Chen, Zhenhua Ye, Li He, Ruijun Ding, Shanghai Institute of Technical Physics of the Chinese Academy of Sciences (China)

Etching at cryogenic temperature can reduced the etch-induced damage in HgCdTe during etch process, which is important to fabricate high performance IRFPAs (Infrared Focal Plane Arrays) detectors. Inductively coupled plasma (ICP) cryoetching of HgCdTe (MCT) using a CH4-based mixture was investigated. The available etching equipment with cryogenic assembly is Oxford Instrument ICP 180. Liquid nitrogen was used to cool down the sample table. SiO2 with a contact layer of ZnS functioned as etch mask during cryoetching. Key process parameters modified during ICP etching process include chamber pressure, ICP-source power, bias power and substrate temperature. The HgCdTe etch rate at cryogenic temperature (123K) under an optimized recipe was studied as a function of etch time, etch dimension and etch depth respectively. The etch profiles and etch uniformity were also investigated.

10177-91, Session PSTue

Forward looking infrared imagery for landmine detection

Aylin Bayram, Gozde Bozdagi Akar, Middle East Technical Univ. (Turkey)

Detection of buried explosive devices and labeling as target and non-target are complex procedures that obtain huge number of data. Pre-screener is preparation phase which minimize required number of data. While enhancing this system, forward-looking long-wave infrared (FL-LWIR) is used in pre-screener process [1], [2]. Detection landmine using FLIR is based on the principle that the difference on thermal conductivity, thermal capacity and/or density between mine and surrounding soil. The mine could be cooler or warmer compared to soil [3]. The temperature difference of the candidate landmine alarm locations is captured by FLIR camera at a very large standoff distance. Although IR imagery is a good technique for landmine detection, this system has some limitations. Firstly, the environment is not homogeneous. There are vegetation, rocks etc. all around the detection area. These cause image clutter in IR imagery and causes FA. When soil and buried target are in thermal equilibrium at times of day, the detection becomes harder [4]. Environment climate is another factor which affects thermal difference and detection performance of IR imagery. The goal of this paper is to analyze the effects of environmental factors, landmine types on FLIR detection algorithms by comparing False Alarm Rate (FAR).

In this paper, we propose a method which is the fusion of landmine detection algorithms based on FLIR imagery. Trainable size contrast filters detection, corner detection, Gaussian mixture model-based detection and maximally stable extremal region based detection are anti-personal landmine detection types that we have implemented in this paper. The results of these algorithms give the possible alarm locations. Additionally, each algorithm performance is analyzed with Receiver Operating Characteristic (ROC) curve. To improve performance of algorithms, mean-shift algorithm is applied for fusion. Mean-shift method aims to find locate maxima of density function given a set of discrete samples iteratively. Furthermore, we compare the ROC curves of each algorithm and define weights for weighted-mean shift algorithm. Weights are calculated with the Covariance Matrix Adaptation Evolution Strategy (CMA-ES) algorithm [5]. The fusion process with weighted-mean shift algorithm gives better performance. Besides detection algorithms, camera registration process is another important issue on FLIR system. While system is moving on the road, FLIR camera records a scene in a multiple frames of video and the pose of scene is different at each time relatively to the camera. In other words, the position and orientation of object is changed from frame to frame in recorded video. Besides, changing on size and shape of the object on video is a challenging; when the object is projected into world coordinates detection performance is improved. Also, the internal parameters and position of the camera should be known for calibration between image plane and world plane transition. For camera calibration, we use perspective projection model and estimate calibration matrix with CMA-ES algorithm.

We applied these algorithms to our dataset. The test setup for our dataset is indicated in Figure 1. We analyze the effects of depth variance, diameter variance, metal density variance, clutter and emptiness. The test setup includes area with 2 m x 1.5 m and soil type is sand. The objects defined at figure are buried at specific depth. In Figure 2, there are Electro-optics (EO) and Infrared (IR) images taken from our test setup.

Test dataset are processed by our algorithms that we implemented and the results are promising.

10177-92, Session PSTue

Design and fabrication of metal-insulator-metal diode for high-frequency applications

Ibrahim Azad, Univ. of South Florida (United States)

Metal-insulator-metal (MIM) diodes play significant role in high speed electronics where high frequency rectification is needed. Quantum based tunneling mechanism helps MIM diodes to rectify at high frequency signals. Rectenna, antenna coupled MIM diodes are becoming popular among due to their potential use as IR detectors and energy harvesters. Because of small active area, MIM diodes could easily be incorporated into integrated circuits (IC's).

The objective of this work is to design and develop MIM diodes for high frequency rectification. In this work, thin insulating layer of ZnO was fabricated using Langmuir-Blodgett (LB) technique which facilitates ultrathin thin, uniform and pinhole free fabrication of insulating layer. The ZnO layer was synthesized from organic precursor of zinc acetate layer. The optimization in the LB technique of fabrication process led to fabricate MIM diodes with high non-linearity and sensitivity. Moreover, the top and

bottom electrodes as well as active area of the diodes were patterned using UV-photolithography technique. The current density – voltage (J-V) characteristics of the diodes were studied to understand quantum tunneling conduction mechanism. The highest sensitivity of the diode was measured around 16 (A/W), and the rectification ratio was found around 38 under low applied bias at ±100 mV. Furthermore, the S11 and S21 parameters of the diode were measured to extract the equivalent circuit of the diode.

10177-94, Session PSTue

Array size and area impact of MIM diodes on nanorectenna performance

Elif Gul Arsoy, Emre C. Durmaz, Atia Shafique, Meriç Özcan, Yasar Gurbuz, Sabanci Univ. (Turkey)

The metal-insulator-metal (MIM) diodes have high speed, small unit area and compatibility with integrated circuits (IC's). Therefore, MIM diodes are very attractive to detect and harvest energy for infrared (IR) regime. Hence, MIM diodes offer a feasible solution for nanorectennas (nano rectifiying antenna) in IR regime. The aim of this study is to design and develop MIM diodes as array format coupled with antennas for energy harvesting and IR detection. Moreover, varying number of rectennas which are 4x4 and 40x30 have been fabricated in parallel having 40, 65 and 80 nm2 diode areas. To investigate diode area effect, Cr-HfO2-Ni set of material was studied. Furthermore, the effect of the array size was investigated by using Ti-HfO2-Ni type of material set. Physical vapor deposition (PVD) technique was implemented for bottom and top electrodes for the MIM diodes. Also, to achieve uniform and very thin insulator layer atomic layer deposition (ALD) was used. The non-linearity 2 mA/V2 and responsivity 3 A/W are achieved for Ti-HfO2-Ni MIM diodes. The responsivity and nonlinearity of Cr-HfO2-Ni are found as 5.5 A/W and 70?A/V2, respectively. The 4x4 elements have higher current level than single element for Ti-HfO2-Ni diodes. The array size is 40x30 elements for Cr-HfO2-Ni type of MIM diodes with 40, 65 nm2 diode areas. By increasing the diode area, the current level increases for same size of array. Therefore resistance is decreased in the range of 10 k? and nonlinearity is increased from 58?A/V2 to 70?A/V2.

10177-95, Session PSTue

Standardizing large format 5" GaSb and InSb substrate production

Rebecca J. Martinez, Wafer Technology Ltd. (United Kingdom); James P. Flint, Gordon Dallas, Galaxy Compound Semiconductors, Inc. (United States); Brian Smith, Marius Tybjerg, Wafer Technology Ltd. (United Kingdom); Mark J. Furlong, IQE (United Kingdom)

In this paper we report on the maturation of large diameter GaSb and InSb substrate production and the key aspects of product quality and process control that have enabled a level of standardization to be achieved that is on par with mass produced compound semiconductor materials such as GaAs and InP. The evolution of commercial production processes for the crystal growth, wafering and epitaxy-ready polishing of antimonide substrates will be discussed together with specific reference to the process tool sets and production methodologies that have transformed a niche material in to one that has set new standards for wafer level product quality, conformity and control. Results will be presented on the production of single crystal >/=6" ingots grown by a modified version of the Czochralski (LEC) technique. Crystal defect mapping will demonstrate that industry standard InSb (211) growth processes have been refined to consistently deliver ulta-low dislocation density substrates. Two approaches to the growth of GaSb crystals will be presented and the merits of each individual technique discussed. Statistical process control data will be presented for large format 5" epitaxy ready finishing processes and compared alongside in-house data for GaAs and InP. Various surface analytical tools are used to characterize 5" InSb and GaSb substrates and our method of providing a unique characterization 'finger print' with each substrate discussed.

We conclude that improvements in InSb and GaSb product quality and consistency have been driven by the industry's persistent need to improve device performance and yield. Whilst substrate size requirements in antimonide wafer production may have peaked, we will discuss how to moving to the next step in substrate diameters, 6", is very attainable and within relatively short timescales too.

10177-96, Session PSTue

Short wavelength infrared photodetector and light emitting diode based on InGaAsSb

Junoh Kim, Tien Dai Nguyen, Korea Research Institute of Standards and Science (Korea, Republic of); Zahyun Ku, Augustine M. Urbas, Air Force Research Lab. (United States); Sang-Woo Kang, Sang Jun Lee, Korea Research Institute of Standards and Science (Korea, Republic of)

Short wavelength infrared detectors and light emitting diode (LED) can be used for a variety of applications in the military and industrial areas such as gas detection. In this study, we report on InGaAsSb infrared photodetector and LED for short wavelength infrared detection and emission. The InGaAsSb samples were grown by molecular beam epitaxy (MBE) system with As2 and Sb2 cracker source on a GaSb substrate. In order to investigate the structural properties of InGaAsSb layer, we took a high resolution XRD and low voltage SEM. The InGaAsSb devices were processed in 400?400 μm2 using inductively coupled plasma etching, followed by the contact metal deposition. We have measured the spectral response of InGaAsSb based photodetector using various temperature and bias. The cut-off wavelength of photodetector was ~ 2.8 μm at room temperature. We also report an electroluminescence of InGaAsSb LED. Detailed study of device design, growth, fabrication and characterizations for these InGaAsSb infrared detectors and LED will be presented.

10177-98, Session PSTue

High-resolution 1280X 1024 12μm pitch InSb detector

Chen-Sheng Huang, Ping-Kuo Weng, Chien-Te Ku, Yau-Tang Gau, National Chung-Shan Institute of Science and Technology (Taiwan)

A 1280X1024/12um backside illuminated photovoltaic indium antimonide (InSb) focal plane arrays (FPA) having spectral response in the medium wavelength infrared (3 to 5um) was designed and developed in National Chung Shang Institute of Science and Technology for use in a variety of military and commercial applications. Fabrication techninique for InSb detector arrays by ion implantation results in a P-type area on n-type substrate, and the P-type active areas are 9x9 ?m2. To approach the minimum surface leakage current, high quality double insulating layers were used as passivation. Then the metals were evaporated as ohmic contact and bonding pad. The InSb and the ROIC arrays are connected using Flip-Chip bonding technology by means of indium bumps. The ROIC design makes use of the advanced and matured CMOS technology, 0.18 μm, which allows for high functionality and relatively low power consumption. Operating at 77K, the arrays had a mean laboratory detectivity of 4.99X10 11cmHz 1/2 /W with f/3 optics. The responsivity non-uniformity was 3%, and the operablility is higher than 99%. The FPA achieves a Noise Equivalent Temperature Difference (NETD) as lower as 25mK at 300K background with f/3 optics. The 12?m pitch InSb FPA based on the matured planar technology is the latest megapixel IRFPA product of National Chung Shang Institute of Science and Technology, and further optimization is in progress.

A 1280X1024/12um backside illuminated photovoltaic indium antimonide (InSb) focal plane arrays (FPA) having spectral response in the medium

wavelength infrared (3 to 5um) was designed and developed in National Chung Shang Institute of Science and Technology for use in a variety of military and commercial applications. Fabrication techninique for InSb detector arrays by ion implantation results in a P-type area on n-type substrate, and the P-type active areas are 9x9 μm2. To approach the minimum surface leakage current, high quality double insulating layers were used as passivation. Then the metals were evaporated as ohmic contact and bonding pad. The InSb and the ROIC arrays are connected using Flip-Chip bonding technology by means of indium bumps. The ROIC design makes use of the advanced and matured CMOS technology, 0.18 μm, which allows for high functionality and relatively low power consumption. Operating at 77K, the arrays had a mean laboratory detectivity of 4.99X10 11cmHz 1/2 /W with f/3 optics. The responsivity non-uniformity was 3%, and the operablility is higher than 99%. The FPA achieves a Noise Equivalent Temperature Difference (NETD) as lower as 25mK at 300K background with f/3 optics. The 12μm pitch InSb FPA based on the matured planar technology is the latest megapixel IRFPA product of National Chung Shang Institute of Science and Technology, and further optimization is in progress.

10177-101, Session PSTue

An advanced presence detection system using the CMOS Infrared (CIR) technology

Tugay Arslan, Gorkem Cilbir, Murat Tepegoz, Tayfun Akin, MikroSens Elektronik San ve Tic A.S. (Turkey)

The recent advancements on microbolometer type uncooled LWIR imaging sensor technology allowed to reduce the fabrication cost of the microbolometer type detectors and the overall wafer cost and therefore to increase the use of this technology in a number of emerging applications, including various consumer applications and advance presence detection systems for smart buildings and smart offices. Such applications require even lower cost detectors, which can be achieved with a recently introduced CMOS infrared (CIR) technology that enables the mass fabrication of microbolometer type sensors in almost any CMOS foundries without additional equipment investment. This paper introduces an advanced presence detection system which uses an LWIR microbolometer type sensor fabricated using the CIR technology. The advanced presence detection (APD) system can provide 80x80 infrared video together with the temperature map of the scene where the sensor can collect LWIR radiation using 120 degrees wide FOV lens. The embedded microprocessor can process the infrared video and provide real time number of people data as output. The APD system can both provide SPI interface for OEM developers and USB interface for fast evaluation and prototyping.

10177-102, Session PSTue

Turret indirect vision systems replacing episcopes on armoured fighting vehicles

Yoram Aron, Instro Precision Ltd. (United Kingdom)

The replacement of traditional episcopes by indirect vision systems will be discussed, including the unique optical performance requirements, image presentation methods, networking, and advanced capabilities of such systems.

10177-53, Session 10

10μm pitch family of InSb and XBn detectors for MWIR imaging

Gal Gershon, Renana Tessler, Maya Brumer, Eran Avnon, Niv Shiloah, Willie Freiman, Tamar Rosenstock, Dima Seref, Lior Shkedy, Yoram Karni, Itay Shtrichman, SCD SemiConductor Devices (Israel)

There is a growing demand over the last years for infrared detectors with smaller pixel size. On one hand, this trend of pixel shrinkage enables the overall size of a Focal Plan Array (FPA) with a specific format to be reduced, allowing more compact, low power, and lower cost electro-optical (EO) systems. On the other hand, it allows a higher resolution for a given FPA dimension, especially suitable for infrared systems with large format for wide Field Of View (FOV) imaging.

In response to these market needs SCD has developed the Blackbird family of 10 μm pitch digital Infrared detectors for the MWIR spectral band. The Blackbird family consists of three different Read-Out Integrated Circuits (ROIC) formats: 1920x1536, 1280x1024 and 640x512, exploiting the advanced and matured 0.18 μm CMOS technology, which allows for high functionality and relatively low power consumption.

The Blackbird family of detectors incorporate two 10 ?m pixel sensing arrays. The first is InSb photo-diode arrays based on SCD's matured planar technology, which covers the full MWIR band, and is designed for operation at 80K. The second is based on the novel XBn-InAsSb technology, which enables equivalent electro-optical performance at operating temperatures as high as 150K for low SWaP applications. Both sensing arrays ,InSb and XBn, are flip-chip bonded to the ROICs by means of indium bumps to create a diverse family of FPAs. The FPAs are assembled in specially designed Dewars, which can withstand harsh environmental conditions while minimizing the detector's heat load. A dedicated proximity electronic board provides power supplies and clocks to the ROIC and enables communication and video output to the system. Together with a wide range of cryogenic coolers, a high flexibility of housing designs and diverse modes of operation, the Blackbird family of detectors present solutions for a wide range of EO systems, from the very high-end applications to the low SWaP-C regime.
In this work we present in detail the characteristic performance of the Blackbird detectors.

10177-54, Session 10

Fabrication of small pitch, high definition (HD) 1kx2k/5μm MWIR focal-plane-arrays operating at high temperature (HOT)

James Jenkins, Sevag Terterian, Mark S. Roebuck, Terry J. De Lyon, Hasan Sharifi, Bor-An Tu, Rajesh D. Rajavel, Wyatt Strong, HRL Labs., LLC (United States); John T. Caulfield, Jon Paul Curzan, Cyan Systems (United States)

We describe our recent results in developing and maturing small pixel (5μm pitch), high definition (HD) mid-wave infrared (MWIR) detector technology as well as focal-plane-array (FPA) hybrids, and prototype 2.4 Megapixel camera development operating at high temperature with low dark current and high operability. Advances in detector performance over the last several years have enabled InAsSb-based high operating temperature (T≥150K), unipolar detectors to emerge as an attractive alternative to HgCdTe detectors. The relative ease of processing the III-V materials into large-format, small-pitch FPAs offers a cost-effective solution for tactical imaging applications in the MWIR band. In addition, small pixel detector technology enables a reduction in size of the system components, from the detector and ROIC chips to the focal length of the optics and lens size, resulting in an overall compactness of the sensor package, cooling and associated electronics. An MBE system has been used to grow bulk InAsSb-based barrier detector structures with 5.1μm cutoff on GaAs substrates with low total thickness variation (TTV) across a 3" wafer, in order to realize high interconnect yield for small-pitch FPAs. A unique indium bump scheme is proposed to realize 5μm pitch arrays with high connectivity yield. Several 1kx2k /5μm hybrids have been fabricated using Cyan's CS3 ROICs with proper backend processing and finally packaged into a portable Dewar camera. The FPA radiometric result is showing low median dark current of 2.3x10-5 A/cm2 with > 99.9% operability, and >60% QE (without AR coating).

"This research was developed with funding from the Defense Advanced Research Projects Agency (DARPA). 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. Approved for public release, distribution unlimited"

10177-55, Session 10

State-of-the-art MCT photodiodes for cutting-edge sensor applications by AIM

Heinrich Figgemeier, Johannes Beetz, Detlef Eich, Petra Fries, Stefan Hanna, Karl-Martin Mahlein, Wilhelm Schirmacher, AIM INFRAROT-MODULE GmbH (Germany)

For about 30 years AIM has been ranking among the leading global suppliers for high performance MCT infrared detectors with its portfolio spanning the photosensitivity cut-off range from the SWIR to the VLWIR and from 1st generation to 3rd generation FPA devices.

AIM presents its latest developments to meet the market demands for SWaP-C- and IR-detectors with additional functionalities such as multicolor detection. In this context, we will present our latest excellent results of 5.3 μm cut-off LPE-grown MWIR-MCT detectors with 1024x768 pixels and a 10 μm pixel pitch.

AIM's powerful low dark current LWIR and VLWIR p-on-n device technology on LPE-grown MCT has by now been extended to the MWIR spectral range, and a comparison of results from n-on-p and p-on-n MWIR-MCT planar photodiode arrays is given. Operating temperatures of 160 K and higher in conjunction with low defect density and excellent thermal sensitivity (NETD) are attained.

Using large GaAs substrates, AIM has been growing MBE-MCT multilayer stacks for cost-effective multicolor application sensing layers for several years. During the development, a design with 640x512 pixels and a 20 μm pitch was tested: Latest results on MWIR/MWIR diodes demonstrate high QE, very low color cross talk, and excellent NETD in conjunction with low defect densities.

MWIR single color MBE-MCT detectors grown on GaAs at AIM are now qualified and have reached a maturity meeting fully customers' requirements. MCT detectors based on MBE on GaAs are available and already delivered.

10177-56, Session 10

MWIR barrier infrared detectors with greater than 5μm cutoff using bulk InAsSb grown on GaSb substrates

Neil F. Baril, Alexander E. Brown, Daniel Y Zuo, Meimei Z. Tidrow, U.S. Army Night Vision & Electronic Sensors Directorate (United States); Dmitri Loubychev, Joel M. Fastenau, Amy W. K. Liu, IQE Inc. (United States); Sumith Bandara, U.S. Army Night Vision & Electronic Sensors Directorate (United States)

Mid-wavelength infrared photodetectors incorporated into a unipolar barrier architecture with a bulk InAsxSb1-x absorber and an AlSb barrier layer are demonstrated. An extended cutoff was achieved by increasing the lattice constant from 6.09 Å of the GaSb substrate to 6.13 Å using a 1.5 μm thick AlSb buffer layer. This enabled the growth of bulk absorber material with a higher antimony content, InAs0.81Sb0.19, and a greater than 5 μm cutoff. Transitioning the lattice to 6.13 Å also enabled the implementation of a simple binary AlSb layer as a unipolar barrier to block majority carrier electrons and reduce dark current noise. Individual test devices with 4 μm thick absorbers displayed 150 K dark current density, cutoff wavelength, quantum efficiency, and specific detectivity of 3 x 10-5 A/cm2, 5.31 μm, 44 % at 3.4 μm, and 4.3 x 1011 cmHz1/2/W at 5 μm, respectively. The instantaneous dark current activation energy at a given bias and temperature was determined via Arrhenius analysis from the Dark current vs. temperature and bias data, and a discussion of valence band alignment between the InAsxSb1-x absorber and AlSb barrier layers is presented. The carrier concentration, mobility, and lifetime of the bulk absorber material and the device performance will be presented and a discussed.

10177-58, Session 10

Digital alloy MWIR nBn detector with extended cut-off wavelength

Alexander Soibel, David Z. Ting, Cory J. Hill, Anita M. Fisher, Linda Höglund, Sam A. Keo , Sarath D. Gunapala, Jet Propulsion Lab. (United States)

Mid-wavelength infrared (MWIR) detectors covering 3-5μm atmospheric transmission windows are of great interest for NASA Earth Science missions. The recently demonstrated nBn or XBn barrier photodetectors offer many advantages for realization of high performance infrared imagers (IR). In our research we investigated a novel approach to extend a cut-off wavelength of Sb-based nBn detectors. We incorporated a series of single InSb monolayer into InAsSb bulk that allowed to realize a digital alloy absorber with an extended cut-off wavelength of λ = 4.6 μm at T = 200 K. The cut-off wavelength extension to 4.6μm is technologically important for realization of detectors covering CO2 absorption line at 4.26μm. At the same time, the constructed digital alloy InAsSb/InSb is a fascinating material system that has an energy bandgap smaller that the random allow with the same material composition. The developed nBn detectors with 2μm thick absorber showed a temperature independent quantum efficiency QE≈0.45 for back-side illumination without antireflection coating. The dark current density was jd=5x10-6 A/cm2 at T = 150K, and increased to jd = 2 x10-3 A/cm2 at T = 200K. At temperatures of T = 150K and below, the demonstrated photodetectors operate in background limited (BLIP) mode, with detectivity D*(?)=3-6x1011 (cmHz0.5/W) for the background temperature of 300K, and f/2 field of view.

10177-59, Session 10

High-quantum efficiency MWIR superlattice photodetector

Alireza Kazemi, The Univ. of New Mexico (United States); Stephen A. Myers, SKINfrared LLC (United States); Sen Mathews, Theodore Schuler-Sandy, Seung Hyun Lee, The Univ. of New Mexico (United States); Vincent M. Cowan, Eli Garduno, Elizabeth H. Steenbergen, Christian P. Morath, Gamini Ariyawansa, John E. Scheihing, Air Force Research Lab. (United States); Sanjay Krishna, The Univ. of New Mexico (United States)

We report a high operating temperature (HOT) MWIR barrier photodetector based on the InAs/GaSb/AlSb type-II superlattice (T2SL) material system. The pBn design consists of a single unipolar barrier (InAs/AlSb T2SL) placed between a 4-micron thick p-doped absorber (InAs/GaSb T2SL) and an n-type contact layer (InAs/GaSb T2SL). At 150 K and Vr=50 mV, the quantum efficiency (QE) was measured to be 64% at 4.5 μm with a dark current of 1.07?10-4 A/cm2 and a 50% cut-off wavelength of 5.3 μm. At 80K, the device was fully turned at zero bias. At 80 K and Vr = 10 mV, the measured QE was 62% at 4.5 μm with a dark current density of 3.05?10-8 A/cm2 and a 50% cut-off wavelength of 5 μm. The measurements were verified at CHTM and multiple AFRL laboratories. The results from this device along with the analysis will be presented in this paper.

10177-60, Session 11

Heterojunction photo transistor for highly sensitive infrared imaging

Mohsen Rezaei, Min-Su Park, Chee Leong Tan, Skyler Wheaton, Hooman Mohseni, Northwestern Univ. (United States)

In this work a model is proposed to calculate the ultimate physical limit on the sensitivity of detectors based on heterojunction phototransistors (HPT). Using the proposed model, a design method is presented for the HPT for ultralow flux photo detection. Model shows that HPT's sensitivity increases by scaling down the emitter and base diameter and potentially can reach close to photon number resolving. However, in practice the low material quality, poor fabrication process and lack of proper surface passivation prevents HPT from operating in its limit of detection. Different material system and band alignments for HPT is experimentally tested. For each structure a combination of wet and dry process together with surface passivation is developed and tested. Measurements on temperatures accessible by TEC cooler shows these device is very promising for highly sensitive imagers. This work reports the progress on making the high frame rate and sensitive imager based on InGaAs/InP HPT.

10177-61, Session 11

Evidence of carrier localization in InAsSb/InSb digital alloy nBn detector

Brian J. Pepper, Alexander Soibel, David Z. Ting, Cory J. Hill, Arezou Khoshakhlagh, Anita M. Fisher, Sam A. Keo, Sarath D. Gunapala, Jet Propulsion Lab. (United States)

Recently we have demonstrated a novel method of extending the cut-off wavelength of InAsSb nBn detectors, by incorporating a series of monolayers of InSb [Soibel et al., App. Phys. Lett. 109, 103505 (2016)]. Here we study photoluminescence and minority carrier lifetime of this InAsSb/InSb digital alloy. While increasing temperature from 15 K to 40 K we show a 19 meV blue shift of the photoluminescence peak energy and a decrease in lifetime. This deviation from the Varshni empirical relation indicates strong carrier localization. We contrast to photoluminescence and lifetime results in bulk InAsSb. We discuss implications of this localization for design of digital alloy InAsSb/InSb nBn detectors.

10177-62, Session 11

Effects of epitaxial structure and processing on electrical characteristics of InAs-based nBn infrared detectors

Xiaoyu Du, Gregory R. Savich, Brendan T. Marozas, Gary W. Wicks, Institute of Optics, Univ. of Rochester (United States)

The nBn infrared photodetector has shown great performance improvements over conventional p-n junction photodiodes owing to its ability to suppress junction related dark currents and surface leakage currents; however, general processing of the nBn structure, which defines the device mesa immediately above the barrier layer (shallow etch), is subject to the lateral diffusion of the minority carriers in the absorber layer. This lateral diffusion currents substantially increases dark currents in small pixel devices and limits the pixel density due to pixel-to-pixel cross talk. The conventional solution to this issue solves the problem by etching through the barrier and absorber to define the mesa devices (deep etch), but can introduce surface leakage currents. In this study, we experimentally examine the effects of different processing conditions and different epitaxial structures on nBn detectors. Various InAs-based nBn structures were grown by Molecular Beam Epitaxy (MBE). Different processing conditions were applied for the fabrication of the mesa devices. Temperature dependent I-V characteristics were measured. Particularly, effects of the deep etch versus the shallow etch were compared. Effects of the barrier thickness were also examined. We have shown that deep etch devices are subject to higher dark currents and a high device failure rate. To avoid the etching of barrier layer, a new detector structure, the inverted-nBn, is proposed. Contrary to the conventional nBn structure, the inverted-nBn structure has the n-type absorber above the barrier. Lateral diffusion currents were compared against shallow etched conventional nBn structure. We have demonstrated that the lateral diffusion currents are effectively eliminated in the inverted-nBn structure.

10177-63, Session 12

Novel vacuum packaged 384x288 broadband bolometer FPA with enhanced absorption in 3-14μm wavelength

Bruno Fisette, Mathieu Tremblay, El-Hassane Oulachgar, Francis Généreux, David Béland, Patrick Beaupré, Christian Julien, David Gay, Sébastien Deshaies, Marc Terroux, Bruno Tremblay, Christine Alain, INO (Canada)

This paper reports the development of a fully packaged focal plane array of broadband microbolometers. The detector makes use of a gold black thin film to enlarge its absorption range from 3 to 14 μm. The bolometers have a spectral responsivity 5 times higher than for a standard 35μm microbolometer without gold black and optimized design.

A low temperature packaging process was developed to minimize sintering of the gold black absorber during vacuum sealing of the bolometer array package. Based on technologies used for packaging of detectors for space applications, a compact package with an f-number of 0.7 was developed. Measurements of INO's MEMS-pirani gauge integrated inside the package cavity indicated a vacuum below 3 mTorr. A refireable electrically activated getter was also integrated to further extend the lifetime of the vacuum sealed package.

The gold black absorber was trimmed on INO's MOPAW laser trimming station in order to prevent lateral diffusion of heat and promote a better MTF.

The fabricated FPAs show a NETD lower than 25 mK at a frame rate of 25 Hz.

In this paper, the performance of this new FPA is compared to standard FPAs in terms of NEP, NETD and response time. The specific detectivity, D*, of the bolometers in the 3 to 14 μm wavelength band is also presented. The main characteristics of the package are also discussed in details.

10177-64, Session 12

High-performance mushroom plasmonic metamaterials for infrared polarimetric imaging

Shinpei Ogawa, Daisuke Fujisawa, Hisatoshi Hata, Mitsuharu Uetsuki, Mitsubishi Electric Corp. (Japan); Takafumi Kuboyama, Masafumi Kimata, Ritsumeikan Univ. (Japan)

Information such as the shape, position and average radiant intensity of objects can be obtained using conventional uncooled infrared (IR) sensors; however, such sensors provide no polarization information. When electromagnetic waves are reflected or emitted from artificial objects such as vehicles and buildings, their polarization can be changed. Therefore, object recognition can be enhanced and human influences can be distinguished from the natural environment using IR polarimetric imaging. Conventional IR polarimetric imaging requires the use of polarizers or filters

with IR cameras, which increases the complexity and cost of such systems. If uncooled IR sensors could selectively detect polarization without any polarizers or filters, this would widen their range of applications. Such sensors would require a small pixel size and strong absorption in the IR region. We have therefore investigated polarization-selective absorbers based on plasmonic metamaterials. Asymmetric mushroom plasmonic metamaterials (MPMs) incorporating tubular posts were fabricated. The MPMs have an all-Al construction and consist of micropatches and a reflector layer connected with tubular posts. The asymmetric-shaped micropatches lead to strong polarization-selective IR absorption due to localized surface plasmon resonance. The operating wavelength region is determined by the micropatch size and the post structure. The tubular posts allow simply fabrication of the MPMs using conventional micromachining without any degradation of the optical properties. The MPMs also have a smaller pixel size and thermal mass than metal-insulator-metal-based metamaterials. They are therefore promising for uncooled IR polarimetric image sensors in terms of both sensor performance and mass production.

10177-65, Session 12

Uncooled infrared photodetectors based on one-dimensional nanowires and two-dimensional materials *(Invited Paper)*

Hehai Fang, Wenjin Luo, Peng Wang, Weida Hu, Xiaoshuang Chen, Wei Lu, Shanghai Institute of Technical Physics of the Chinese Academy of Sciences (China)

Infrared photodetectors based on traditional thin-film semiconductors such as InGaAs and HgCdTe as well as novel type-II superlattice exhibit highly sensitive detection capability. However these devices always need to work at low temperature, resulting in an additional large and expensive cooling system. Recently one-dimensional (1D) nanowires (NWs) and two dimensional (2D) materials have attracted tremendous attention owing to their bandgap tunability and potential optoelectrical applications. Here we report the progress on uncooled infrared photodetectors based on NWs and 2D materials.

NW-based photodetectors are more likely to show high optical gain with the assistance of antenna-like shape and limited dimension. Nevertheless as a photoconductive detector the signal-to-noise ratio could be low without the suppression of dark current. The performance of 2D photodetectors is less affected by surface states, however the optical absorption is weak and the electron-hole separation efficiency is restricted. Here we fully exploit the detection ability of NWs and 2D materials by introducing localized-field, including ferroelectric filed, periodic nano-arrays near optical field, heterojunction field, p-n junction photovoltaic field and so forth. With a strong induced localized-field, high performance photodetectors based on 1D NWs (InP, InAs) and 2D materials (Graphene, MoS_2, WS_2, $MoSe_2$, Black phosphorus, Black arsenic-phosphorus etc.) in the visible to infrared wave band may lead to a disruptive revolution in prospective low dimensional electronic/optoelectronic devices. Our study opens a new avenue for the controllable fabrication of built-in localized-field in 1D and 2D devices, which is a prominent challenge in low dimensional material research.

10177-66, Session 12

A low-power CMOS readout IC design for bolometer applications

Arman Galioglu, Shahbaz Abbasi, Atia Shafique, Sabanci Univ. (Turkey); Mehmet Kaynak, IHP (Germany); Omer Ceylan, Melik Yazici, Yasar Gurbuz, Sabanci Univ. (Turkey)

A prototype of a readout IC (ROIC) designed for high temperature coefficient of resistance (TCR) SiGe microbolometers is presented. The ROIC is designed in a column-wise architecture. The problem of resistance variation across the bolometers which introduce fixed pattern noise is addressed by setting a tunable reference resistor shared for each column which can be calibrated offline to set the common-mode level. Previous works employing reference resistor ROICs have opted to make use of complex bias offset correction techniques and/or differential input stages that increase circuit footprint to overcome this problem. The column-wise architecture in this work reduces the number of integrators needed in the architecture and enables 17x17 μm2 pixel sizes. The prototype has been designed and fabricated in 0.25-μm CMOS process.

10177-67, Session 12

Wide-bandwidth absorption in the MWIR region using a thin and simple metamaterial absorber

Kadir Üstün, Gönül Turhan-Sayan, Middle East Technical Univ. (Turkey)

In this study, we propose metamaterial absorber structures that operates in the mid-wave infrared (MWIR) region. In the infrared band, mid wave infrared (MWIR) band (wavelengths from 3 μm to 5 μm) is one of the regions especially important for defense and security systems, because of the transparent behavior of the atmosphere in this region. There are several theoretical and experimental studies on infrared absorbers for this band in the literature that offer wide bandwidth, but with a price of large number of layers, or geometries with small dimensions that reduce the throughput and increase the fabrication cost. Here we aim to reveal simple and thin designs that would remove these inconveniences. Our metamaterial absorbers are composed of a planar metal layer that serves as a ground plane with approximately zero transmission, a low-loss dielectric spacer layer, and a top metal pattern that consists of infinite array of rectangular patches with four different edge lengths. The total thickness of the structure is 300 nm. The minimum metamaterial-plane feature size is 730 nm, enabling the use of optical lithography. The structure achieves absorptance values higher than 80 percent in the wavelength interval between approximately 3.67 μm and 4.19 μm, exceeding 500 nm in bandwidth. We suppose that this structure can increase the efficiency of microbolometers operating in MWIR region.

10177-69, Session 12

Spectral response of microbolometers for infrared hyperspectral imaging

Casey I. Honniball, Robert Wright, Paul G. Lucey, Hawai'i Institute of Geophysics and Planetology (United States)

Hyperspectral imaging (HSI) is a technique with a growing list of applications and potential users, as this technique combines the power of imaging with the chemical discrimination of spectroscopy. Because HSI divides light from the scene into narrow slices of wavelength, the technique is typically thought to require cryogenic arrays to achieve the ultimate sensitivity. However, within the last two decades microbolometer arrays have improved in sensitivity, pixel count and total array area. In Hawaii we have shown that microbolometer arrays can provide sufficient sensitivities for a variety of infrared HSI applications. The ability of microbolometer arrays to operate at ambient-temperature make them attractive candidates for low power applications, including space-based instruments on small satellites. We have two NASA projects to determine the suitability of uncooled microbolometers for HSI systems with the aim of HSI measurements from smaller satellites than is possible with cryogenic instruments. The suitability of a detector is governed in part by its spectral response. Microbolometers have wide variations in spectral response by technology and vendor, as part of our NASA projects we are conducting a spectral response measurement campaign on five different microbolometer cameras. Three of the cameras are sensitive to the long-wave infrared from 7.5 to 14 microns (two FLIR cameras and a Sofadier camera), one to the mid-wave infrared from 3 to 5 microns (LumaSense camera), and the last is sensitive to both regions from 3 to 14 microns (INO camera). Results from this campaign will be presented.

10177-100, Session 12

An 80x80 microbolometer type thermal imaging sensor using the CMOS infrared technology

Firat Tankut, Haluk Cologlu, Hidir Askar, MikroSens Elektronik San ve Tic A.S. (Turkey); Hande Ozturk, MikroSens Elektronik San ve Tic A.S (Turkey); Hital K. Dumanli, Feyza Oruc, Bilge Tilkioglu, Birel Ugur, MikroSens Elektronik San ve Tic A.S. (Turkey); Orhan Sevket Akar, MikroSens Elektronik San ve Tic A.S (Turkey); Murat Tepegoz, Tayfun Akin, MikroSens Elektronik San ve Tic A.S. (Turkey)

This paper introduces first time an 80x80 microbolometer array with 35um pixel pitch where the detector is fabricated with the CMOS infrared (CIR) technology, which is developed to reduce the detector cost in order to enable the use of microbolometer type sensors in the mass market. A number of companies all over the world try to reduce the fabrication cost of the wafers so that they can put their sensors into the consumer products such as mobile-device add-on thermal cameras. This paper announces a novel microbolometer fabrication technique which is named as CMOS infrared (CIR) technology. Unlike current microbolometer approaches, Mikrosens' CMOS infrared (CIR) detector technology is developed to be truly fabless and to be produced at any standard CMOS and/or MEMS foundry with only few simple post-CMOS etching steps with one additional masking layer, leading to cost advantage, simplicity, scalability, and flexibility. Mikrosens' CIR approach does not require the use of special high TCR materials like VOx or a-Si, and the detectors are implemented with standard CMOS layers and components, and therefore it allows the use of industrially mature but high temperature wafer level vacuum packaging technologies such as glass frit or AlGe which are extensively used by high volume CMOS/MEMS foundries. The fabricated and wafer-level vacuum packaged sensor, namely MS0835A, is measured to provide NETD values lower than 200 mK for 30fps frame rate and 100 mK for 4fps frame rate with F/1 optics, which is suitable for advanced presence detection and human counting applications. The new CIR approach of Mikrosens allows to reduce the pixel pitch even further and to increase the array size for various other low-cost, high volume applications.

10177-70, Session 13

A PFM based MWIR DROIC employing off-pixel fine conversion of photocharge to digital using integrated column ADCs

Shahbaz Abbasi, Arman Galioglu, Atia Shafique, Omer Ceylan, Melik Yazici, Yasar Gurbuz, Sabanci Univ. (Turkey)

A 32x32 prototype of a digital readout IC (DROIC) for medium-wave infrared focal plane arrays (MWIR IR-FPAs) is presented. The DROIC employs in-pixel photocurrent to digital conversion based on a pulse frequency modulation (PFM) loop and boasts a novel feature of off-pixel residue conversion using 10-bit column SAR ADCs. The remaining charge at the end of integration in typical PFM based digital pixel sensors is usually wasted. Previous works employing in-pixel extended counting methods make use of extra memory and counters to convert this left-over charge to digital, thereby performing fine conversion of the incident photocurrent. This results in a low quantization noise and hence keeps the readout noise low. However, focal plane arrays (FPAs) with small pixel pitch are constrained in pixel area, which makes it difficult to benefit from in-pixel extended counting circuitry. Thus, in this work, a novel approach to measure the residue outside the pixel using column parallel SAR ADCs has been proposed. Moreover, a modified version of the conventional PFM based pixel has been designed to help hold the residue charge and buffer it to the column ADC. In addition to the 2D array of pixels, the prototype consists of 32 SAR ADCs, a timing controller block and a memory block to buffer the residue data coming out of the ADCs. The prototype has been designed and fabricated in 90nm CMOS.

10177-71, Session 13

Development of a fully programmable ROIC with 15 μm pixel pitch for MWIR applications

Oguz Altun, Reha Kepenek, ASELSAN A.S. (Turkey); Ferhat Tasdemir, Fatih Akyurek, Can Tunca, Mehmet Akbulut, Omer Lutfi Nuzumlali, Ercihan Inceturkmen, ASELSAN A.S. (Turkey)

A 15 μm pixel pitch 640x512 Readout Circuit (ROIC) for MWIR applications is designed and fabricated using 0.18 um CMOS process. The ROIC is implemented using Direct Injection (DI) input stage with programmable pixel gain where maximum full-well-capacity (FWC) is more than 13Mé. All analog current and voltage bias values can be programmed through a digital interface. Additionally, integration time can be programmed with 0.1 μsec resolution by internal timing circuitry. ROIC has 1, 2 and 4 output modes with a frame rate of 120fps at 4 output mode. The design supports Integrate-Then-Read (ITR) and Integrate-While-Read (IWR) modes in snapshot operation. Photodetector reverse bias voltage is controlled by adjusting the bias of the common-gate input stage at the input of DI pixel. An on-chip low-dropout voltage regulator is used to generate the detector common voltage. With 2x2 binning feature, the ROIC can also be used for 30 μm pixel pitch 320x256 photodetector arrays. An Analog-Front-End (AFE) card has been designed to operate the ROIC and to convert analog video output to a 14-bit digital world. This digital video data is handled by external video processor card which supports 1-point and 2-point Non-Uniformity Correction (NUC), histogram equalization, bad pixel replacement and filtering. The ROIC has been extensively tested with a prototype FPA at 77°K. According to these test results, functionality of all modes have been verified and a noise level of 700e is achieved at 4.5Mé FWC.

10177-72, Session 13

Low-power design considerations for digital readout integrated circuits

Joseph H. Lin, MIT Lincoln Lab. (United States)

In addition to gaining increased functionality from Moore's Law scaling, digital readout integrated circuits (DROICS) can also take advantage of low?power enhancements at advanced CMOS process nodes. We provide an analysis of DROIC power consumption at various CMOS process nodes, and compare this to a conventional focal plane array. The power savings can lead to larger focal plane arrays that have less thermal load. One powerful technique common in low?power digital circuit design is to use a reduced supply voltage, which trades off transistor switching speed with power consumption In order to operate the DFPA at a near?threshold supply rail, modifications were made to the pixel circuit, and level shifting circuits were introduced to translate between supply voltage domains . We discuss these architectural modifications as well as test results from test chips that were fabricated with and without these modifications. The test chips were fabricated in a 65nm CMOS process and were hybridized to SWIR detector arrays.

10177-73, Session 13

A 1024x768-12μm digital ROIC for uncooled microbolometer FPAs

Selim Eminoglu, Mikro-Tasarim Elektronik San. ve Tic. A.S. (Turkey)

This paper reports the development of a new digital microbolometer Readout Integrated Circuit (D-ROIC), called MT10212BD. It has a format of 1024 ? 768 (XGA) and a pixel pitch of 12μm. MT10212BD is Mikro Tasarim's second 12μm pitch microbolometer ROIC, which is developed specifically for surface micro machined microbolometer detector arrays with small pixel pitch using high-TCR pixel materials, such as VOx and a Si. MT10212BD has an all-digital system on-chip architecture, which generates programmable timing and biasing, and performs 14-bit analog to digital conversion (ADC). The signal processing chain in the ROIC is composed of pixel bias circuitry, integrator based programmable gain amplifier followed by column parallel ADC circuitry. MT10212BD has a serial programming interface that can be used to configure the programmable ROIC features and to load the Non-Uniformity-Correction (NUC) date to the ROIC. MT10212BD has a total of 8 high-speed serial digital video outputs, which can be programmed to operate in the 2, 4, and 8-output modes and can support frames rates above 60 fps. The high-speed serial digital outputs supports data rates as high as 400 Mega-bits/s, when operated at 50 MHz system clock frequency. There is an on-chip phase-locked-loop (PLL) based timing circuitry to generate the high speed clocks used in the ROIC. The ROIC is designed to support pixel resistance values ranging from 30KΩ to 90kΩ, with a nominal value of 60KΩ. The ROIC has a globally programmable gain in the column readout, which can be adjusted based on the detector resistance value.

10177-75, Session 14

Long-distance image fusion system for short-wave and mid-wave infrared cameras

Junju Zhang, Nanjing Univ. of Science and Technology (China)

Abstract: Short-wave and mid-wave infrared cameras are the two most common imaging systems for a wide-range of critical applications related to surveillance, reconnaissance, intelligence gathering, and security. However, neither of them can give the complete spectral image information. To overcome these problems, some gray image fusion algorithms are adopted and fused images are produced, which preserve all relevant information from the original data. In principle, color imagery has several benefits over monochrome imagery. Therefore, the increasing availability of fused multi-band infrared imaging systems has led to a growing interest in the color display of night vision imagery. In this paper, we has developed a simple and fast lookup-table based method to derive and apply natural daylight colors to multi-band infrared images, and designed a long-distance image fusion system for short-wave and mid-wave infrared cameras. The new color lookup-table can be obtained either by applying a statistical transform to the entries of the original lookup-table, or by a procedure that replaces entries of the original lookup-table by their corresponding natural color values. The statistical transform method transfers the first order statistics of the color distribution of a representative natural color daytime reference image to the false color multi-band infrared image. This mapping is usually performed in a perceptually decorrelated color space. The colors in the resulting colorized multi-band infrared images closely resemble the colors in the daytime color reference image. Also, object colors remain invariant under panning operations and are independent of the scene content. Here we describe the implementation of this method in a prototype long-distance image fusion system. The system provides co-aligned images from two short-wave and mid-wave infrared cameras. The two infrared cameras have a 320x256 pixel focal plane array, and the spectral sensitivity range are 0.9-1.7μm and 3.5-4.7μm, which are the range of most interest for outdoor applications. It delivers wide dynamic range (14-bit) analog video output at 25 fps. The key hardware is a high-speed processing board made up of FPGA and DSP. The color mapping is implemented as a real-time lookup-table transform. The resulting colorized video streams can be displayed in real-time on head mounted displays. Preliminary field trials demonstrate the potential of these systems for applications like surveillance, security and target detection.

10177-77, Session 14

Time-encoded multiplexed imaging *(Invited Paper)*

Joseph H. Lin, MIT Lincoln Lab. (United States)

We describe a technique for multiplexed imaging that is based on the concept of mapping scene features to unique temporal codes, and using smart digital pixels to efficiently decode at the focal-plane. We use this technique to demonstrate multiplexed multispectral imaging using actively encoded LEDs, and multiplexed hyperspectral imaging using a digital micromiror spatial light modulator. Both experiments utilize a computational imaging array comprised of a 32x32 array of digital pixels with the capability of acquiring eight concurrent measurements that can be modulated with a time-varying duo-binary signal (+1,-1,0) at MHz rates. This results in eight decoded images per frame at a maximum frame rate of 1600 frames per second. The total frame rate of the imaging system depends on the number of encoded features and the number of decoding channels within the digital pixel. We explore these trades as well as discuss limitations and areas for future improvement.

10177-78, Session 14

Small pixel infrared sensor technology *(Invited Paper)*

John T. Caulfield, Cyan Systems (United States)

Cyan Systems has developed and made improvements to a small pixel ROIC/FPA and associated sensor components that demonstrates these features. We will report on recent data from the HD 1080+ format small pixel IR sensor technology.

We will review the capabilities of smaller pixels including how using temporal and spatial oversampling can compensate and effectively increase SNR lost with smaller pixels. We will quantify the limits of performance of Oversampling based on theory, and also with Monte Carlo type analysis using realistic parameters such as shot noise and thermal noise. We will report on key sensor characterization measurements such as uniformity and MTF.

We will also show HD imaging data to illustrate the improvements in resolution and field coverage and other capabilities of Cyan Systems Small Pixel HD IR sensor.

10177-79, Session 15

Infrared engineering for the advancement of science: A UK perspective *(Invited Paper)*

Ian M. Baker, Leonardo-Finmeccanica (United Kingdom)

No Abstract Available

10177-80, Session 15

My life in IRFPA research and development *(Invited Paper)*

Masafumi Kimata, Ritsumeikan Univ. (Japan)

I started working in infrared technology in 1980, meaning that I've spent almost 40 years in IRFPA R&D, and even though our path was not the mainstream, I have always enjoyed my research. In my talk, I will introduce our accomplishments during my R&D history, which can be divided into three eras. The first was from 1980 to the mid-1990s, which was devoted to PtSi IRFPAs at Mitsubishi Electric. Even though we started from the elementary stage, we successfully developed a 512x512 PtSi IRFPA in 1987 and a Mega-pixel PtSi IRFPA in 1991. We also launched a commercial infrared camera business with this technology in 1988.

The second era, from the mid-1990s to 2004, was dominated by uncooled IRFPAs, also at Mitsubishi Electric. As everyone knows, two noteworthy uncooled IRFPA results were reported in 1992. At that time, I felt that it was very difficult for PtSi technology to compete with uncooled IRFPAs. Recognizing the situation, we shifted to the uncooled field, where instead of diving into the dominant microbolometer river, we waded into the minor but original stream of SOI diode technology.

After the end of the second era, I transferred to Ritsumeikan University and changed my role, fueled by a great modification in R&D infrastructure. From my university position, I continue to encourage the infrared community in Japan through the Infrared Array Sensor Forum that I personally organize.

10177-81, Session 16

Advances in low-cost infrared imaging using II-VI colloidal quantum dots

Richard E. Pimpinella, Christopher Buurma, Anthony J. Ciani, Christoph H. Grein, Sivananthan Labs., Inc. (United States); Philippe Guyot-Sionnest, The James Frank Institute (United States)

II-VI colloidal quantum dots (CQDs) have made significant technological advances over the past several years, including the world's first demonstration of MWIR imaging using CQD-based focal plane arrays. The ultra-low costs associated with synthesis and device fabrication, as well as compatibility with wafer-level focal plane array fabrication, make CQDs a very promising infrared sensing technology. In addition to the benefit of cost, CQD infrared imagers are photon detectors, capable of high performance and fast response at elevated operating temperatures. By adjusting the colloidal synthesis, II-VI CQD photodetectors have demonstrated photoresponse from SWIR through LWIR. We will discuss our recent progress in the development of low cost infrared focal plane arrays fabricated using II-VI CQDs.

10177-82, Session 16

Effects of doping on photoelectron kinetics and characteristics of quantum dot infrared photodetector

Xiang Zhang, Vladimir Mitin, Univ. at Buffalo (United States); Andrei Sergeev, Kimberly A. Sablon, U.S. Army Research Lab. (United States); Michael Yakimov, Serge Oktyabrsky, SUNY Polytechnic Institute (United States)

Quantum dot infrared photodetectors (QDIPs) have attracted significant attention due to its selective coupling to IR radiation, high photoconductive gain, and numerous possibilities for nanoscale engineering. Our approach to improving QDIP is based on the management of three dimensional nanoscale potential profile created by charged quantum dots (QDs). Quantum dot charging allows us to control the photoelectron lifetime, which determines the detector operating rate, detector responsivity, the spectral density of noise, noise bandwidth, and the detector dynamic range. In this work we study various ways of selective doping and their effects on characteristics of photodetectors. We investigate and compare intra-dot doping, inter-dot doping, and complex bipolar doping that increases potential barriers around dots. The reported research aims at the identification of key tradeoffs in QDIP performance related to doping. The detector sensitivity is improved due to high photon-electron coupling, which increases with doping level and increases responsivity. The sensitivity decreases due to large dark current, which increases with doping level and increases the generation-recombination noise current. To investigate effects of selective doping, we fabricated AlGaAs/InAs QD structures with the n-doping of QD layers, the structures with n-doping of barriers, and structures with p-doping of QD layers and n-doping of interdot space. We have measured spectral photoresponse, temperature dependence of responsivity, dark current, and spectral noise characteristics. The results show that bipolar doping provides the decoupled control of electron population in QDs and the potential barriers around QDs. This allows us to enhance the photon-electron coupling and suppress the generation-recombination noise.

10177-83, Session 16

Resonator-QWIPs for 10.6 micron detection

Kwong-Kit Choi, U.S. Army Research Lab. (United States); Richard E. Bornfreund, FLIR Systems, Inc. (United States); Jason N. Sun, Eric A. DeCuir, U.S. Army Research Lab. (United States)

Two resonator-quantum well infrared photodetectors (R-QWIPs) with 11 micron cutoff were demonstrated. The QWIP materials were designed to detect at Wp of 10.6 micron with a cutoff at 11.2 micron. The active material is 1.0 micron thick. To lower the dark current, two low doping densities, 0.2 and 0.3E18 cm-3, were selected. The R-QWIP geometry was designed to resonate at 10.6 micron, where the quantum efficiency is calculated to be 30% for the lower doping (Det. A) and 40% for the higher doping (Det. B) R-QWIPs.

Detector arrays with a 320 x 256 format and 30 micron pitch were fabricated from the acquired wafers A and B. They were hybridized to fanout circuits as well as ROICs for radiometric measurement. The test results from the fanouts and the ROICs agree with each other. For Det. A, the measured QE is 29.4% at 2.5V, in agreement with the predicted QE of 30%. However, for Det. B, the QE is 26.3%, which is lower than the predicted 40%. This discrepancy is attributed to the shorter resonant wavelength Wres of the R-QWIP geometry, which is at 10.2 micron, relative to the observed material Wp of 10.6 micron for A and 10.7 micron for B. A more accurate geometry design should be able to shift Wres to Wp and increase the QE. With the present QEs, both detectors are BLIP around 65 K under F/2. The projected NETD is 20 mK at 2 ms and 60 K, demonstrating the high performance of R-QWIPs.

10177-84, Session 16

Towards flexible quantum well infrared photodetectors

Shilong Li, Han Wang, Honglou Zhen, Wei Lu, Shanghai Institute of Technical Physics of the Chinese Academy of Sciences (China)

Quantum well infrared photodetectors (QWIPs) based on GaAs have attracted much attention owing to its matured material growth technique. In order to obey the selection rule of polarization, various grating structures have been attached to planar QWIPs. Recently, we experimentally demonstrated that strained planar QWIPs could be self-rolled up into an out-of-plane tubular geometry so that the polarization selection rule is sufficiently subdued without any extra grating structure. Such self-rolled-up QWIPs show a broadband enhancement of responsivity and detectivity over a wide incident angle. The well-defined curved QWIPs pave a path towards flexible QWIPs for flexible optoelectronics.

10177-85, Session 16

Novel high-resolution VGA QWIP detector

Himanshu Kataria, Carl Asplund, Sergiy Smuk, Susann Sehlin, Smilja Becanovic, Pia Tinghag, Linda Höglund, Eric M. Costard, IRnova AB (Sweden)

Continuing with its legacy of producing high performance infrared detectors, IRnova introduces its high resolution LWIR IDDCA (Integrated Detector Dewar Cooler assembly) based on QWIP (quantum well infrared photodetector) technology. The Focal Plane Array size is highly compact, with small (15μm) pixel pitch, and based on the FLIR-Indigo ISC0403 Read Out Circuit (ROIC). Detector stability and response uniformity inherent to III/V based material will be demonstrated in terms of high performing detectors. Results showing low NETD at high frame rate and stability over repeated temperature cycling will be presented. This makes it one of the first 15μm pitch QWIP based LWIR IDDCA commercially available in the market. We will also demonstrate the maturity of the MOVPE (Metal Organic Vapour Phase Epitaxy) technology for growing QWIP structures at IRnova. High operability and stability of our other QWIP based products will also be shared.

Conference 10178: Infrared Imaging Systems: Design, Analysis, Modeling, and Testing XXVIII

Tuesday - Wednesday 11–12 April 2017

Part of Proceedings of SPIE Vol. 10178 Infrared Imaging Systems: Design, Analysis, Modeling, and Testing XXVIII

10178-1, Session 1

Electro-optical field performance validation in the presence of turbulence, encoding, and resampling

Stephen D. Burks, U.S. Army RDECOM CERDEC NVESD (United States)

Currently, electro-optical sensors utilizing image processing steps that are non-linear and non-shift-invariant processes require controlled perception studies to evaluate their performance. Processes such as video encoding and turbulence mitigation are often dependent on the specific scene content and are notoriously difficult to model directly. However, under certain conditions, it is generally accepted that these scene dependent effects either have a minimal effect (such as a high bit-rate encoding) or can be approximated with a linear degradation model (turbulence MTF). An electro-optical field collection was recently performed that included turbulence measurements across the full image range. The imagery from this collection was encoded at various data rates and presented to trained observers in a perception test. Together with objective targets collected with the base imagery in the field, the correlation between model prediction and human performance are summarized and presented.

10178-2, Session 1

Testing of next-generation nonlinear calibration based non-uniformity correction techniques using SWIR devices

McKenna R. Lovejoy, Mark A. Wickert, Univ. of Colorado at Colorado Springs (United States)

A known problem with infrared imaging devices is their non-uniformity. This non-uniformity stems from the fact that each pixel in an infrared focal plane array (FPA) has its own photo response. To improve performance, non-uniformity correction (NUC) techniques are applied. Standard calibration techniques use linear, or piecewise linear models to approximate the nonlinear response. Piecewise linear models perform better than the one and two-point models, but in many cases require storing an unmanageable number of correction coefficients. Most nonlinear NUC algorithms use a second order polynomial to improve performance and allow for a minimal number of stored coefficients. However, advances in technology now make higher order polynomial NUC algorithms feasible. This study comprehensively tests higher order polynomial NUC algorithms targeted at short wave infrared (SWIR) imagers. Using data collected from actual SWIR cameras, the nonlinear techniques and corresponding performance metrics are compared with current linear methods including the standard one and two-point NUC algorithms. Machine learning, including principal component analysis, is explored for identifying and replacing bad pixels. The data sets are analyzed and the impact of hardware implementation is discussed. Initial results show 48 percent less non-uniformity when using a third order polynomial correction algorithm rather than a second order algorithm. To maximize overall performance, a trade off analysis on polynomial order and coefficient precision is performed. Comprehensive testing, across multiple data sets, provides next generation model validation and performance benchmarks for higher order polynomial NUC methods.

10178-3, Session 1

A turn-key calibration roadmap for temperature and radiance from 0.3-14μm

Christopher N. Durell, Labsphere, Inc. (United States); Alan Irwin, Santa Barbara Infrared, Inc. (United States); Joseph Jablonski, Labsphere, Inc. (United States); Donald F. King, Santa Barbara Infrared, Inc. (United States); Dan Scharpf, Labsphere, Inc. (United States)

Many existing and emerging remote sensing applications in the SWIR (0.8-2.6) and MIR (2.5-5.0) regions are challenging the conventional thinking of radiance and temperature calibration techniques. While the relationship between blackbody temperature and optical radiation is well understood, often there is an "invisible" dividing line between treatments of these values as either optical radiance or temperature. It is difficult to perform seamless temperature and radiance calibrations across the point of 2.5um: wavelengths longer than this are conventionally discussed in temperature units, while shorter wavelengths may be spoken of terms of either temperature or optical radiance. There is also a natural dividing line at 5um due to emissivity, reflectance and temperature (emissivity can start to interfere or dominate reflectance). NMI traceability in the area of 2.5-5.0um can also be a problem (especially for optical radiance) and <2.5um for temperature signatures as well. This paper will outline a possible turn-key test bench solution that provides traceable solutions for both temperature and radiance value in these regimes. The intent is to offer a possible solution, as well as to challenge the infrastructure that exists today over the 0.3-14um range such that science and applications can obtain a valid spectral radiance or temperature value, or both, to establish better results and new applications.

10178-4, Session 1

Measuring reflective-band imaging systems for performance prediction

Andre Slonopas, Bradley L. Preece, David P. Haefner, U.S. Army Night Vision & Electronic Sensors Directorate (United States)

An objective performance of the reflective-band imaging systems is required in order to provide the warfighter with the right technology for a specific task. Various methods to measure and model performance in the visible and short-wave infrared (Vis-SWIR) spectral regions have been proposed in the literature. This correspondence seeks to establish measurement and modeling procedures to evaluate the systems against a common specification. Conditions are derived from the performance tasks typically conducted by the user community. An optimal chromatic shape for the potential measurement sources is identified by leveraging target reflectivity signatures and atmospheric modeling conditions. Atmospheric conditions that were considered were representative of the dawn, day, and dusk illumination conditions. The measurement source's upper and lower flux constraints were obtained through the modeling optimization of notional sensor modalities. The spectral response, noise (spatial and temporal), Modulation Transfer Function (MTF), instantaneous Field of View (iFOV), and conversion efficiency of a real system were then measured. In an effort to support reproducible research, the following steps are performed. First, the sketch of the experimental setup and equipment with all of the specifications are provided. Second, MATLAB code utilized in the analysis is released to the MathWorks file exchange.

10178-5, Session 1

In-flight optical performance measurement of high-resolution airborne imagery

Richard Gueler, Craig Olson, Andrew W. Sparks, L-3 Sonoma EO (United States)

In-flight measurement of the Modulation Transfer Function (MTF) is essential in understanding the optical performance of high resolution airborne imaging systems and verifying they meet resolution requirements. The use of slant edge targets to measure MTF of the entire in-flight imaging chain are investigated including atmospheric effects and aircraft jitter. In addition, through the use of slant edge targets, the relative edge response (RER) can be extracted to calculate NIIRS. These results are compared to theoretical calculations and laboratory measurements to validate optical performance models and identify areas of concern. By understanding the effects of the imaging chain on MTF, opportunities for improvement can be identified.

In this paper, actual visible airborne imagery of slant edge and bar targets at various slant ranges will be evaluated. These results will be compared to in-lab optical performance measurements made on the same system and compared to theoretical values. The optical performance measurement process will be detailed and effects due to each part of the imaging change will be evaluated. Challenges with the measurement process will be discuss with recommendations for measurement process improvements.

10178-7, Session 2

A read-in IC for infrared scene projectors with voltage-drop compensation for improved uniformity of emitter current

Uisub Shin, Min Ji Cho, Hee Chul Lee, KAIST (Korea, Republic of)

As the technology of infrared imaging systems matures, there has been a rising need for infrared scene projectors (IRSPs) with higher spatial resolutions and wider dynamic ranges in order to accurately evaluate these imaging systems. However, the improvement in the spatial resolution and dynamic range of IRSPs leads read-in integrated circuits (RIICs) to draw higher currents, thus introducing significant voltage drops along the power lines. The resultant voltage variations in the power lines differ across the RIIC unit cell array and they are scene-dependent, which exacerbates the non-uniformity of the emitter current.

This paper proposes a RIIC that compensates for the voltage drops in the ground line in order to improve the uniformity of the emitter current. A current output digital-to-analog converter is utilized to convert the digital scene data into analog data currents. The unit cells in the array receive the scene data current and convert it into data voltage, which simultaneously self-adjusts to account for the voltage drops in the ground line in order that the desired emitter current can be generated independent of the ground voltage variations. In order to verify the design concept, the proposed RIIC is fabricated in a 0.18 μm CMOS process. The experimental results demonstrate that the fabricated RIIC can output a maximum emitter current of 150 μA and compensate for a voltage drop in the ground line of up to 500 mV under a 3.3 V supply. The uniformity of the emitter current is significantly improved compared with that of conventional RIICs.

10178-8, Session 2

Hybrid-mode read-in integrated circuit for infrared scene projectors

Min Ji Cho, Uisub Shin, Hee Chul Lee, KAIST (Korea, Republic of)

Infrared scene projectors (IRSPs) are a tool for evaluating infrared sensors by producing infrared images. Because sensor testing with IRSPs is safer than field-testing, the usefulness of IRSPs is widely recognized at present. The important performance characteristics of IRSPs are thermal resolution and thermal dynamic range. However, due to an existing trade-off between these requirements, it is often difficult to find a workable balance between them.

The read-in integrated circuit (RIIC) drives voltage or current to radiation-emitting devices. The voltage mode has the advantage of a fine thermal resolution. However, the thermal dynamic range in this mode is not sufficient if used to generate high-radiance scenes. The current mode has the advantage of a wide thermal dynamic range but does not allow the production of high-resolution scenes. In this paper, a hybrid-mode RIIC which offers both of the aforementioned advantages is proposed.

The proposed RIIC can operate in two distinct modes. The voltage mode, which provides a fine thermal resolution, is suitable for low-radiance scenes, while the current mode, which provides a wide thermal dynamic range, is feasible for high-radiance scenes. The mode-selective characteristic of the proposed RIIC allows users to generate high-fidelity scenes.

A prototype of the hybrid-mode RIIC was fabricated using a 0.18-μm 1-poly 6-metal CMOS process. We calculated parameters based on measured data. The thermal resolution of the voltage mode estimated by MATLAB at 300K was 23 mK with a 12-bit gray-scale resolution, and the thermal dynamic range of the current mode was from 261K to 790K.

10178-39, Session 2

High-temp MIRAGE XL (LFRA): 7 times the Max Radiance

Steve W. McHugh, Joseph D. Laveigne, Gregory Franks, Santa Barbara Infrared, Inc. (United States)

The development of very-large format infrared detector arrays has challenged the IR scene projector community to develop larger-format infrared emitter arrays. Many scene projector applications also require much higher simulated temperatures than can be generated with current technology. This paper will present an overview of resistive emitter-based (broadband) IR scene projector system development, as well as describe recent progress in emitter materials and pixel designs applicable for legacy MIRAGE XL Systems to achieve >1000K in the MWIR. These new high temperature MIRAGE XL (LFRA) DEEs will be "plug and play" equivalent with legacy MIRAGE XL DEEs, the rest of the system is reusable.

Under multiple DoD-funded programs, Santa Barbara Infrared, Inc. (SBIR) has developed new IR scene projection architectures and emitter technologies capable of producing both very large format (>2048x2048) resistive emitter arrays and very high apparent temperatures (1500K). These new emitter materials can be utilized with legacy RIICs to produce pixels that can achieve 7X the radiance of the legacy systems with low cost and low risk. Complete plans of this development will be discussed

10178-10, Session 3

Development and validation of the AFIT scene and sensor emulator for testing (ASSET)

Shannon Young, Bryan J. Steward, Kevin C. Gross, Air Force Institute of Technology (United States)

ASSET is a physics-based model used to generate synthetic wide area motion imagery (WAMI) data sets with realistic radiometric properties, noise characteristics, and sensor artifacts. It was developed to meet the need for applications where precise knowledge of the underlying truth is required but is impractical to obtain. For example, due to accelerating advances in imaging technology, the volume of data available from WAMI sensors has drastically increased over the past several decades, and as a result, there is a need for fast, robust, automatic detection and tracking algorithms. Evaluation of these algorithms is difficult for targets that traverse a wide

area (100-10,000 km) because obtaining accurate truth for the full target trajectory often requires costly instrumentation. Additionally, tracking and detection algorithms perform differently depending on factors such as the target kinematics, environment, and sensor configuration. A variety of truth data sets spanning these parameters are needed for thorough testing, which is often cost prohibitive. The use of synthetic data sets for algorithm development allows for full control of scene parameters with full knowledge of truth. However, in order for analysis using synthetic data to be meaningful, the data must be truly representative of real sensor collections. ASSET aims to provide a means of generating such representative data sets for WAMI sensors operating in the visible through thermal infrared. The work reported here describes the ASSET model, as well as provides validation results from comparisons to laboratory imagers, small-area yet high-fidelity validated models, and satellite data (e.g. LANDSAT-8).

10178-11, Session 3

NVIPM imager emulator for measured systems

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

Characterizing an imaging system through the use of linear transfer functions allows prediction of the output for an arbitrary input. Through careful measurement of the systems transfer function, imaging effects can then be applied to desired imagery in order to conduct subjective comparison, image based analysis, or evaluate algorithm performance. The Night Vision Integrated Performance Model (NV-IPM) currently utilizes a two-dimensional linear model of the systems transfer function to emulate the systems response and additive signal independent noise. In this correspondence, we describe how a two-dimensional MTF can be obtained through correct interpolation of one-dimensional measurements. We also present a model for the signal dependent noise (additive and multiplicative) and the details of its calculation from measurement. Through modeling of the experimental setup, we demonstrate how the emulated sensor replicates the observed objective performance in resolution, sampling, and noise.

10178-12, Session 3

A new radiometric unit of measure to characterize SWIR illumination

Austin A. Richards, FLIR Systems, Inc. (United States); Martin Huebner, Airbus Defence and Space (Germany)

We propose a new radiometric unit of measure we call the 'SWUX' to unambiguously characterize scene illumination in the SWIR spectral band between 0.9μm-1.68μm, where most of the ever-increasing numbers of deployed SWIR sensors (based on standard InGaAs focal plane arrays) are sensitive. Both military and surveillance applications in the SWIR currently suffer from a lack of a standardized SWIR radiometric unit of measure that can be used to definitively compare or predict different SWIR imager sensor performance with respect to SNR and range metrics. We propose a unit comparable to the photometric illuminance lux unit; see Ref. [1]. This lack becomes even more critical if one uses lux levels to describe SWIR sensor performance at twilight or even low light condition, since particularly in clear, no-moon conditions in rural areas naturally-occurring SWIR radiation from nightglow will dominate over visible starlight. Thus, even well-intentioned efforts to characterize a test site's ambient illumination levels in the SWIR band may fail based on photometric instruments that only measure visible light. A study of this by one of the authors in Ref. [2] showed that the correspondence between lux values and total SWIR irradiance in typical illumination conditions can vary by more than two orders of magnitude, depending on the spectrum of the ambient background. In analogy to the photometric lux definition, we propose the SWIR illuminance equivalent 'SWUX' level, derived by integration over the scene SWIR spectral irradiance weighted by an idealized square band quantum efficiency curve within the 0.9μm-1.68μm spectral range.

10178-13, Session 3

Power spectral density of 3D noise measurements

David P. Haefner, U.S. Army RDECOM CERDEC NVESD (United States)

When evaluated with a spatially uniform irradiance, an imaging sensor exhibits both spatial and temporal variations, which can be described as a three-dimensional (3D) random process considered as noise. In the 1990s, NVESD engineers developed an approximation to the 3D power spectral density (PSD) for noise in imaging systems known as 3D noise. In this correspondence, we describe how the full 3D PSD can be decomposed into the familiar components from the 3D Noise model. The standard 3D noise method assumes spectrally white random processes, which as we demonstrate is not typically the case with complex modern imaging sensors. Using the spectral shape allows for more appropriate analysis of the impact of the noise of the sensor. The processing routines developed for this work consider finite memory constraints and utilize Welch's method for unbiased PSD estimation.

10178-14, Session 3

Improvements to the ShipIR/NTCS adaptive track gate algorithm and 3D flare particle model

Srinivasan Ramaswamy, David A. Vaitekunas, W. R. Davis Engineering, Ltd. (Canada); Willem H. Gunter, Fait February, Institute for Maritime Technology (South Africa)

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 gate the selected target to further improve tracker performance. Similarly, a key component in any soft-kill response to an incoming guided missile is the flare /chaff decoys used to distract or seduce the seeker homing system away from the naval platform. This paper describes the recent improvements to the naval threat countermeasure simulator (NTCS) of the NATO-standard ship signature model (ShipIR).

Efforts to analyse and match the 3D flare particle model using actual IR measurements from a Chemring TALOS IR round (during the NATO Sapphire trial, 2006), are described, and which resulted in further refinements to the 3D flare particle distribution. These same refinements necessitated a similar round of developments to further improve the adaptive track gate (ATG) algorithm to use a new set of parameters and statistics to help distinguish the flare decoy from the ship signature. A series of test scenarios are used to demonstrate the impact of flare and ship signatures on ATG performance.

10178-15, Session 4

Noise-insensitive no-reference image blur estimation by convolutional neural networks

Daniel Wegner, Michael Koerber, Endre Repasi, Fraunhofer-Institut für Optronik, Systemtechnik und Bildauswertung (Germany)

A few image quality metrics for blur assessment have been presented in the last years. However, most of those metrics do not take image noise into account. Yet, image noise is an unavoidable part of the image forming process with digital cameras. Some thermal imagers show larger sensor noise and inhomogeneity compared to cameras operating in the visible range.

Further, natural imagery might contain a combination of several degradations. Assessment of degraded images by observer trials is expensive and time consuming. A single robust quality metric might be derived by metrics highly responsive to single degradations and insensitive to others. Hence separate assessment of image blur and noise seems to be reasonable.

In this paper we present a deep learning approach for noise-insensitive blur predictions by using Convolutional Neural Networks (CNN) on image patches. In contrast to current blur metrics the model output is highly correlated to blur distortion over a wide range of image noise. The model is trained on images of ImageNet database impaired by Gaussian blur and noise and tested on artificial and natural image data. Local blur estimation based on patches is especially useful for estimation of non-uniform blur due to motion and atmospheric turbulence.

10178-16, Session 4

leveraging simulation to validate system performance models

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

The development of image simulation techniques which map the effects of a notional, modeled sensor system onto an existing image can be used to evaluate the image quality of camera systems prior to the development of prototype systems. Image simulation or virtual prototyping can be utilized to reduce the time and expense associated with conducting extensive field trials as well. In this paper we examine the development of an experiment to assess the validity of the NVESD imager performance metric as a function of fixed pattern noise drift. Measurement of a vehicle or human activities target set as a function of time is a very difficult problem and the use of image simulation is leveraged to provide an accurate representation of the task. The paper discusses the development of the model theory and the implementation and execution of the experiment with an analysis of the results and lessons learned.

10178-17, Session 4

Low-cost panoramic infrared surveillance system

Ian Kecskes, Ezra Engel, Christopher M. Wolfe, U.S. Army Research Lab. (United States); George M. Thomson, Oak Ridge Institute For Science and Education (United States)

An optical surveillance package concept, comprised of a Tamarisk 640 DRS camera and a modified GoPano plus optical system, gives a continuous 360° azimuthal field of view (FOV) that extends from well below the horizon to more than 45° above it, all without the use of multiple cameras or lenses. The GoPano plus optical system uses a reflective surface to project the 360° FOV image onto the focal plane of the DRS camera. To allow the GoPano to operate in the thermal infrared, the glass window between GoPano lens and the optical housing was replaced with Barium Fluoride BaF_2. Both the camera and the optical system are readily available, off-the-shelf, inexpensive products. The large FOV, compactness and portability of this optical package offers significant advantages over existing infrared surveillance systems. In this work, the optical concept is evaluated on its ability to detect objects from 10 m to 70 m in 20 m increments in the thermal IR spectral range. The raw camera images are converted from rectangular to polar coordinates using Matrox Imaging Library 9 to increase the ease-of-view and also to locate potential threats in azimuth. Color mapping is applied to give viewers a user-friendly and intuitive image. In addition, background subtraction is used to distinguish moving objects from static background objects. The level of detail of the images acquired with the GoPano optic are compared to those taken simultaneously with a commercially available 50-mm f/1.2 ATHERM lens from Ophir Optics, LLC connected to a second Tamarisk 640 DRS camera. This was done in order to demonstrate how a combination of a wide field surveillance optic may be coupled to a higher resolution system for the detection and assessment of a potential threat.

10178-37, Session 4

Extending the range performance of diffraction limited imagers

Richard H. Vollmerhausen, Ronald G. Driggers, St. Johns Optical Systems (United States)

Diffraction from the finite aperture size of a camera reduces the contrast of high spatial frequencies as well as limiting the maximum frequency in the image. Reclaiming the high frequency contrast can theoretically double camera resolution, thereby doubling what is normally thought of as “diffraction limited” range performance. This paper describes using inverse filters to reclaim high frequency detail. The imager characteristics needed to support deconvolution are described, and simulation is used to illustrate the performance benefit of deconvolution.

10178-33, Session PSTue

The influence of the earth radiation on space target detection system

Xiaofeng Su, FanSheng Chen, Shanghai Institute of Technical Physics of the Chinese Academy of Sciences (China)

In the view of space remote sensing, such as satellite detection, space debris detection etc., visible band is usually used, in order to have the all-weather detection capability, long wavelength infrared (LWIR) detection is also an important supplement. However, in the tow wave band, the earth can be a very strong interference source, especially in the dim target detecting. When the target is close to the earth, especially the LEO target, the background radiation of the earth will also enter into the baffle, and became the stray light through reflection, the stray light can reduce the signal to clutter ratio (SCR) of the target and make it difficult to be detected. In the visible band, the solar albedo by the earth is the main clutter source while in the LWIR band the radiation of the earth is the main clutter source. So, in this paper, we establish the energy transformation from the earth background radiation to the detection system to assess the effects of the stray light. Firstly, we discretize the surface of the earth to different unit, and using MODTRAN to calculate the radiation of the discrete point in different light and climate conditions, then, we integral all the radiation which can reach the baffle in the same observation angles to get the energy distribution, finally, according the target energy and the non-uniformity of the detector, we can calculate the design requirement of the system Point Source Transmittance (PST), which provides the design basis for stray light suppression of the optical system.

10178-34, Session PSTue

Study on IR signatures of a ship for different seasonal marine environmental conditions

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

Infrared energy is emitted from every object over 0K (absolute temperature). Recently, IR sensors are applied for various guided missiles and they affect a crucial influence on object’s survivability. Especially, it is more vulnerable to attack by IR guided missile in marine environment since there are nearly no objects for conceal. For object’s survivability, IR

signal of object need to be analyzed carefully by considering various marine environments. Owing to direct measurement of IR signal on object using IR camera is costly and time consuming job, computer simulation method is developing nowadays rapidly to replace those experimental tasks. The IR signatures of a ship in marine environment consist of emitting energy on object surface by temperature and reflected energy by external sources. As a ship's surface thermal property, likes paint, an emissivity is different and reflected energy is affected by sensor's geometric positions and various conditions in marine environment. All of these factors, IR signal, coming to IR sensor, on ship in marine environment has been decided finally. In this study, measured weather data and IR images are used in seasonal marine environment conditions to analysis more accurate IR signals on ship. IR images are obtained by the IR camera, Long-Wavelength Infrared (LWIR), in marine environment and IR signal of ship is calculated by computer simulation with seasonal marine environment conditions. Through this IR signal, we analyze the characteristic of IR signal from the ship against the background in seasonal marine environment conditions.

10178-35, Session PSTue

Lock-on range estimation in an air-to-air engagement situation

Birkan Çetin, Kutlu D. Kandemir, TÜBITAK SAGE (Turkey)

In missile applications, it is important to know the approximate lock-on range distance between the missile and target. With the usage of correct radiometric approaches, these distances can be estimated. In the mentioned calculations, irradiances of target and background on the detector calculated with Planck equations are taken into account as well as other noise contributors. Transmission of air and clouds are calculated via atmospheric codes and implemented into the irradiance equations. In this aspect, the lock-on ranges are calculated for considered engagement situations before launch. However, in an air-to-air case, due to the dome heating after launch, signal to noise ratio (SNR) decreases and possibility of losing target becomes as a significant issue. In this work, the SNR is also calculated after launch with respect to time. In order to stop the decreament of the SNR, noise radiance which mainly comes from the dome should be eliminated with using midwave bandpass filters. Simulations show that the selection of cut-on and cut-off wavelengths of midwave bandpass filters which are implemented in front of the optics of the seeker are very important in order not to lose the target.

10178-36, Session PSTue

Mid-wavelength infrared continuous zoom lens design

Jun-Qi Wang, National Chung-Shan Institute of Science and Technology (Taiwan)

In recent years, thermal imager has been developed for the concept of portable products. Military aircraft, armored vehicle, warship, and soldiers can execute mission by using thermal imager system. Thermal imager is able to see through smoke, fog, and haze in inclement weather and observe distand targets. By using thermal imager, soldiers can obtain the possible threat factors to avoid unnecessary losses at any time.

The hand-held thermal imager consists of infrared lens module, visible light lens module, telescope, and laser range finder. In this paper, we study the design of infrared zoom lens and propose new method to correct image. Traditionally, thermal imgaer system sets diffuser between infrared lens and detector. It lets the sensor to appear ther original noise of the system, and then use image processing method to remove the original noise in order to avoid interference with the system noise and scene signals which affects identification distance. In this paper, we propose the optical non-uniformity correction method to remove the original noise of the system. This method will generate a diffused beam by setting lens at special positions, and the diffused beam will fall on the detector focal plane array to present the original noise of the system. By using image processing method, it gets the same effect of clear image compared to traditional way. It also reduces the size of the system space, and improves system reliability.

10178-18, Session 5

Understanding system trades

Gerald C. Holst, JCD Publishing (United States)

With the older models, trade-off analysis was laborious: change one input and run the model. Repeat as often as necessary. NVIPM offers loop analysis by which trades can performed quickly. While actual values are required for system optimization, this paper focusses on the curve shape (e.g., range versus f-number with and w/o noise). The shape depends upon a myriad of variables. When the detector and optics MTFs are dominant and only photon shot noise is present, range is maximized when F?/d approaches two. The various shapes will be related to the various components of the targeting task performance (TTP) variable.

10178-20, Session 5

Small pixel cross-talk MTF and its impact on MWIR sensor performance

Tristan M. Goss, Airbus DS Optronics (Pty) Ltd. (South Africa); Cornelius J. Willers, Individual Capacity (South Africa)

As pixel sizes reduce in the development of modern High Definition (HD) Mid Wave Infrared (MWIR) detectors the inter-pixel cross-talk becomes increasingly difficult to regulate. The diffusion lengths required to achieve the quantum efficiency and sensitivity of MWIR detectors are typically longer than the pixel pitch dimension, and the probability of inter-pixel cross-talk increases as the pixel pitch/diffusion length fraction decreases.

Inter-pixel cross-talk is most conveniently quantified by the focal plane array sampling Modulation Transfer Function (MTF). Cross-talk MTF will reduce the ideal sinc square pixel MTF that is commonly used when modelling sensor performance. However, cross-talk MTF data is not always readily available from detector suppliers, and since the origins of inter-pixel cross-talk are uniquely device and manufacturing process specific, no generic MTF models appear to satisfy the needs of the sensor designers and analysts. In this paper cross-talk MTF data has been collected from recent publications and the development for a generic cross-talk MTF model to fit this data is investigated. The resulting cross-talk MTF model is then included in a MWIR sensor model and the impact on sensor performance is evaluated in terms of the National Imagery Interoperability Rating Scale's (NIIRS) General Image Quality Equation (GIQE) metric for a range of f-number/detector pitch configurations and operating environments.

By applying non-linear boost transfer functions in the signal processing chain the contrast loses due to cross-talk may be compensated for. Boost transfer functions, however, also reduce the signal to noise ratio of the sensor. In this paper boost function limits are investigated and included in the sensor performance assessments.

10178-21, Session 5

A computational imaging target specific detectivity metric for shift- and non-shift invariant systems

Bradley L. Preece, U.S. Army RDECOM CERDEC NVESD (United States); George Nehmetallah, The Catholic Univ. of America (United States)

Due to the large quantity of low-cost, high-speed computational processing available today, computational imaging (CI) systems are expected to have a

major role for next generation multifunctional cameras. The purpose of this work is to quantify the performance of theses CI systems in a standardized manner. Due to the diversity of CI system designs that are available today or proposed in the near future, significant challenges in modeling and calculating a standardized detection signal-to-noise ratio (SNR) to measure the performance of these systems. In this paper, we developed a mathematical framework for the calculation of a standardized detectivity metric (DM) for CI systems. The DM is developed from the peak signal to noise ratio (SNR) and is calculated using the target Energy Spectral Density, the target matrix, the background Power Spectral Density, or the covariance matrix. The DM represents the highest SNR achievable by an optimal linear matched filter algorithm searching for a target within a background. The DM has the flexibility to handle various types of CI systems and specific targets while keeping the complexity and assumptions of the systems to a minimum. The DM is designed to assess the performance of CI systems searching for a specific target or signal of interest, and is defined as the well-known matched filter SNR, similar to the Hotelling SNR, calculated in computational space with special considerations for standardization. The DM is a number that can be measured in the laboratory and can be used to understand the tradeoffs of a CI system.

10178-38, Session 5

The TTP Metric: Past, present, and future

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

The targeting task performance (TTP) metric was introduced by the US Army Night Vision and Electronic Sensors Directorate (NVESD) in 2006 to improve target acquisition performance modeling. For many imaging systems, the Johnson metric and the TTP metric provide similar range predictions over a wide set of camera design parameters. However for systems that strongly modify the shape of the Modulation Transfer Function (MTF) due to optics design or digital post processing, the TTP metric better reflects these image quality changes. In 2013 NVESD introduced improvements to the underlying human observer model of the TTP metric which further reduced the variance of measured versus modeled range performance data. In this paper, the behavior of the TTP metric and the human observer model used within the Night Vision Integrated Performance Model (NV-IPM) are reviewed and contrasted for legacy NVESD models, current versions of the model, and possible future variants.

10178-22, Session 6

Empirical LWIR scene simulation based on E/O satellite and airborne LWIR imagery

Alan Hsu, David I. Klick, Christopher Bowen, MIT Lincoln Lab. (United States)

Target detection in background clutter is a challenging problem and evaluating system performance of long-wave infrared (LWIR) imaging systems requires accurate simulation of the background scene. First-principles models for scene simulation often lack validated parameters such as at-source apparent temperature for various terrain types. We present a tractable, empirical LWIR ground scene simulation approach based on (1) material classification of satellite electro-optical (E/O) imagery and (2) LWIR simulation of the terrain types based on airborne measurements from a wide-field-of-regard LWIR imaging system developed by MIT Lincoln Laboratory. The LWIR measurements are used to derive empirical coefficients for the at-source apparent temperature for several terrain types as a function of surface temperature and sun irradiance. Atmospheric transmission and path radiance are then calculated using MODTRAN, and the at-sensor LWIR scene irradiance can be accurately simulated as shown by good agreement with airborne LWIR measurements of a variety of scenes in the New England area for both nadir and horizon view geometries. Given the wide availability of global E/O satellite imagery, any location at any time of day could potentially be simulated in LWIR with reasonable accuracy if LWIR imagery for the corresponding terrain types is available.

10178-23, Session 6

The European computer model for optronic system performance prediction (ECOMOS)

Endre Repasi, Fraunhofer-Institut für Optronik, Systemtechnik und Bildauswertung (Germany); Piet Bijl, TNO Earth, Life & Social Sciences (Netherlands); Luc Labarre, ONERA (France); Wolfgang Wittenstein, Consultant (Germany); Helge Bürsing, Fraunhofer-Institut für Optronik, Systemtechnik und Bildauswertung (Germany)

ECOMOS is a multinational effort within the framework of an EDA Project Arrangement. Its aim is to provide a generally accepted and harmonized European computer model for computing nominal Target Acquisition (TA) ranges of optronic imagers operating in the Visible or thermal Infrared (IR). The project involves close co-operation of defense and security industry and public research institutes from five nations: France, Germany, Italy, The Netherlands and Sweden. ECOMOS will use and combine existing European tools, to build up a strong competitive position.

In Europe, there are two well-accepted approaches for providing TA performance data: the German TRM (Thermal Range Model) model and the Netherlands TOD (Triangle Orientation Discrimination) method. ECOMOS will include both approaches. The TRM model predicts TA performance analytically, whereas the TOD prediction model utilizes the TOD test method, imaging simulation and a Human Visual System model in order to assess device performance. For the characterization of atmosphere and environment, ECOMOS uses the French model and software MATISSE (Modélisation Avancée de la Terre pour l'Imagerie et la Simulation des Scènes et de leur Environnement).

In this presentation, the central idea of ECOMOS is exposed. The overall structure of the software and its underlying models are shown and elucidated. The status of the project development is given and the work share between participating nations is addressed.

10178-24, Session 6

TRM4: Range performance model for electro-optical imaging systems

Stefan Kessler, Fraunhofer-Institut für Optronik, Systemtechnik und Bildauswertung (Germany); Raanan Gal, Gal Consultant (Israel); Wolfgang Wittenstein, Consultant (Germany)

TRM4 is a commonly used model for assessing device and range performance of electro-optical imagers. The latest version, TRM4 v2, has been released by Fraunhofer IOSB of Germany in June 2016. While its predecessor, TRM3, was developed for thermal imagers, assuming black body targets and backgrounds, TRM4 extends the TRM approach to assess three imager categories: imagers that exploit emitted radiation (TRM4 category Thermal), reflected radiation (TRM4 category Visible), and both emitted and reflected radiation (TRM4 category General).

Performance assessment in TRM is based on the perception of standard 4-bar test patterns, whether distorted by undersampling or not. Spatial and sampling characteristics are taken into account by the AMOP (Average Modulation at Optimum Phase), which replaces the system MTF used in previous models. The MTDP (Minimum Temperature Difference Perceived) figure of merit was introduced in TRM3 for assessing the range performance of thermal imagers. In TRM4, this concept is generalized to the MDSP (Minimum Difference Signal Perceived) figure of merit, which can be applied for all imager categories.

In this paper, we outline and discuss the TRM4 approach and pinpoint differences to TRM3. In addition, an overview of the TRM4 software and its functionality is given. Features newly introduced in TRM4, such as atmospheric turbulence, illumination sources, and libraries are addressed. We conclude with an outlook on the new module for image-intensified cameras that is currently under development.

10178-25, Session 6

Virtual DRI dataset development

Jonathan G. Hixson, Tana O. Maurer, Christopher M. May, U.S. Army Night Vision & Electronic Sensors Directorate (United States)

The U.S. Army RDECOM CERDEC NVESD MSD's target acquisition models have been used for many years by the military analysis community for sensor design, trade studies, and field performance prediction. This paper analyzes the results of perception tests performed to compare the results of a field DRI (Detection, Recognition, and Identification Test) performed in 2009 to current Soldier performance viewing the same imagery in a laboratory environment and simulated imagery of the same data set. The purpose of the experiment is to build a robust data set for use in the virtual prototyping of infrared sensors. This data set will provide a strong foundation relating, model predictions, field DRI results and simulated imagery.

10178-26, Session 6

Estimating top-of-atmosphere thermal infrared radiance using MERRA2 atmospheric data

Tania Kleynhans, Matthew Montanaro, Aaron D. Gerace, Rochester Institute of Technology (United States)

The Thermal Infrared Sensor (TIRS) on board Landsat 8, has displayed anomalies in the Earth imagery. After several calibration techniques were applied without significant success it was deduced that stray light from outside the field of view is contaminating the thermal images. An operational stray light correction algorithm was introduced to improve image quality. This algorithm requires temporally coincident out of field thermal infrared radiance data. Currently the radiance values at the edge of the TIRS image are used to infer the out of field radiance values. As an alternative method to provide better out of field radiance values for use in the algorithm, the Modern-Era Retrospective analysis for Research and Applications, Version 2 (MERRA2) reanalysis data is being investigated for use in creating a three hourly thermal radiance world map (10-12.5?m). Top-of-atmosphere radiances are estimated from (1) calculating the dew point depressions at each layer in the atmosphere to predict the of likelihood of clouds, (2) models developed to predict TOA radiance based on skin or cloud temperature and altitude. These models are based on numerous Moderate resolution atmospheric transmission (MODTRAN) simulations at various altitudes, temperature and atmospheric conditions. The low spatial resolution MERRA2 data is resampled to a 5x5km ground sampling distance for use in the stray light correction algorithm. Coincident Terra/MODIS thermal data is used as validation of the produced radiance map. This product could lead to more accurate TIRS data that could lead to better global water management for which TIRS data is primarily used.

10178-27, Session 6

A dynamic IIR seeker model for air-to-air missile design

Kutlu D. Kandemir, Birkan Çetin, TÜBITAK SAGE (Turkey)

An air-to-air IIR seeker design is a multidimensional decision making problem related to different mission parameters. For a selected set of scenarios, it should be ensured that SNR of the target image obtained by the FPA is above a certain threshold during the entire flight.

Due to the dynamic and intricate nature of air-to-air engagement, it is very hard to identify the impact of individual seeker parameters on system performance by relying on simplified models or calculations trimmed for specific steady flight conditions.

The optical and electromechanical sub-systems composing the seeker and, the external effects like aerodynamic heating, target aspect and atmospheric losses have significant influence on SNR during the mission. Therefore it is crucial to construct a detailed seeker model at the early phases of the design and observe the combined effect of each parameter on system performance.

A detailed dynamic air-to-air engagement model including optics, detector, and target radiometric model, gimbaled pointing and tracking system dynamics, kinematic engagement scenarios, and resulting aerodynamic heating noise was constructed. The coupled sub-system models are linked to IIR detector radiometric calculations, and resulting temporal signal on the detector was selected as the figure of merit. The model was then run and verified with a set of generic air-to-air engagement data.

Results showed the temporal effect of mechanical, radiometric and optical parameters on seeker imaging performance. Unlike the related studies, this work constructed a guideline for IIR seeker design task by incorporating various physical phenomena and considering their time dependency.

10178-28, Session 7

Frequency modulated continuous wave lidar performance model for target detection

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

The desire to provide the warfighter both ranging and operational intensity information is increasing to meet expanding operational needs. Lidar imaging systems can provide the user with intensity, range, and even velocity information of a scene. The ability to predict the performance of Lidar systems is critical for the development of future designs without the need to conduct time consuming and costly field studies. Performance modeling of a frequency modulated continuous wave (FMCW) Lidar system is challenging due to the addition of the chirped laser source and waveform mixing. The FMCW Lidar model is implemented in the NV-IPM framework using the custom component generation tool. This paper presents an overview of the FMCW Lidar, the customized Lidar components, and a series of trade studies using the Lidar model. Finally, the limitations of the Lidar model will be discussed.

10178-29, Session 7

Progress in sensor performance testing, modeling and range prediction using the TOD method: an overview

Piet Bijl, Maarten A. Hogervorst, Alexander Toet, TNO Earth, Life & Social Sciences (Netherlands)

The Triangle Orientation Discrimination (TOD) methodology includes a widely applicable, accurate end-to-end EO/IR sensor test, an image-based sensor system model and a Target Acquisition (TA) range model. The method has been extensively validated against TA field performance for a wide variety of well- and under-sampled imagers, systems with advanced image processing techniques such as dynamic super resolution and local adaptive contrast enhancement, and sensors showing smear or noise drift, for both static and dynamic test stimuli and as a function of target

contrast. Recently, significant progress has been made in many directions. Dedicated visual and NIR test charts for lab and field testing are available and thermal test benches are on the market. Automated sensor testing using an objective synthetic human observer is within reach. An analytical TOD model has recently been published, an image-based TOD model is being implemented in the European Target Acquisition model ECOMOS and in the EOSTAR TDA, and the methodology is being applied for design optimization of high-end security camera systems. Finally, results from a recent perception study suggest that DRI ranges for real targets can be predicted by replacing the relevant distinctive target features by TOD test patterns of the same characteristic size and contrast, enabling a totally new TA modeling approach. This paper provides an overview.

10178-30, Session 7

Current target acquisition methodology in force on force simulations

Jonathan G. Hixson, Brian S. Miller, Brian P. Teaney, U.S. Army Night Vision & Electronic Sensors Directorate (United States)

The U.S. Army RDECOM CERDEC NVESD MSD's target acquisition models have been used for many years by the military analysis community in force on force simulations for training, testing, and analysis. There have been significant improvements to these models over the past few years. The significant improvements are the transition of ACQUIRE TTP-TAS (ACQUIRE Targeting Task Performance Target Angular Size) methodology for all imaging sensors and the development of new discrimination criteria for urban environments and humans. This paper is intended to provide an overview of the current target acquisition modeling approach and provide data for the new discrimination tasks.

This paper will discuss advances and changes to the models and methodologies used to: (1) design and compare sensors' performance, (2) predict expected target acquisition performance in the field, (3) predict target acquisition performance for combat simulations, and (4) how to conduct model data validation for combat simulations.

10178-31, Session 7

Visible and thermal spectrum synthetic image generation with DIRSIG and MuSES for ground vehicle identification training

Jeffrey S. Sanders, Trideum Corp. (United States); Christopher M. May, Tana O. Maurer, Kimberly E. Kolb, U.S. Army Night Vision & Electronic Sensors Directorate (United States)

There is a ubiquitous and never ending need in the US armed forces for training materials that provide the warfighter with the skills needed to differentiate between friendly and enemy forces on the battlefield. The current state of the art in battlefield identification training is the Recognition of Combat Vehicles (ROCV) tool created and maintained by the Communications - Electronics Research, Development and Engineering Center Night Vision & Electronic Sensors Directorate (CERDEC NVESD). The ROC-V training package utilizes measured visual and thermal imagery to train soldiers about the critical visual and thermal cues needed to accurately identify modern military vehicles and combatants. This paper presents an approach that has been developed to augment the existing ROC-V imagery database with synthetically generated multi-spectral imagery that will allow NVESD to provide improved training imagery at significantly lower costs.

10178-32, Session 7

LWIR image visualization preserving local details and global distribution by gradient-domain image reconstruction

Takashi Shibata, Masayuki Tanaka, Masatoshi Okutomi, Tokyo Institute of Technology (Japan)

Recent developments of long wavelength infrared (LWIR) devices and LWIR sensor technologies enable us to obtain an LWIR image with high bit depth and low signal-noise ratio. In general, a pseudo color transformation is usually applied to visualize the LWIR image. Although the pseudo color transformation is effective to represent the global distribution of the input temperature, it is difficult to recognize local temperature details. These subtle details are often neglected in many LWIR visualization methods, while recent sophisticated LWIR cameras are capable of measuring the temperature with high accuracy. To exploit these recent developments, we propose a novel temperature visualization method that can simultaneously represent the global distribution and the local details of the input temperature. The proposed method, first, transforms the input temperature to a pseudo color image, which represents the global distribution of the input temperature. Next, the output luminance is generated by a gradient-domain image reconstruction. This image reconstruction is carried out by minimizing the energy functional composed of both a gradient-residual constraint and an intensity-range constraint. The local details of the input temperature are preserved by the gradient-residual constraint, while the output luminance lies within a specified intensity range by the intensity-range constraint. Finally, the output color image is generated by combining the generated luminance with the chrominance component of the pseudo color image. Experimental results on real LWIR images show that the proposed method can generate the output image which simultaneously visualizes the global distribution and the local details of the input temperature.

Conference 10179: Window and Dome Technologies and Materials XV

Tuesday - Wednesday 11–12 April 2017

Part of Proceedings of SPIE Vol. 10179 Window and Dome Technologies and Materials XV

10179-1, Session 1

Research and development of transparent ceramic materials at Alfred University

Yiquan Wu, New York State College of Ceramics at Alfred Univ. (United States)

No Abstract Available

10179-2, Session 1

Powder processed ZnS materials for infrared and luminescence applications

John S. McCloy, Muad Saleh, Kelvin G. Lynn, Washington State Univ. (United States)

Several samples of legacy and recent powder processed ZnS ceramics were compared to assess crystallographic, mechanical, optical, and luminescence properties. X-ray diffraction was used to quantify hexagonality. Vickers' hardness was measured as a proxy for erosion damage. Visible and infrared transmission was measured, and extrinsic absorption and scattering assessed. For consideration as luminescent materials, both photoluminescence (UV-VIS excitation) and radioluminescence (low energy x-ray excitation) was investigated. Trap states were determined for some materials using thermoluminescence. Comparison with commercial ZnS powder phosphors and laboratory synthesized Zn(S,O) powders is discussed.

10179-3, Session 1

Evaluation of undoped ZnS single crystalline materials for x-ray imaging applications

Muad Saleh, Kelvin G. Lynn, John S. McCloy, Washington State Univ. (United States)

ZnS-based materials have a long history of use for x-ray luminesce, but have been thus far limited to thin powder screens due to opacity to blue/green scintillation light. ZnS in bulk form has high transmission as opposed to powder screens. The performance of ZnS is compared to CsI:Tl, Bi4Ge3O12 (BGO), and Ce:Y3Al5O12 (Ce:YAG) for low energy (<10KeV) imaging, based on its calculated scintillation gain absolute efficiency. The study gives insight into the spatial resolution of these scintillators. Further, the luminescence properties of several commercial undoped ZnS materials are studied using Photoluminescence (PL), PL Excitation (PLE), Radioluminescence (RL) and Thermoluminescence (TL).

10179-4, Session 1

Broadband, ultralow reflectance surface structures on silica windows for high-energy laser applications

Lynda E. Busse, Jesse A. Frantz, L. Brandon Shaw, U.S. Naval Research Lab. (United States); Menelaos K. Poutous, Ishwar D. Aggarwal, The Univ. of North Carolina at Charlotte (United States); Jasbinder S. Sanghera, U.S. Naval Research Lab. (United States)

The characteristics of broadband transmission, environmental durability, and laser damage resistance are critical for silica glass exit aperture windows for their use in kW-level, high energy laser systems. The use of conventional antireflective (AR) coatings on windows for high energy lasers operating in the near infrared is impacted by laser induced damage that occurs under high power irradiation as well as the potential for delamination in operational environments. Novel methods for fabricating antireflective surface structures (ARSS) directly on optics have resulted not only in reduced reflection loss, but also in other advantages to AR coatings as well. The ARSS approach involves sub-wavelength surface structures fabricated directly into the actual surface of the window, eliminating the need for a coating of extraneous materials. We will report on results for ARSS fabricated on silica glass windows. Recently we have reported broadband, low reflectance (< 0.02% at 1 μm) for silica glass windows with random ARSS, fabricated using reactive ion etching. These windows have shown remarkably high laser damage thresholds of 100 J/cm2 at 1.06 μm, which is 5x the threshold measured for a conventional AR coating. We will also present results for MILSPEC durability tests on silica windows, both with and without ARSS, for rain and sand erosion as well as salt fog testing, conducted at a government facility. We will also report on scale up of ARSS on silica windows of large sizes (33 cm), making them practical for system implementation.

10179-5, Session 1

Superhydrophobic, infrared transmissive moth eye-like substrates for use in wet conditions

Darryl A. Boyd, Jesse A. Frantz, Lynda E. Busse, Woohong Kim, Shyam S. Bayya, Jasbinder S. Sanghera, U.S. Naval Research Lab. (United States)

Infrared (IR) transmissive Moth Eye-like substrates, including randomly patterned fused silica and various periodically patterned germanium substrates, were surface modified using a simple process. Goniometric analysis showed that the surface modification altered the surface wettability of each substrate, rendering them superhydrophobic. Following the surface modification, it was determined that the desirable IR transmission and anti-reflective properties of each substrate type were maintained. Furthermore, the hydrophobicity, IR transmission and anti-reflective capabilities of the substrates were shown to be significantly enhanced in comparison to native, non-Moth Eye fused silica and germanium substrates that underwent the same processes. The results of this work provide an opportunity for the development of enhanced utility infrared transmissive optics in wet or humid conditions.

10179-7, Session 2

History of magnesium fluoride as an optical dome and window material

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

Magnesium Fluoride optical components began to become more widely developed in the 1950s, leading to a commercial poly-crystalline material for infrared transparent windows and domes by the 1960s. This paper will examine the transition of magnesium fluoride window and dome science and technology from the laboratory to the field, with special emphasis on the development and properties of magnesium fluoride polycrystalline materials.

10179-8, Session 2

Weibull analysis and area scaling for infrared windows

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

This tutorial talk explains the maximum likelihood method for Weibull analysis of mechanical strength of ceramic materials and how strength scales with area under stress. Weibull parameters for a variety of infrared window materials are presented. Calculation of the Weibull static probability of survival is illustrated.

10179-9, Session 2

Slow crack growth study of polycrystalline alumina and multispectral zinc sulfide

Lee R. Cambrea, Daniel C. Harris, Naval Air Warfare Ctr. Weapons Div. (United States); Steven M. Goodrich, Univ. of Dayton Research Institute (United States); Mark V. Parish, Marina R. Pascucci, CeraNova Corp. (United States)

Window lifetime limited by slow crack growth under stress was calculated for multispectral zinc sulfide and polycrystalline alumina using the procedure set forth by Wiederhorn. This paper describes the derivation of Weibull and slow crack growth parameters from strength measurements over a range of stress rates and how these parameters are applied during window design to predict window lifetime under stress. Proof testing is employed to ensure that a window begins its life with a known, minimum strength.

10179-10, Session 2

Low-level background absorption in durable window materials

Michael E. Thomas, Johns Hopkins Univ. (United States)

The understanding and characterization of low level absorption in window materials is important for applications involving high energy lasers and hot windows in front of detectors. Impurities are important as well as defects. Distributed defects can produce a weak absorption tail that can manifest itself as a background continuum absorption between the band gap and the multiphonon absorption edges. A characteristic functional form is observed as given by the following equation for the absorption coefficient

beta_abs = beta0 exp(nu/nu0)

where beta0 and nu0 are empirically chosen. The weak absorption tail has been characterized in certain semiconductors and glasses, but not in crystalline or polycrystalline materials that are typical durable window materials.

Low-level absorption in the visible and near infrared has been reported for single crystal o-ray sapphire and the measurements follow the form of the above equation. A survey of reported measurements in regions of high transparency on other materials is presented.

10179-11, Session 3

Measurement of dn/dT and dk/dT of optical crystals, ceramics, and chalcogenide glasses between 80K and 1050K

Eoin S. O'Keefe, QinetiQ Ltd. (United Kingdom); Christopher Craig, Daniel W. Hewak, Univ. of Southampton (United Kingdom); Peter A Hobson, Alastair Humphrey, QinetiQ Ltd. (United Kingdom); Daniel A. C. Pearce, QinetiQ Group plc (United Kingdom); Andrea Ravagli, Univ. of Southampton (United Kingdom)

Optical designers frequently need to know the optical constants of materials across the electro-optic spectrum at the temperatures prevailing in optical elements in the light path. In many applications optical elements formed in multispectral materials need to operate at temperatures that can easily change over several hundred K and in some cases temperature changes of a thousand K or more are encountered. In this paper we describe the measurement of transmission and reflection of selected materials between 0.2 and 20 microns at temperatures between 80K and 1050K at the UK MoD-Industry STAAR Facility. The measurements are used to derive the temperature dependent optical coefficients ?n/?T, ?k/?T. We relate these measured values to predictions from a computational multi-phonon absorption model running in MatLab® and further describe use of this model to interpolate the data and perform limited extrapolations to higher temperatures. Worked examples are shown for well-known and characterised materials such as single crystal sapphire and barium fluoride together with some of the new and emerging glasses from the EPSRC supported Chalcogenide Advanced Manufacturing Partnership (ChAMP).

10179-12, Session 3

Scattering properties of hot isostatic pressed multispectral zinc sulfide

Marcus Trost, Nadja Felde, Sven Schröder, Fraunhofer-Institut für Angewandte Optik und Feinmechanik (Germany); Shay Joseph, Arit E. Shienmann, Rafael Advanced Defense Systems Ltd. (Israel)

Electrooptical systems operating in the visible and simultaneously in the infrared spectral range under extreme environmental conditions require the use of window materials with high optical throughput as well as optimal imaging properties. A common window material for such purposes is multispectral zinc sulfide (MS-ZnS), which offers a high optical transmittance between 400 nm and 12 µm. Depending on the manufacturing process, MS-ZnS can, however, exhibit large scattering losses (> 10%) in particular in the visible spectral range which degrade the imaging quality.

In this contribution, hot isostatic pressed (HIPed) ZnS windows manufactured using graphoil and platinum foils during the fabrication process are characterized with respect to their scattering properties over the entire visible spectral range with the help of a supercontinuum light source as well as at 1064 nm and 4.6µm using a Nd:YAG laser and quantum cascade laser, respectively. The focus of the work was to separate the different sources for light scattering, which includes roughness induced scattering, bulk scattering, and scattering from subsurface damage as well as to correlate the scattering characteristics with the structural properties resulting from the fabrication process.

For this purpose, different samples with thicknesses ranging from 2 mm to 15 mm were fabricated and polished to the same roughness level of ~2 nm. This allows analyzing the bulk scattering properties independently from the surface roughness. The latter is analyzed with the help of first-order scattering theory in combination with a detailed roughness analysis based on atomic force microscopy and white light interferometry. The results

demonstrate that the roughness induced scattering mainly dominates the scattering properties at angles larger than 30° from the specular beam, while the near angle scattering is mainly influenced by the bulk properties.

10179-13, Session 3

High-temperature materials characterization for multispectral window applications

James Park, Air Force Research Lab. (United States)

Development of aerospace sensors that can sustain under extreme environment requires technical insight into the impact of thermal stress on window and dome materials. Furthermore, as demand for multispectral and multi-mode sensors grows, it becomes necessary to understand the material properties in broad spectra of interest. To investigate the temperature dependence of dielectric material property, free-space methods using Gaussian beams and Nicolson-Ross-Weir (NRW) method using waveguide structures have been widely applied to material characterization with heat sources such as furnace or oven. Additionally, in the Air Force Research Laboratory (AFRL), we have investigated high temperature RF material characterization approach using high power laser. High power laser can provide an extreme heating to the samples and their permittivity can be measured by cavity perturbation method (CPM). In the presentation, we will report the analysis of window materials' permittivity in high temperature using FEM based simulations and various measurement methods.

10179-14, Session 4

Refractive index of transparent polycrystalline alumina

Daniel C. Harris, Linda F. Johnson, Lee R. Cambrea, Naval Air Warfare Ctr. Weapons Div. (United States); Lawrence Baldwin, Meghan Baronowski, Naval Air Warfare Center Weapons Div (United States); David E. Zelmon, William B. Poston, John D. Kunkel, Air Force Research Lab. (United States); Mark V. Parish, Marina R. Pascucci, John J. Gannon, CeraNova Corp. (United States); Tzu-Chien Wen, The Univ. of Utah (United States)

The refractive index of polycrystalline α-alumina prisms with a grain size of ~0.4 μm is reported for the wavelength range 0.9 to 5.0 and the temperature range 293 to 498K. Results agree with those predicted for randomly oriented grains of single-crystal aluminum oxide. This talk will provide some tutorial background on the behavior of birefringent materials.

10179-15, Session 4

Strength characteristics of transparent alumina and spinel ceramics

Mark V. Parish, Marina R. Pascucci, John J. Gannon, CeraNova Corp. (United States); Daniel C. Harris, Naval Air Warfare Ctr. Weapons Div. (United States)

Transparent ceramics are finding increasing use in optical applications with demanding operating conditions. Polycrystalline ceramics provide a unique combination of mechanical, dielectric and optical properties for sensor window applications that were previously not possible. The mechanical strength of CeraNova's transparent alumina and spinel was measured by an equibiaxial strength test method. The results of the tests and their analysis, included those at elevated temperatures for transparent alumina, will be presented.

10179-16, Session 4

Recent developments in spinel at NRL

Shyam S. Bayya, Guillermo Villalobos, Woohong Kim, Michael Hunt, Benjamin Rock, Jasbinder S. Sanghera, U.S. Naval Research Lab. (United States); Bryan Sadowski, Ishwar D. Aggarwal, Sotera Defense Solutions, Inc. (United States)

Transparent magnesium aluminate spinel (MgAl2O4) ceramic has excellent transmission from the UV to mid-wave IR. It is rugged with strength that is 5x that of glass. Spinel also has better IR transmission compared to sapphire and ALON. Because of its superior mechanical and optical properties, it is considered as a sensor window for numerous military platforms. At the Naval Research Laboratory (NRL), we have focused on process developments to facilitate wider acceptance of spinel for various applications. These developments include purification of spinel to reduce the absorption and scattering losses, as well as new processes to make conformal spinel windows and also to reduce manufacturing and finishing costs. In this presentation, we will provide an update on all the spinel activities at NRL

10179-17, Session 4

Conformal ALON and Spinel windows

Lee M. Goldman, Mark Smith, Surmet Corp. (United States); Mohan Ramisetty, Surmet (United States); Santosh K. Jha, Suri A. Sastri, Surmet Corp. (United States)

No Abstract Available

10179-18, Session 4

Scale up of large ALON and Spinel windows

Lee M. Goldman, Uday K. Kashalikar, Mohan Ramisetty, Santosh K. Jha, Suri A. Sastri, Surmet Corp. (United States)

No Abstract Available

10179-19, Session 5

Drying step optimization to obtain large-size transparent magnesium-aluminate spinel samples

Johan Petit, Lucile Lallemant, ONERA (France)

Transparent polycrystalline ceramics are generally recognized as an alternative to polymers, glasses or single crystals in optical applications such as windows, armors, discharge lamps envelopes or jewels. The growing interest for this type of materials is mainly due to their strong thermo-mechanical properties up to high temperature (>1000°C) and their intrinsic transparency over the visible-IR range. Nevertheless, obtaining high light transmission requires a careful control of the chemical composition and the microstructure all over the process.

Green bodies processing is probably the most critical step of the process as it strongly influences the following sintering step. Among the known techniques, wet shaping processes are particularly interesting because they enable the particles to find an optimum position on their own. Nevertheless, the presence of water molecules leads to drying issues. During the water removal, its concentration gradient induces internal stresses or cracks limiting the sample size. The aim of this study is to introduce finite element

simulations as a useful complementary tool to avoid cracks formation during the drying step of large samples.

Conditions in our climatic test chamber were modeled. First test samples were dried measuring the water loss to fixe model parameters. Then, the temperature and hygrometry profiles were optimized to reduce the water gradient trying to keep the step time reasonable.

Thus, 80 mm diameter 10 mm thickness highly transparent spinel plates were obtained. This method is now used to obtain larger samples and with other compounds (alumina, yttria).

10179-20, Session 5

Development of optical ceramic materials for infrared applications by optimizing sintering conditions

Masafumi Isogai, Masahiko Sano, NEC Corp. (Japan)

The authors developed production process of polycrystalline Zinc Sulfide (ZnS) materials which have been widely applied to windows and domes for infrared sensor systems. Commercially available ZnS powders were used as a starting material and Spark Plasma Sintering method (SPS) was applied to the powders for firing process. It was found that the densification of the sintered materials was inhibited by outgassing from ZnS powders during the sintering process (ca. 400 Celsius). Thermal desorption spectroscopy analyses revealed the components of outgassing, such as hydrogen sulfide, sulfur oxide and organic molecules. Based on these analyses, the optimum conditions on heating rate and starting temperature of uniaxial pressurization were investigated to remove the outgassing. The polycrystalline ZnS materials fired under the optimized SPS conditions have such characteristics as better transmittance than 65 % and good uniformity in both 3~5 um and 8~12 um wavelength regions. These results show the importance of removing outgassing from starting materials.

10179-21, Session 5

Manufacturing and metrology for IR conformal windows and domes

Ian Ferralli, Todd Blalock, Matthew J. Brunelle, Timothy P. Lynch, Brian W. Myer, Kate Medicus, Optimax Systems, Inc. (United States)

Freeform and conformal optics have the potential to dramatically improve optical systems by enabling systems with fewer optical components, reduced aberrations, and improved aerodynamic performance. These optical components differ from standard components in their surface shape, typically a non-symmetric equation based definition, and material properties. Traditional grinding and polishing tools are unable to handle these freeform shapes. Additionally, standard metrology tools cannot measure these surfaces. Desired substrates are typically hard ceramics, including poly-crystalline alumina or aluminum oxynitride. Notwithstanding the challenges that the hardness provides to manufacturing, these crystalline materials can be highly susceptible to grain decoration.

We will show progress towards addressing the unique challenges of manufacturing conformal windows and domes. Particular attention is given to our robotic polishing platform. This platform is based on an industrial robot adapted to accept a wide range of tooling and parts. The robot's flexibility has provided us an opportunity to address the unique challenges of conformal windows. We can change slurries and polishing active layers easily for varying materials and to address grain decoration. We have the flexibility to change tool size and shape to address the varying sizes and shapes of conformal optics. In addition, we can use the robotic platform as a base for a deflectometry metrology tool to measure surface form error. This system (which is independent of the robot's positioning accuracy) will allow us to measure optics in-situ saving time and reducing part risk. In conclusion, we will show examples of the conformal windows manufactured using our developed processes.

10179-22, Session 6

18x36x1.5 inch sapphire panels for visible and infrared windows

Matthew Montgomery, Clark Blockburger, Rubicon Technology Inc. (United States)

No Abstract Available

10179-23, Session 6

Refractive index homogeneity TWE effect on large aperture optical systems

Melissa Stout, Brian W. Neff, II-VI Optical Systems (United States)

No Abstract Available

10179-24, Session 6

New advancements in freeform optical metrology

Scott DeFisher, Greg Matthews, James Ross, OptiPro Systems (United States)

No Abstract Available

10179-25, Session 6

Grinding and polishing of conformal windows and domes

Edward Fess, Frank L. Wolfs, James Ross, OptiPro Systems (United States)

No Abstract Available

10179-26, Session 7

Sources of variability in the sand erosion testing of infrared materials

Matthew W. Barnett, Raytheon Co. (United States); William H. Poisl, Judy E. Young, Raytheon Missile Systems (United States); Cheryl Castro, Air Force Research Lab. (United States)

No Abstract Available

10179-27, Session 7

Small particle impact damage on different glass substrates

Ibrahim Guven, Virginia Commonwealth Univ. (United States); Perry A. Gray, NASA Marshall Space Flight Ctr. (United States); Rachel Waxman, Virginia Commonwealth Univ. (United States)

No Abstract Available

10179-28, Session 7

Peridynamic modeling of indentation and impact damage in IR aperture materials

Ibrahim Guven, Forrest Baber, Virginia Commonwealth Univ. (United States); Brian J. Zelinski, Raytheon Missile Systems (United States)

No Abstract Available

10179-29, Session 7

Validation testing of a peridynamic impact damage model using NASA's MicroBallistic Particle Gun

Brian J. Zelinski, Raytheon Missile Systems (United States); Ibrahim Guven, Virginia Commonwealth Univ. (United States); Perry A. Gray, NASA Marshall Space Flight Ctr. (United States)

No Abstract Available

Conference 10180: Tri-Technology Device Refrigeration (TTDR) II

Tuesday 11–11 April 2017

Part of Proceedings of SPIE Vol. 10180 Tri-Technology Device Refrigeration (TTDR) II

10180-1, Session 1

Development of a miniature Stirling cryocooler for LWIR small satellite applications *(Invited Paper)*

Carl S. Kirkconnell, Robert C. Hon, West Coast Solutions (United States); Mostafa Ghiaasiaan, Thomas M. Crittenden, Georgia Institute of Technology (United States)

The optimum small satellite (SmallSat) cryocooler system must be extremely compact and lightweight, achieved in this paper by operating a linear cryocooler at a frequency of approximately 300 Hz. Operation at this frequency, which is well in excess of the 100-150 Hz reported in recent papers on related efforts, requires an evolution beyond the traditional Oxford-class, flexure-based methods of setting the mechanical resonance. A novel approach that optimizes the electromagnetic design and the mechanical design together to simultaneously achieve the required dynamic and thermodynamic performances is described. Since highly miniaturized pulse tube coolers are fundamentally ill-suited for the sub-80K temperature range of interest because the boundary layer losses inside the pulse tube become dominant at the associated very small pulse tube size, a moving displacer Stirling cryocooler architecture is used. Compact compressor mechanisms developed on a previous program are reused for this design, and they have been adapted to yield an extremely compact Stirling warm end motor mechanism. Supporting thermodynamic and electromagnetic analysis results are reported.

10180-2, Session 1

A miniature pulse tube cryocooler used in a superspectral imager *(Invited Paper)*

Zhenhua Jiang, Yinong Wu, Shanghai Institute of Technical Physics of the Chinese Academy of Sciences (China)

In this paper, we describe a high-frequency pulse tube cryocooler used in a superspectral imager to be launched in 2020. The superspectral imager is a field-dividing optical imaging system and uses 14 sets of integrated IR detector cryocooler dewar assembly. For the requirements of less heat loss and smaller size, each set is highly integrated by directly mounting the IR dectector's sapphire substrate on the pulse tube's cold tip, and welding the dewar's housing to the flange of the cold finger. Driven by a pair of moving magnet linear motors, the dual-opposed piston compressor of the cryocooler is running at 120Hz. Filled with customized stainless screens in the regenerator, the cryocooler reaches 8.1% carnot efficiency at the cooling power of 1W@80K with 35Wac input power.

10180-3, Session 1

Lockheed Martin microcryocoolers *(Invited Paper)*

Jeffrey R. Olson, Eric W. Roth, Lincoln Sanders, Ted C. Nast, Lockheed Martin Space Systems Co. (United States)

Lockheed Martin's Advanced Technology Center has developed a series of long life microcryocoolers for avionics and space sensor applications. We report the development and testing of three varieties of single-stage, compact, coaxial, pulse tube microcryocoolers. These coolers support emerging large, high operating temperature (100-150K) infrared focal plane array sensors with nominal cooling loads of 200-2000 mW, and all share long life technology attributes used in space cryocoolers, which typically require 10 years of continuous operation on orbit without degradation. These three varieties of microcryocooler are the 345 gram Micro1-1, designed to provide 1 W cooling at 150 K, the 450 gram Micro1-2, designed to provide 2 W cooling at 105 K, and the 330 gram Micro1-3, designed to provide 300 mW cooling at 125 K while providing the capability of cooling the IR focal plane to 125K in less than 3 minutes. The Micro1-3 was also designed with a highly compact package that reduced the coldhead length to 55 mm, a length reduction of more than a factor of two compared with the other coldheads.

This presentation will also report on recent design studies of 2-stage microcryocoolers capable of providing cooling at 30-80K. LM-ATC is an industry leader in multiple-stage coolers, having successfully built and tested eight 2-stage coolers (typically cooling to 35-55K), and four coolers with 3 or 4 stages (for cooling to 4-10K). The 2-stage microcryocooler offers a very low mass and compact package capable of cooling HgCdTe focal planes, while providing simultaneous optics cooling at a higher temperature.

10180-4, Session 1

RICOR Cryocoolers for HOT IR detectors from development to optimization for industrialized production *(Invited Paper)*

Amiram Katz, RICOR Cryogenic & Vacuum Systems (Israel)

The modern needs of electro-optical market for small low-power and light-weight IR systems are impelling research and development of High Operating Temperature (HOT) IR detectors, requiring development of dedicated "HOT" cryocoolers.

The development of cryocoolers with emphasis on the "SWAP^3" configuration means small size, low weight, improved performance, low power consumption and low price, in order to optimize IDDCA for future hand held thermal sights.

This paper will present the development and the progress made with the new "HOT" cryocooler, including customer data after the evaluation process, performances achieved using a generic cold finger, test results update on a large series of production coolers, life and qualification test update and acoustic noise reduction. All the information above relates to the FPA temperature range of 130 - 200K for various cryocooler models based on rotary & linear design concepts.

The paper will also review the progress with the latest development activities implemented in the cryocoolers and the electronic control modules in order to improve reliability and minimize regulated power consumption.

10180-5, Session 1

Ceramic 3D printed Joule Thomson mini cryocooler intended for HOT detectors *(Invited Paper)*

Anatoly Parahovnik, Alexander Shapiro, Rafael Advanced Defense Systems Ltd. (Israel)

No Abstract Available

10180-6, Session 1

AIM linear cryocoolers: An overview *(Invited Paper)*

Ingo N. Rühlich, Carsten Rosenhagen, Markus Mai, Thomas Wiedmann, Sebastian Zehner, AIM INFRAROT-MODULE GmbH (Germany)

In the past years, cryocooler developments focused on the improvement of SWaP,C characteristics. Advanced detector materials allow the operation at higher FPA operating temperatures enabling and raise the demand for very compact, highly efficient, reliable, and cost-effective cryocoolers. In addition, longwave-IR detectors, large detector arrays, and many commercial devices still required low cooling temperatures and/or higher heat loads.

To meet the specific requirements of various customers and users, AIM's cryocooler family includes a large number of different compressor and coldfinger/inner dewar options combined with suitable digital controllers. AIM's ¼ dewar for example can be operated by 5 different linear compressors covering the range from just small heat loads at 150K with a 160g compressor till some hundred Milliwatts at 70K with a 750g compressor.

Technical details and performance data of the most relevant combinations of expander and compressor will be presented. New developments will be introduced and different compressor/expander configurations will be discussed.

10180-7, Session 1

RMO1: Qualification results of the rotary miniature Stirling cryocooler at Thales Cryogenics *(Invited Paper)*

Jean-Yves Martin, Cédric Seguineau, Sébastien Van Acker, Mikel Sacau, Julien Le Bordays, Thierry Etchanchu, Christophe Vasse, Christian Abadie, Gilles Laplagne, Thales Cryogénie S.A. (France); Tonny Benschop, Thales Cryogenics B.V. (Netherlands)

The trend for miniaturized Integrated Dewar and Cooler Assemblies (IDCA) has been confirmed over the past few years with several mentions of a new generation of IR detector working at High Operating Temperature (HOT). This key technology enables the use of cryocooler with reduced needs of cryogenics power. As a consequence, miniaturized IDCA are the combination of a HOT IR detector coupled with a low-size, low-weight and low-power (SWaP) cryocooler. Thales Cryogenics has developed his own line of SWaP products. Qualification results on linear solution where shown last year. The current paper focuses on the latest results obtained on RMO1 prototypes, the new rotary SWaP cryocooler from Thales Cryogenics. The paper describes the impact of the generic coldfinger interface which has been adopted for this product. In a second part, progress is discussed on compactness and weight on one side, and on power consumption on the other side. It shows how the trade-off made between weight and power consumption could lead to an optimized solution at system level. At least, an update is made on the qualification status.

10180-8, Session 2

Characterizing transverse thermoelectrics: Novel techniques for anisotropic ambipolar semiconductors *(Invited Paper)*

Matthew Grayson, Northwestern Univ. (United States)

No Abstract Available

10180-9, Session 2

Laser cooling in semiconductors *(Invited Paper)*

Jun Zhang, Institute of Semiconductors, Chinese Academy of Sciences (China)

Laser cooling of semiconductor is very important topic in science researches and technological applications. Here we will report our progresses on laser cooling in semiconductors. By using of strong coupling between excitons and longitudinal optical phonons (LOPs), which allows the resonant annihilation of multiple LOPs in luminescence up-conversion processes, we observe a net cooling by about 40 K starting from 290 kelvin with 514-nm pumping and about 15 K starting from100 K with 532-nm pumping in a semiconductor using group-II–VI cadmium sulphide nanobelts. We also discuss the thickness dependence of laser cooing in CdS nanobelts, a concept porotype of semiconductor cryocooler and possibility of laser cooling in II-VI semiconductor family including CdSSe, CdSe, CdSe/ZnTe QDs and bulk CdS et al., Beyond II-VI semiconductor, we will present our recent progress in laser cooling of organic-inorganic perovskite materials, which show a very big cooling power and external quantum efficiency in 3D and 2D case. Further more, we demonstrate a resolved sideband Raman cooling of a specific LO phonon in ZnTe, in which only one specific phonon resonant with exciton can be cooled or heated. In the end, we will discuss the nonlinear anti-Stokes Raman and anti-Stokes photoluminescence upcoversion in very low temperature as low as down to liquid 4.2 K. In this case, the anti-Stokes resonance induces a quadratic power denpendece of anti-Stokes Raman and anti-Stokes PL. We proposed a CARS-like process to explain it. This nonlinear process also provides a possible physics picture of ultra-low temperatures phonon assisted photoluminescence and anti-Stokes Raman process.

10180-10, Session 3

Recent advances in optical refrigeration of a load *(Invited Paper)*

Aram Gragossian, Junwei Meng, Mohammadreza Ghasemkhani, Alexander R. Albrecht, Eric Lee, The Univ. of New Mexico (United States); Bernardo Farfan, Guy Symonds, Richard Epstein, ThermoDynamic Films (United States); Mansoor Sheik-Bahae, The Univ. of New Mexico (United States)

Laser cooling of solids has advanced immensely in recent years and temperatures well below 100 K have been demonstrated in Yb:YLF crystals. We will discuss our progress towards developing a functional all-solid-state cryocooler based on this principle. We present data and analysis concerning laser coupling efficiency, thermal link between the cooling crystal and the cold-finger, shielding the load from the fluorescence, and overall thermal load management. Considerations for building a cooler prototype for specific applications will also be discussed.

10180-11, Session 3

Forward to cryogenic temperature: laser cooling of Yb: LuLiF crystal *(Invited Paper)*

Biao Zhong, Hao Luo, Yongqing Lei, Yanling Shi, Jianping Yin, East China Normal Univ. (China)

The 7.5% Yb^{3+}:$LuLiF_4$ crystal with the geometry of 2mm x 2mm x 5mm is supported by two fibers of the diameter of 200 μm in a ~10-3 Pa vacuum chamber. The cooling setup is a single pass configuration and the environment temperature is about 294.5 K. The absolute temperature of the crystal is about 165 K after 20 minutes when the 20 W CW laser

at wavelength of 1020 nm was used to irradiate it. The temperature of the sample is measured by the DLT method. These experimental results demonstrate that in the near future the temperature of the Yb3+:LuLiF4 crystal can been cooled below the cryogenic temperature by the radiation.

10180-12, Session 4

Tactical versus space cryocoolers: a comparision

Roel Arts, Jeroen C. Mullie, Harrie Leenders, Garmt de Jonge, Tonny Benschop, Thales Cryogenics B.V. (Netherlands)

In recent years, several space cryocooler developments have been performed in parallel at Thales Cryogenics. On one end of the spectrum are research programmes such as the ESA-funded 30-50 K system developed in cooperation with CEA and Absolut System and the LPT6510 cooler developed in cooperation with Absolut System. On the other end of the spectrum are commercial designs adapted for space applications, such as the LPT9310 commercial coolers delivered for JPL's ECOSTRESS instrument and the LSF9199/30 SADA-compatible cooler delivered for various space programmes at Sofradir.

In this paper, an overview is presented of the latest developments regarding these coolers. Initial performance results of the 30-50K cooler are discussed, pending developments for the LPT6510 cooler are presented, and the synergies between COTS and space are reviewed, such as design principles from space coolers being applied to an upgraded variant of the COTS LPT9310, as well as design principles from COTS coolers being applied to the LPT6510 for improved manufacturability.

10180-13, Session 4

Ricor's anniversary of 50 innovative years in cryogenic technology

Avishai Filis, RICOR Cryogenic & Vacuum Systems (Israel)

Ricor cryogenics was established in 1967 and since then it has focused on innovative technologies in the cryogenic field.

The paper reviews the initial research & development efforts invested in various technologies that have yielded products such as Cryostats for Mossbauer effect measurement, Liquid gas Dewar containers, Liquid helium vacuum transfer tubes, Cryosurgery for medical treatment and other innovative products.

The major registered patents that matured into products reviewed such as a magnetic vacuum valve operator, pumped out safety valve and other innovations.

As a result of the continuous R&D investment, a new generation of innovative Stirling cryogenic products has developed over the years that began with massive split slip-on coolers and has continued as far as miniature IDDCA coolers mainly for IR applications.

The accumulated experience in Stirling technology is used also as a platform for developing self-contained water vapor pumps products called MicroStar and NanoStar and also used for mutual development with a research institute in the field of High Temperature Superconductors.

The continuous growth in cryogenic products range together with market needs impelled Ricor to expand the in-house manufacturing facility and become a worldwide leader with more than 120,000 cryocoolers manufactured to date.

The actual cryogenic development efforts and challenges are also reviewed mainly in the field of long life cryocoolers, ruggedized products, miniaturization and products for space applications.

10180-16, Session 4

Ricor's K527 highly reliable linear cooler: Applications and model overview

Ilan Nachman, Eli Levin, Adam Perach, Sergey V. Riabzev, Dan Gover, RICOR Cryogenic & Vacuum Systems (Israel)

The K527 linear cooler was developed in order to meet the requirements of reliability, cooling power needs and versatility for a wide range of applications such as hand held, 24/7 and MWS.

In recent years the cooler was implemented in variety of systems. Some of those systems can be sensitive to vibrations which are induced from the cooler. In order to reduce those vibrations significantly, Tuned Dynamic Absorber (TDA) was added to the cooler. Other systems, such as MWS type, are not sensitive to those vibrations, but require a robust cooler in order to meet the high demand for vibration and temperature. Therefore various mounting interfaces are designed to meet system requirements. The latest K527 version was designed to be integrated with the K508 cold finger, in order to give it versatility to suit detectors that are already designed for the K508 cooler type.

The reliability of the cooler is of a high priority. In order to meet the 30,000 working hours target, a special design features were implemented. Ten K527 coolers have passed the 18,000 working hours without degradations, and are still running according to our expectations.

10180-22, Session 4

Attenuation of cryocooler induced vibration in infrared imagers using multimodal tuned dynamic absorbers

Alexander Veprik, SCD SemiConductor Devices (Israel); Vladimir I. Babitsky, Loughborough Univ. (United Kingdom); Avi Tuito, Israel Ministry of Defense (Israel)

Modern infrared imagers often rely on split Stirling linear cryocoolers comprising compressor and expander units interconnected by the configurable transfer line. The relative position of the cryocooler components is governed by the optical design and packaging constraints.

Vibration export produced by such a cryocooler may be thought of as a pair of tonal and coherent forces resulting in angular line of sight jitter and translational defocusing affecting imaging performance of the long range and high resolution infrared imagers.

Since linear cryocooler is usually driven at a fixed and precisely adjustable frequency, a tuned dynamic absorber (TDA) is ideally suited and cost effective, lightweight tool for attenuation the cooler induced vibration and improving optical performance of such inherently vibration sensitive infrared imagers.

In attempt of further improving attainable performance, the authors are enhancing the concept of traditional, unimodal TDA. As different from the regular approach, the authors are considering multimodal TDA (MTDA) made in the form of weakly damped mechanical resonator, where the frequencies of particular dynamic modes are essentially tuned to the driving frequency.

Dynamic analysis and experimental testing show that the dynamic reactions (forces and moments) produced by such a MTDA may simultaneously attenuate both translational and angular components of cryocooler-induced vibration, thus improving the imagery quality. The authors are advising on different embodiments and their suitability for different packaging concepts.

10180-17, Session 5

A pump driving liquid cooling circuit for the aperture of an infrared cold optical system

RongJian Xie, Shanghai Institute of Technical Physics of the Chinese Academy of Sciences (China)

To enhance the optical recognition and wavelength filtering of an infrared cold optical system, some lens need to be maintained within a certain temperature range, which requires specific thermal management of the aperture. In this article, a 250K liquid cooling circuit designed for this purpose is introduced, and the experimental system is established and operated in a vacuum environmental simulation chamber. A practical cooling power source of radiation cooling equipment is adopted and the sun exposure heat load is imitated by array of planar membrane heaters attached on the specific designed structure of the aperture. Controlling the aperture temperature and improving the optical system performance are proved effective. Numerical optimization of the cooling circuit and simulation of the aperture are performed while in the mean time the factors affect the optical system performance are also investigated.

10180-18, Session 5

How to manage MTTF larger than 30,000hr on rotary cryocoolers

Jean-Marc Cauquil, Cédric Seguineau, Sébastien Van Acker, Jean-Yves Martin, Thales Cryogénie S.A. (France); Tonny Benschop, Thales Cryogenics B.V. (Netherlands)

The cooled IR detectors are used in a wide range of applications. Most of the time, the cryocoolers are one of the components dimensioning the lifetime of the system. Indeed, Stirling coolers are mechanical systems where wear occurs on millimetric mechanisms. The exponential law classically used in electronics for Mean Time to Failure (MTTF) calculation cannot be directly used for mechanical devices. Systems based on Rotary Stirling cryocoolers are especially sensitive to cooler's MTTF. With new applications for thermal sensor like border surveillance, an increasing reliability has become mandatory for rotary cooler. The current needs are above several tens of thousands of continuous hour of cooling. Thales Cryogenics made specific development on that topic, for both linear and rotary applications. The time needed for validating changes in processes through suited experimental design is hardly affordable by following a robust and rigorous standard scientific approach. The targeted Mean Time to Failure (MTTF) led us to adopt and innovative approach to keep development phases in line with expected time to market. This non-conventional approach is today widespread on all of Thales Cryogenics rotary products and results in a proven increase of MTTF for RM2, RM3 and recently RM1. This paper will then focused on the current MTTF figures measured on RM1, RM2 and RM3. After explaining the limit of a conventional approach, the paper will then describe the current method. At last, the authors will explain how these principles are taken into account for the new SWaP rotary cooler of Thales Cryogénie SAS.

10180-19, Session 5

Low temperature-fluctuation cold plate for miniature Stirling cryocoolers

Hao Sun, Junruo Chen, Kunming Institute of Physics (China)

Miniature Stirling cryocoolers are smoothly used to cool infrared sensors utilizing Integrated Dewar-Detector assemblies (IDDA). But some sensors are sensitive to operating temperature. The temperature fluctuation at cold plate cooled by periodic operation cooler, such as Stirling cooler, maybe has an unexpected effect on those accurate sensors. Therefore, there is a need to a novel cold plate formed the cold finger end to suppress the temperature fluctuation. And the balance of thermal resistance and thermal mass will be performed in the novel cold plate design. In this work, the low temperature-fluctuation cold plate is developed. We indentify the temperature fluctuation at cold end and adapt thermal conduction to suppress the fluctuation.

10180-20, Session 5

Ricor's Nanostar water vapor compact cryopump: Applications and model overview

Ilan Nachman, RICOR Cryogenic & Vacuum Systems (Israel); Rodney S. Harris, RICOR USA, Inc. (United States); Tomer Tauber, Michael Kootzenko, Boris Barak, Eli Aminov, Dan Gover, RICOR Cryogenic & Vacuum Systems (Israel)

Using our well understood and utilized Stirling cycle cryogenic cooling technology, Ricor Systems has developed a compact, single stage cryopump that fills the gap where GM and other type cryopumps can't fit in. Stirling cycle technology is highly efficient and is the primary cryogenic technology for use in IR, SWIR, HOT FPA, and other IR detector technology in military, security, and aerospace applications.

Current GM based dual stage cryopumps have been the legacy type water vapor pumping system for more than 50 years. However, the typically large cryopanel head, compressor footprint, and power requirements make them not cost and use effective for small, tabletop evaporation / sputtering systems, portable analysis systems, and other systems requiring small volume vacuum creation from medium, high, and UHV levels.

This single stage cryopump works well in-line with diffusion and molecular turbopumps. Studies have shown effective cooperation with non-evaporable getter technology as well for UHV levels. Further testing in this area are ongoing.

Temperatures created by Stirling cycle cryogenic coolers develop a useful temperture range of 40 to 150K. Temperatures of approx.imately 100 K are sufficient to condense water and all hydrocarbons oil vapours.

10180-21, Session 5

Performance, optimization, and latest development of the SRI family of rotary cryocoolers

Klemen Dovrtel, Franc Megušar, LE-Tehnika d.o.o. (Slovenia)

In this paper the SRI family of Le-tehnika rotary cryocoolers is presented (SRI401, SRI423/SRI421 and SRI474). The coolers cooling power range starts from 0.25W to 0.75W at 77K with available temperature range from 60K to 150K and are fitted to typical dewar detector sizes and powers supply voltages.

The DDCA performance optimizing procedure is presented. The procedure includes cooler steady stated performance mapping and optimization and cooldown optimization.

The current cryogenic performance status and reliability evaluation method and figures are presented on the existing and new units. The latest improved SRI401 demonstrated MTTF close to 30'000 hours and the test is still on going.

Conference 10181: Advanced Optics for Defense Applications: UV through LWIR II

Sunday - Monday 9 –10 April 2017

Part of Proceedings of SPIE Vol. 10181 Advanced Optics for Defense Applications: UV through LWIR II

10181-2, Session 1

Design of multiband optics using updated athermal/achromatic glass map

Jamie Ramsey, Blair L. Unger, Rochester Precision Optics, LLC (United States)

Recently, optical materials have been developed by Schott and NRL to improve material selection in the SWIR, MWIR, and LWIR wavelength regions. In addition, new multiband detectors are reaching maturity, leading to a natural push for common aperture lens systems. Detectors that can span the SWIR/MWIR, MWIR/LWIR or SWIR/MWIR/LWIR wavelengths regions will require complex optical systems to effectively utilize their full potential. Designing common aperture wide-band systems that are both achromatized and passively athermal, especially while maintaining SWAP-c (size, weight, power and cost), poses significant challenges. Through use of the updated YV-V diagram, which provides guidance on material combinations that both achromatize and athermalize, part of that challenge is reduced. This updated YV-V diagram uses instantaneous Abbe number and peak wavelength. The instantaneous Abbe number is a function of wavelength and is the scaled reciprocal of the instantaneous dispersion. The instantaneous Abbe number is defined at the peak wavelength, which occurs when the second derivative of the index of refraction goes to zero. Three examples will be presented using this updated athermal/achromatic glass map to demonstrate its effectiveness. These design examples will include a SWIR/MWIR design, a MWIR/LWIR design and, a SWIR/MWIR/LWIR design.

10181-3, Session 1

Comparison of gimbal approaches to decrease drag force and radar cross sectional area in missile application

Do?an U?ur Sakarya, Roketsan A.S. (Turkey)

Drag force effect is an important aspect of range performance in missile applications especially for long flight time. However, old fashioned gimbal approaches force to increase missile diameter. This increase has negative aspect of rising in both drag force and radar cross sectional area. A new gimbal approach was proposed recently. It uses a beam steering optical arrangement. Therefore, it needs less volume envelope for same field of regard and same opto-mechanical assembly than the old fashioned gimbal approaches. In addition to longer range performance achieved with same fuel in the new gimbal approach, this method provides smaller cross sectional area which can be more invisible in enemies' radar. In this paper, the two gimbal approaches - the old fashioned one and the new one- are compared in order to decrease drag force and radar cross sectional area in missile application. In this study; missile parameters are assumed to generate gimbal and optical design parameters. Optical design is performed according to these missile criteria. Two gimbal configurations are designed with respect to modeled missile parameters. Moreover, analyzes are performed to show decreased drag force and radar cross sectional area in the new approach for comparison.

10181-4, Session 1

Optimization of tunable phase shifters for integrated optical phased arrays

Dwayne D. Macik, Tyler E. Bravo, Seeley M. Pentecost, Francisco A. Espinal, Christi K. Madsen, Texas A&M Univ. (United States)

A low-loss, high-speed optical phased array (OPA) has been designed and fabricated. Two different platforms have been utilized for comparison purposes. A hybrid lithium niobate ($LiNbO_3$)-Arsenic Trisulfide (As_2S_3) optical phased array has been fabricated. This OPA allows for the non-mechanical beam steering (NMBS) of 1550 nm light on an integrated optic platform and takes advantage of the high electro-optic (EO) coefficient (r_{33} = 30.8 pm/V) of $LiNbO_3$ for electro-optic phase tuning. The other OPA is based on a silicon nitride (Si_3N_4) platform and uses thermo-optic (TO) phase tuning for NMBS. To characterize and tune each device, a 3 lens imaging system was employed to produce both near- and far- field intensity patterns of the OPAs' output on a static image plane. At the image plane, a single infrared 'point' detector was used for tuning the phase of each arm in each OPA for a given far-field propagation angle, while a high resolution infrared camera was used to observe the resulting intensity pattern. The control software for tuning the OPAs reads the intensity incident on the point detector, and has a PWM interface to drive either the thermo-optic or electro-optic phase controls. Beam steering can then be accomplished in one of two ways. The first method is to maximize the intensity on the point detector in one direction, and then apply a linear phase delta across the array. This method assumes that the change in optical phase of every OPA arm with respect to PWM input signal is equal. The second method is to create a mapping of PWM outputs associated with different maximized far field intensity angles, and then iterate through them. This defeats the limitations of the first method, which is the risk of non-linear and non-uniform phasing controls.

10181-28, Session 1

Expanded IR glass map with new NRL glasses for multispectral optics designs

Shyam S. Bayya, Daniel J. Gibson, Vinh Nguyen, Jasbinder S. Sanghera, U.S. Naval Research Lab. (United States); Mikhail Kotov, Sotera Defense Solutions, Inc. (United States); Collin McClain, Univ. Research Foundation (United States); Jay Vizgaitis, optX Imaging Systems (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. NRL is working on developing new IR glasses that transmit from 0.9 to > 12 μm in wavelength, with refractive index ranging from 2.38 to 3.17, to expand the glass map and provide compact solutions to multispectral imaging systems. These glasses were specifically designed to have comparable glass molding temperatures and thermal properties so that they can be laminated and co-molded into optics with reduced number of air-glass interfaces (lower Fresnel reflection losses). These new NRL glasses also have negative or very low 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, as well fabrication and characterization of new optics.

10181-5, Session 2

Day vision unit DC focal motor controller design on FPGA

Can Ugur Oflamaz, Murat Kalkan, ASELSAN A.S. (Turkey)

This paper introduces a solution for FPGA based high precision motor control. Focal lens position controller is designed and implemented for day vision unit. This controller contains a pre-filter and a PI controller. Firstly, the filter and PI controller blocks are designed in Matlab environment. Then by using Matlab to VHDL conversion toolbox, the blocks are converted into VHDL code. The proposed model is designed and simulated using Simulink and then simulated also on Modelsim by using VHDL code. Afterwards, the VHDL code is synthesized and implemented on an FPGA. The design is tested and verified in -32 °C and +55 °C temperature environment. This implementation offers significant advantages: flexibility, reliability and rapid prototyping.

10181-6, Session 2

Stray light analysis considerations for a laser spot tracker

Osman Ozdemir, Beyza Akarca, Göktug G. Artan, TÜBITAK SAGE (Turkey)

Stray light can be defined as a collection of sensors detecting unwanted rays in an optical system. It is encountered in every optical system regardless of the design quality. Stray light can never be fully eliminated but it can only be reduced. In some applications, stray light is considered vital for the overall performance of the system such as laser spot trackers. In order for laser spot trackers to detect from long range, the sensing elements of the four quadrant detector are required to have high gain. Even though this increases the detection probability, using detectors with high gain causes more stray light as a result. Optical properties such as aperture and field of view as well as optomechanical properties such as stop position and optoelectronic properties such as gain selection significantly affect the amount of stray light. In this sense, first of all, the effects of the entrance aperture and field of view on stray light are analysed. Also, practical issues such as the contribution of scattering caused by manufacturing quality of optical elements to stray light are also taken into consideration. After an initial analysis, different optomechanical designs are made to minimize stray light and reduce the noise falling on the detector. The stray light analysis is performed with these designs while varying the positions of different surfaces and investigating several paint and mechanical roughness options. Finally, the effects of stray light on the overall performance of the laser spot tracker are analysed and interpreted.

10181-7, Session 2

Stray light reduction with engineered grooves

Kevin J. McIntyre, DRS RSTA, Inc. (United States)

Stray light, caused by unwanted reflections off opto-mechanical housing features, can cause serious degradation to the performance of an imaging system by introducing artifacts to the final image. In a typical scenario, radiation from a bright source (such as the sun or a fire), located outside the field of a view of a camera, enters the lens system and reflects off an inner mechanical surface. This energy then re-enters the optical path and strikes the detector array producing an undesirable pattern in the image. Typically, grooves/threads or baffles are added to the housing design to re-direct the unwanted radiation away from the detector. In some cases, this re-directed radiation may reflect off a lens element and then propagate to the detector. This can be problematic when the lens surface has significant reflectance. For infrared systems, hard carbon coatings, used to protect outer lens surfaces, can have a relatively large reflectance (>5%). In this paper, it is shown engineered or shaped grooved surfaces can eliminate these reflection paths and hence prevent formation of what would otherwise be objectionable, stray light artifacts in the final image. In particular, grooves with a convex cross section can be used to diffuse the stray radiation away from the detector.

10181-8, Session 3

Ternary versus binary material systems for gradient index optics *(Invited Paper)*

Guy Beadie, U.S. Naval Research Lab. (United States); Joseph N. Mait, Predrag Milojkovic, U.S. Army Research Lab. (United States); Richard A. Flynn, U.S. Naval Research Lab. (United States)

Previous work developed a theory and figure of merit for optimizing material selection for gradient index (GRIN) achromatic singlets. The theory was based on a model of blending two pure materials to form the GRIN. Here we present an analogous study, highlighting the improvements which can be achieved by considering a blend of three (or more) materials, rather than just two, to achieve additional chromatic control. Dispersion curves of real materials never generate perfect achromatic behavior over wide bandwidths. While two materials can be chosen that minimize chromatic effects, it stands to reason that the addition of a third material could help balance the remaining chromatic aberrations. In this talk we will present our model for the incorporation of a third material, discuss how a third material allows for independent control of both index and dispersion, present results from a full search over the Schott Glass catalog to identify the optimum ternary system for the visible bandwidth, and discuss the implications of this approach for developing novel GRIN material systems.

10181-9, Session 3

Optical design of athermal, multispectral, radial GRIN lenses

Andrew M. Boyd, Excelitas Qioptiq (United Kingdom)

Military infrared systems must generally exhibit stable optical performance over a wide operating temperature range. We present a model for the first order optical design of athermal radial gradient index systems based on a form of the thermo-optic glass coefficient adapted to inhomogeneous material combinations.

Advances in focal plane array technology potentially enable the integration of multiple wavebands onto a common sensor. To achieve reduced system SWAP we would like the optics of a multispectral system to have a common aperture. The design of such multispectral optics can be very challenging using conventional materials, leading to heavy, complex designs.

This novel first order modelling technique is used to find a starting solution for a SWIR-LWIR optical design based on theoretical blends of common chalcogenide and crystalline materials. An optical design derived from this starting point is demonstrated. We find that GRIN lenses can significantly reduce the optical power of lens components in athermal, multispectral systems, which introduces the scope for a new class of simplified multispectral infrared solutions with significantly improved SWAP.

10181-10, Session 3

Using GRIN to save 50% lens weight for a 6x rifle scope design

Richard A. Flynn, Guy Beadie, U.S. Naval Research Lab. (United States)

Previous work demonstrated the design of a passively athermal, achromatic doublet based on the performance of a polymer gradient index (GRIN) optic. Starting with a literature-based design for a rifle scope, we demonstrate the potential to replace large, heavy glass lenses with polymer-based GRIN lenses with little optical penalty, while saving 50% of the lens weight in the system. Several properties of the primary design are chosen to favor manufacturability, such as leaving glass for the external surfaces and choosing polymers & GRIN geometries based on proven fabrication

techniques. Compared to the reference design which weighed 154 g, the GRIN-substituted design weighed 76 g while maintaining visually constant performance from 0-40°C.

10181-11, Session 3

IR-GRIN optics: design and fabrication

Daniel J. Gibson, Shyam S. Bayya, Vinh Nguyen, Jasbinder S. Sanghera, U.S. Naval Research Lab. (United States); Mikhail Kotov, Sotera Defense Solutions, Inc. (United States); Collin McClain, Sotera Defence Solutions, Inc. (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 has developed axial GRIN lenses compatible with all IR wavebands (SWIR, MWIR and LWIR). These new optics can be used to replace multiple refractive elements in an imaging system saving size and weight. The IR-GRIN lens technology, design space and modeling considerations will be presented in this paper.

10181-12, Session 3

Athermal achromat theory for polymer gradient Index optics

Guy Beadie, Richard A. Flynn, U.S. Naval Research Lab. (United States)

Previous work demonstrated a ray trace simulation of a passively athermal, achromatic doublet based on the performance of a polymer gradient index (GRIN) optic. The design was made possible by the GRIN degrees of freedom in the system. This work expands on the theory behind GRIN-based athermal design, and provides guidance on how to choose materials based on their thermo-optic properties for optimal performance. Like our previously published work on a figure of merit approach for GRIN achromat material selection, the work is based on the analysis of a simplified expression for the focal length of a GRIN-based lens system. Equations are derived for the simultaneous conditions of athermal and achromatic performance, which reveal relationships that must hold among the thermo-optic properties of the materials involved. Though the equations are simplistic approximations of lenses with non-paraxial focal lengths, the results provide attractive starting points and material combinations, as shown by fully raytraced designs in standard optical design software. An important goal of this work is to demonstrate the possibility of hybrid glass/plastic lenses which save significant weight in fielded systems, without the thermal penalty commonly associated with polymer optics. By contrast, it is precisely the large thermo-optic and thermo-mechanical coefficients of polymers which enable these designs.

10181-31, Session 3

Effect of molding index drop on chalcogenide GRIN profiles

George P. Lindberg, Blair L. Unger, Richard H. Berg, John Deegan, Robert Benson, Rochester Precision Optics, LLC (United States); Dan Gibson, Shyam Bayya, Jasbinder Sanghera, Vinh Nguyen, Naval Research Labs, Code 5620 (United States); Mikhail Kotov, Sotera Defense Solutions (United States)

Gradient index (GRIN) lenses have been created for use in imaging for the infrared regime using diffusion of chalcogenide glasses. The GRIN lenses are shaped using a combination of precision glass molding and single point diamond turning. The precision glass molding step has been shown to cause a drop in the index of refraction, and this drop is related to the cooling rate during the molding process. Since the GRIN lenses have an index of refraction profile created by diffusion of multiple layers of chalcogenide glasses, we would expect that the index drop would vary as a function of position. In this paper we investigate the expected profile change due to the index drop of the constituent chalcogenide glasses, as well as performance data on the GRIN lenses created for this project.

10181-13, Session 4

Using material advances in chalcogenide glasses to improve imaging lenses in the 8-14 μm waveband

Jan Verplancke, Umicore (United States); John W. Franks, Umicore Coating Services (United Kingdom); Norbert Schuster, Umicore Electro-Optic Materials (France)

Athermalization of optics is a key technology in compensating for focus drift due to changes in refractive index over temperature and material expansion. One strategy to achieve this is by using an active focus mechanism and a lookup table or focus finder to shift the lens or detector accordingly. As SWaP-C requirements become ever more important, however, the need for passive athermalization strategies becomes increasingly apparent.

The conventional method to ensure maximal resolution over a wide temperature range, is to incorporate in the mechanical design of an objective an element that expands or contracts in a way opposite to the movement of the optimal focus point. This Passive Mechanical Athermalization (PMA) is conceptually the easiest way to achieve athermal performance.

Passive Optical Athermalization (POA) exploits the different material properties and shapes of a multi-lens system. By balancing thermal expansion and index change of the optical and mechanical materials with optical power of the elements themselves, essentially constant performance can be obtained over a wide temperature range.

Passive Optical and Mechanical Athermalization (POMA) is a hybrid technique that combines material properties with mechanical movement, allowing only one of multiple elements to be moved for thermal compensation.

In this paper, all three methods above will be elaborated upon with emphasis on which materials are suitable for either technique. Special attention will be devoted to the concepts needed to combine mechanical and optical properties with the aim to achieve superior performance over a wide range of operating temperatures.

10181-15, Session 4

Digital correction of aberrations introduced by tilted plane-parallel plates in convergent beams

Catherine Greenhalgh, Stan Szapiel, Stefan Atalick, Michael D. Thorpe, Raytheon ELCAN Optical Technologies (Canada)

Attempts to sufficiently correct non-symmetric aberrations introduced by tilted PPPs span many decades. Cube beamsplitters are heavy and are impractical in thermal IR bands, while pellicles are too fragile for field applications. More sophisticated approaches introduce customized refractive correctors, which use tilted and/or decentered spherical or non-spherical elements, including cylinders. Many of these solutions can correct only certain types of aberrations and perform well for large enough f-numbers and small FOVs.

We attempt to solve the above problem by proposing a digital correction of image blur component introduced by tilted PPPs. We show that, for a

properly calibrated system, this blur can be essentially deconvolved. The method is especially interesting when ray incidence angles on tilted PPPs are moderate, which is commonly required for efficient dichroic coatings in multispectral imagers.

The self-calibration routine uses optical prescription data and optical design software packages (ZEMAX/CODEV) to generate initial input for a blind deconvolution algorithm. This approach usually results in fairly quick convergence to the "true" PSF kernel, which is then routinely used over entire FOV in a classic image restoration procedure based on inverse filtering.

Trade-off analysis is provided which compares our new approach with selected optical hardware based solutions. The method has a potential to reduce cost and SWaP factors in compact, field-deployable imagers.

10181-16, Session 4

A system perspective on designing for field-dependent SNR in wide-angle point-source detection lenses

Craig Olson, L-3 Communications (United States); Andrew W. Sparks, Robert Cline, Timothy D. Goodman, L-3 Sonoma EO (United States)

The use of staring focal plane arrays in sensors for point-source detection is becoming a viable technology for many applications, including infrared search-and-track (IRST). Lens designers for these sensors must consider the radiometric impact of maintaining signal-to-noise ratio (SNR) over fields of view often exceeding 100 degrees.

The SNR for such a sensor, in the background-limited case, is proportional to the ratio of collected flux from a point source to the extended irradiance produced by the background. Often, sensor models used to derive requirements for optics only consider on-axis performance, with some consideration given to balancing resolution or blur size at field.

From a radiometric point of view, however, the sensor system must also optimize SNR performance over the full field. Using f-theta distortion allows each pixel to subtend a constant solid angle in object space, equalizing noise-equivalent irradiance over field. The relative illumination determines the roll-off of image irradiance (and consequently background shot noise) as a function of field.

The total flux from a point source, however, depends on the irradiance collected by the entrance pupil, which is distributed over the point-spread function at the image. The entrance pupil shape, which can change dramatically at field in high-distortion lenses, will determine the signal flux and impact the sensor SNR over field.

We survey of a number of published wide-angle lenses and evaluate quantitative field-dependence relationships between relative illumination, point-source SNR, and lens distortion. In addition, we explore an aberration-based expression for the field dependence of point-source SNR that can be used to generate both lens design and system design requirements, providing potential optimization targets for the lens designer.

10181-17, Session 4

Expanding the mission plan for large scale telescope systems via skew path optical conditioners

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

Changing requirements in theater often dictate the use of optical systems in roles for which they had not been originally designed. An added level of complexity invariably occurs when any new requirement must work around pre-existing architecture. This paper will describe a case study in which a telescope system, originally designed for a large format, visible camera, needed MWIR imaging capabilities while maintaining its original setup. The dedicated telescope system was adapted to share its existing optics with a new imaging module via a skew path concept. The challenges of non-rotationally symmetric design are explored along with an explanation of the methodology used to analyze and address the unique configuration.

10181-18, Session 5

Antireflective surface structures on infrared optics

Lynda E. Busse, Jesse A. Frantz, L. Brandon Shaw, Shyam S. Bayya, Guillermo Villalobos, U.S. Naval Research Lab. (United States); Ishwar D. Aggarwal, Sotera Defense Solutions, Inc. (United States); Jasbinder S. Sanghera, U.S. Naval Research Lab. (United States)

Infrared-transmitting optics used in imaging systems have high refractive indices ($n=1.4$ to $n > 3$) that require antireflective (AR) coatings. These coatings have limitations in that they can delaminate in operational environments, which is a problem particularly for broadband coatings that consist of multiple layers of dissimilar materials. In addition, residual reflections within an imaging system can cause ghost reflections, degrading performance. Recently, new methods have been developed for fabrication of anti-reflective surface structures (ARSS) on optics that significantly reduce reflection losses at the surface. The ARSS approach provides a more robust solution by using surface structures built directly into the actual surface of the optics, without the need for a coating with extraneous materials. We present recent results that demonstrate superior ARSS performance on a variety of optics for use in the infrared spectral region. These materials have been successfully patterned with ARSS using reactive ion etching (RIE) or using photolithography and etching. We report on reflection losses as low as 0.02% for fused silica at 1.06 microns, and have also demonstrated low reflection losses for ARSS on germanium, spinel ceramic, and sapphire, all of which are important for mid- to long-wave infrared imaging applications.

10181-19, Session 5

Design of broadband anti-reflective metasurfaces based on an effective medium approach

Nicholas S. Nye, Univ. of Central Florida (United States); Andrew Swisher, The Pennsylvania State Univ. (United States); Corey Bungay, Steve Tuenge, Lockheed Martin Corp. (United States); Theresa Mayer, Virginia Polytechnic Institute and State Univ. (United States); Demetrios N. Christodoulides, CREOL, The College of Optics and Photonics, Univ. of Central Florida (United States); Clara Rivero-Baleine, Lockheed Martin Missiles and Fire Control (United States)

In this paper we show how to systematically design anti-reflective metasurfaces based on the effective medium method for the short- and mid-wavelength infrared regions. We have utilized multilayer arrangements, consisting of readily available materials, and perforated on the surface by densely-packed circular holes in a hexagonal fashion. In addition we have developed appropriate genetic algorithms by exploiting the effective medium approach, which provide the dimensions of the surface features on our metasurface design. Hereby, we report power reflection coefficients of less than 5% for a broad range of incidence angles [0 65] (in degrees) and wavelengths $\lambda\varepsilon[1\mu m\ 5\mu m]$, independently of the incident polarization (TE, TM, random polarized); such results have been verified by our experimental setup and our full-wave finite element simulations. Overall, our systematic approach can provide a robust method in order to design perforated metasurfaces, which allow the efficient control of the amplitude and phase

of the incident electric field and in conjunction with phase-changing and nonlinear materials can lead to desired applications, like dynamic spatial light modulation, beam-switching and advanced pulse-shaping.

10181-20, Session 5

Large area precision coatings by pulse magnetron sputtering

Peter Frach, Fraunhofer-Institut für Organische Elektronik, Elektronenstrahl-und Plasmatechnik FEP (Germany); Daniel J. Gloess, Thomas Goschurny, Andy Drescher, Fraunhofer-Institut für Elektronenstrahl- und Plasmatechnik (Germany); Jan Hildisch, Fraunhofer-Institut für Organische Elektronik, Elektronenstrahl- und Plasmatechnik FEP (Germany); Hagen Bartzsch, Fraunhofer-Institut für Elektronenstrahl- und Plasmatechnik (Germany); Andreas Heisig, Harald Grune, Von Ardenne Anlagentechnik GmbH (Germany); Lothar Leischnig, Steffen Leischnig, LSA GmbH (Germany); Carsten Bundesmann, Leibniz-Institut für Oberflächenmodifizierung e.V. (Germany)

Pulse magnetron sputtering is very well suited for the deposition of optical coatings. Due to energetic activation during film growth, sputtered films are dense, smooth and show an excellent environmental stability. Films of materials like SiO2, Al2O3, Nb2O5 or Ta2O5 can be produced with very little absorption and scattering losses and are well suited for precision optics.

FEP's coating plant PreSensLine, a deposition machine dedicated for the development and deposition of precision optical layer systems will be presented. The coating machine (VON ARDENNE GmbH) is equipped with dual magnetron systems (type RM by FEP). Concepts regarding machine design, process technology and process control as well as in situ monitoring are presented to realize the high demands on uniformity, accuracy and reproducibility. Results of gradient and multilayer type precision optical coatings are presented.

Application examples are edge filters and special antireflective coatings for the backlight of 3D displays with substrate size up to 300x400mm. The machine allows deposition of rugate type gradient layers by rotating a rotary table with substrates between two sources of the dual magnetron system.

By combination of the precision drive (by LSA) for the substrate movement and a special pulse parameter variation during the deposition process (available with the pulse unit UBS-C2 of FEP), it is possible to adjust the deposition rate as a function of the substrate position exactly. The aim of a current development is a technology for the uniform coating of 3D-substrates and freeform components as well as laterally graded layers.

10181-21, Session 5

Linear variable narrow bandpass optical filters in the far infrared

Thomas D. Rahmlow Jr., Omega Optical, Inc. (United States)

We are currently developing linear variable filters (LVF) with very high wavelength gradients. In the visible, these filters have a wavelength gradient of 50 to 100 nm/mm. In the infrared, the wavelength gradient covers the range of 500 to 900 microns/mm. Filter designs include band pass, long pass and ulta-high performance anti-reflection coatings. The active area of the filters is on the order of 5 to 30 mm along the wavelength gradient and up to 30 mm in the orthogonal, constant wavelength direction. Variation in performance along the constant direction is less than 1%. Repeatable performance from filter to filter, absolute placement of the filter relative to a substrate fiducial and, high in-band transmission across the full spectral band is demonstrated.

Applications include order sorting filters, direct replacement of the spectrometer and hyper-spectral imaging. Off-band rejection with an optical density of greater than 3 allows use of the filter as an order sorting filter. The linear variable order sorting filters replaces other filter types such as block filters. The disadvantage of block filters is the loss of pixels due to the transition between filter blocks. The LVF is a continuous gradient without a discrete transition between filter wavelength regions.

If the LVF is designed as a narrow band pass filter, it can be used in place of a spectrometer thus reducing overall sensor weight and cost while improving the robustness of the sensor. By controlling the orthogonal performance (smile) the LVF can be sized to the dimensions of the detector. When imaging on to a 2 dimensional array and operating the sensor in a push broom configuration, the LVF spectrometer performs as a hyper-spectral imager.

This paper presents performance of LVF fabricated in the far infrared on substrates sized to available detectors. The impact of spot size, F-number and filter characterization are presented. Results are also compared to extended visible LVF filters.

10181-22, Session 5

Novel materials greatly enhance interference filter performance in the NIR for imaging and sensing applications

Robert W. Sprague, Materion Barr Precision Optics & Thin Film Coatings (United States)

The bandwidth of an optical interference filter when used in an optical system is limited by the angular range of its illumination. The limitation has two main aspects: The central wavelength of the filter shifts to shorter wavelength and the shape of the transmission band degrades. The first effect results in filters with increased transmission width while the second results in reduction in the average transmission of the filter. For compact systems with high numerical aperture these effects can be pronounced. By minimizing the propagation angles in the filters these effects can be substantially reduced in the near infra red (NIR) to levels similar to IR filters. We have recently developed materials and design techniques that permit us to obtain low angle shift coating that maintain very high transmission in the spectral range from 800 to 1100 nm. In this paper we will demonstrate the performance, design and fabrication, of fully blocked (200 to 1200 nm) narrow band pass filters and their measured performance over a range of angles (0-30°). Filters with bandwidths from 15 to 100 nm will be shown to illustrate the versatility of these techniques.

10181-23, Session 5

Optimizing the effect of electric-field enhancement in nodular defects

Tao He, Xinbin Cheng, Hongfei Jiao, Jinlong Zhang, Bin Ma, Zhanshan Wang, Tongji Univ. (China)

For the near-infrared laser reflection film, the nodule defects are the major factor to the laser injury. Nowadays, the effect of electric-field enhancement had been demonstrated to be the main reason for the injury in nodular defects. It has been verified that a broadband high-reflection film can decrease electric field enhancement effect by reducing the amount of penetrating light under normal incidence. However, in general situation, the incident radiation enter into film obliquely. It is impossible to design an omnidirectional HR coatings except for controlling the angle position of transmission band. So, it's very important to study the law of electric-field enhancement inside nodular defects in the case of oblique incident. Herein, the electric-field enhancement was simulated using a three-dimensional finite-difference time-domain code. Different structures and films were

designed to study the influence of transmission band at different angles. These results indicated that transmittance at big angle contributes to focusing. The damage morphologies of polarizers reproduced the simulated electric-field intensity distributions very well. Then, the conclusion was verified further by the films with transmission band at big and small angles in the case of normal incidence. Controlling the angle position of transmission band at small angle can reduce the electric-field enhancement in the usual case, thus increasing the laser induced damage threshold of films.

10181-32, Session 5

Optimizing ITO for incorporation into multilayer thin film stacks for visible and NIR applications

Tyler Roschuk, David Taddeo, Raytheon ELCAN Optical Technologies (Canada); Arthur A. Morrish, Raytheon Space and Airborne Systems (United States); Zachary J. Levita, Douglas J. Brown, Raytheon ELCAN Optical Technologies (Canada)

Indium Tin Oxide, ITO, is the industry standard for transparent conductive coatings. As such, the common metrics for characterizing ITO performance are its transmission and conductivity/resistivity (or sheet resistance). In spite of its recurrent use in a broad range of technological applications, the performance of ITO itself is highly variable, depending on the method of deposition and chamber conditions, and a single well defined set of properties does not exist. This poses particular challenges for the incorporation of ITO in complex optical multilayer stacks while trying to maintain electronic performance. Complicating matters further, ITO suffers increased absorption losses in the NIR – making the ability to incorporate ITO into anti-reflective stacks crucial to optimizing overall optical performance when ITO is used in real world applications.

In this work, we discuss the use of ITO in multilayer thin film stacks for applications from the visible to the NIR. In the NIR, we discuss methods to analyze and tune the film properties to account for, and minimize, losses due to absorption and to optimize the overall transmission of the multilayer stacks. The ability to obtain high transmission while maintaining good electrical properties, specifically low resistivity, is demonstrated. Spectroscopic ellipsometry is used to characterize the ITO films themselves and to deduce some details of the film structure. Trade-offs between transmission and conductivity with variation of process parameters are discussed in light of optimizing the performance of the final optical stack and not just with consideration to the ITO film itself.

10181-33, Session 5

Characterization of reactive plasma ion assisted HfO2 films for low-loss optical coatings in the MWIR and DUV

Jue Wang, Michael Cangemi, Corning Incorporated (United States); Christopher Chinhong, Corning Incorpirated (United States); Michael J. D'Lallo, James Platten, Jean Francois Oudard, Leonard Wamboldt, Corning Incorporated (United States)

Hafnium oxide has a broad band optical transparency ranging from the LWIR down to the DUV. The optical properties of HfO_2 films depend on deposition technologies and parameter settings. HfO_2 films derived from reactive plasma ion assisted deposition were investigated using variable angle spectroscopic ellipsometry, atomic force microscopy, UV-VIS-NIR spectrophotometry, Fourier transform infrared spectrometry and high humidity exposure. The correlation between film structure and optical properties was established. The results indicate that porous HfO_2 harbors moistures leading to increased absorption in the MWIR and scatter loss in the DUV. Over-bombardment of the plasma ions narrows the band gap of the corresponding HfO_2 films, generating absorption loss in the DUV. Optimized deposition parameters enable low loss and environmentally stable HfO_2 coatings, leading to a number of defense applications from the MWIR down to the DUV.

10181-24, Session 6

Compositional dependence of properties and lens performance of As-Se chalcogenide glass

Jacklyn Novak, Spencer Novak, Jeremy Huddleston, Alan Symmons, LightPath Technologies, Inc. (United States); Erik Stover, M3 Measurement Solutions (United States)

The market for thermal imaging sensors and cameras has been increasingly focused on higher volumes and lower costs. Precision glass molding (PGM) is a high volume, low cost method which has been utilized for decades to produce lenses from oxide glasses. Due to the recent development of high quality precision-molded chalcogenide glasses, which are transparent at critical thermal imaging wavelengths, PGM has emerged as the enabling technology for low cost infrared optics. Since the price of germanium is high and volatile, it plays a large role in the high price of chalcogenide glasses that contain it. $As_{40}Se_{60}$ has previously been investigated as a lower-cost alternative to germanium-containing chalcogenide glasses and was found suitable for the PGM process. This paper investigates the composition-dependence of PGM-relevant properties for $As_{38}Se_{62}$µ and standard $As_{40}Se_{60}$ and presents a comparison of molding behavior and lens performance.

10181-25, Session 6

Structural modification of Ga-La-S glass for a new family of chalcogenides

Andrea Ravagli, Christopher Craig, Katrina A. Morgan, Ioannis Zeimpekis, Armen Aghajani, Edwin Weatherby, Daniel W. Hewak, Optoelectronics Research Ctr., Univ. of Southampton (United Kingdom)

In this work, the effect of adding Se, Te, In, Cs, Y to gallium lanthanum sulphide glass was studied. Structural modifications to the glassy network were achieved by substitution of sulphur, gallium or lanthanum using a melt-quench method in an inert atmosphere. Optical, thermal and mechanical characterisation of the samples revealed tailorable features according to the nature and the amount of glass modifier.

In particular, the addition of selenium and tellurium resulted in an extended transmission in the infrared up to 12 ?m. Furthermore, for small amounts of selenium, the position of the bandgap did not change significantly, maintaining visible transmission. The addition of indium led to the formation of glasses with longer transmission in the infrared and a cut-off edge around 600nm in the UV-visible range.

Over-all, the addition of these modifiers resulted in stronger materials with improved thermal stability and similar mechanical properties to original Ga-La-S glass. The outcome of this work aims to bring a new family of chalcogenide glasses for applications in the infrared and visible range.

10181-35, Session 6

Assessment of an approach to printed polymer lenses

Peter L. Marasco, Air Force Research Lab. (United States); Bobby D. Foote, Rockwell Collins, Inc. (United States)

Additive manufacturing is proving its relevancy across a wide spectrum of development, prototyping and manufacturing in the US. However, there is a desire to move the capability beyond modeling and structural components. The use of additive manufacturing techniques to fabricate low-cost optics and optical systems is highly desirable in a number of markets. But processes and techniques for successfully printing an optic are currently very new. This paper discusses early advances in printing optics suitable for commercial and military applications. Data from and analysis of early prototype lenses fabricated using one possible technique will be included and discussed. The potential for additive manufacturing of optics to open the design space for complex optics and reduce development time, lowering cost and speeding up time to market, will also be discussed.

10181-26, Session 7

Progress on high-performance rapid prototype aluminum mirrors

Kenneth S. Woodard, Bruce H. Myrick, Leonard Wamboldt, Corning Incorporated (United States)

Near net shape mirror blanks can be produced using some very old processes (investment casting) and the relatively new direct metal laser sintering process (DMLS). These processes have significant advantages for complex lightweighting and costs but are not inherently suited for producing high performance mirrors. The DMLS process can provide extremely complex lightweight structures but the high residual stresses left in the material results in unstable mirror figure retention. Although not to the extreme intricacy of DMLS, investment casting can also provide complex lightweight structures at considerably lower costs than DMLS and even conventional wrought mirror blanks but the less than 100% density for casting (and also DMLS) limits finishing quality.

This paper will cover the progress that has been made to make both the DMLS and investment casting processes into viable near net shape blank options for high performance aluminum mirrors. Finish and figure results will be presented to show performance commensurate with existing conventional processes.

10181-27, Session 7

Chalcogenide molded freeform optics for mid-infrared lasers

Francois Chenard, Oseas Alvarez, IRflex Corporation (United States); Allen Y. Yi, The Ohio State Univ. (United States)

Mid-infrared lasers such as Quantum Cascade Lasers (QCLs) are recent infrared sources, which cover the whole mid-infrared spectrum range from 3 to 12 microns with high-power and good wall-plug efficiency. Due to the micron sized and non-circular cross-section of the active region, the QCL beam quickly diverges in the direction perpendicular to the plane of the active region (fast axis), while slowly diverging in the parallel direction (slow axis). As such, it is a necessity for many applications to first collimate the fast-axis direction with high numerical aperture (NA) and short focal length micro-lenses. High precision molded cylindrical micro-lens prototypes with aspheric contour, high NA~0.8 and small focal length (f~2 mm) were successfully fabricated to collimate the QCL fast axis beam. Chalcogenide glass is a suitable material for the production of high-precision molded micro-lenses. Chalcogenide glass is transparent from 1um to 12um and offers high refractive index, low coefficient of thermal expansion, low dn/dT and high damage threshold. An innovative freeform micro-lens design has been developed to collimate and circularize the QCL beam. The chalcogenide freeform micro-lens has an input acylindrical surface to collimate the fast axis and an orthogonal output acylindrical surface to collimate the slow axis. Also the thickness of the micro-lens is such that the output fast- and slow-axis beams have the same diameter. This paper presents recent results on the chalcogenide molded freeform micro-lens specifically designed to collimate and circularize QCL beam at 4.6 microns.

10181-29, Session 8

Mid-infrared imaging fiber bundle

Francois Chenard, Oseas Alvarez, IRflex Corporation (United States)

Infrared cameras for thermal imaging applications can operate between 2-12 microns. These cameras produce a thermal image using two-dimensional arrays of infrared detectors (such as ferroelectric detectors or microbolometers). The proposed imaging fiber bundle is targeted primarily at military applications for mid-infrared viewing of harsh environment and/or in tight space where infrared camera cannot be used such as combustion processes in turbines combustors and afterburners. Other critical military applications include surveillance, reconnaissance, and threat warning systems. Imaging fiber bundles are commonly used in the visible and near infrared (0.4 to 1 microns) to remotely transfer images to cameras. Unfortunately, imaging fiber bundles for thermal infrared imaging are not commercially available. This paper presents the latest results on the fabrication techniques to produce innovative coherent fiber bundles for infrared thermal imaging that are inexpensive, flexible, rugged, and high fiber-count. The mid-infrared imaging fiber bundle fabrication process can produce low-cost coherent fiber bundles that are 2-10 meters in length, 4000 fibers in a 3 mm diameter bundle, minimum bend radius of 10 cm, and attenuation less than 0.5 dB/m over the spectral range of 1.5 to 6 microns. High-quality chalcogenide fibers are used to produce the mid-infrared imaging fiber bundle. Individual chalcogenide fiber pixel size is 35 microns and the numerical aperture is 0.3. The fabrication process will be discussed and the optical characterization of the mid-infrared imaging fiber bundle will be presented.

10181-30, Session 8

UV scale calibration transfer from an improved pyroelectric detector standard to field UV-A meters and 365nm excitation sources

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

Calibration of the emitted radiation from UV sources peaking at 365 nm, is necessary to perform the ASTM required 1 mW/cm2 minimum irradiance in certain military material (ships, airplanes etc) tests. These UV "black lights" are applied for crack-recognition using fluorescent liquid penetrant inspection. At present, these nondestructive tests are performed using the 365 nm excitation line of Hg-lamps. The response function of the UV meters used to measure the irradiance from the UV sources (recently LEDs), is based on the International Committee of Illumination (CIE) standardized UV-A function. This function has a rectangular shape which can be realized only with large spectral mismatch. The different spectral responsivities of the commercially available UV meters cause significant measurement errors even if the same UV-365 source is measured. In order to make the UV irradiance measurements uniform, a pyroelectric radiometer standard with spectrally flat (constant) response in the UV-VIS range has been developed. The relative response of this standard meter is determined from spectral reflectance measurement. The relative curve is converted into a spectral

irradiance responsivity with <0.5% (k=2) uncertainty as a result of using absolute tie points from a Si-trap detector traceable to the primary standard cryogenic radiometer. The flat pyroelectric radiometer standard can be used to perform uniform integrated irradiance measurements from all kinds of UV sources (with different peaks and distributions) without using any source standard. Using this broadband calibration method, yearly spectral calibrations for the reference UV (LED) sources and irradiance meters is not needed. Field UV meters (including existing commercial meters) may be calibrated against the pyroelectric radiometer standard for broadband (integrated) irradiance responsivity measuring the same UV source. In this case, spectrally flat response for the field meter is not required. Using the broadband procedure, the UV measurement uncertainties could be decreased by a factor of five.

10181-34, Session 8

Non-mechanical beam steering in the mid-wave infrared

Jesse A. Frantz, Jason D. Myers, U.S. Naval Research Lab. (United States); Robel Y. Bekele, Univ. Research Foundation (United States); L. Brandon Shaw, Jasbinder S. Sanghera, Christopher M. Spillmann, Jawad Naciri, Jakub Kolacz, U.S. Naval Research Lab. (United States); Henry Gotjen, Bennett Sodergren, Ying-Ju Wang, Scott D. Rommel, Michael H. Anderson, Scott R. Davis, Michael Ziemkiewicz, Vescent Photonics Inc. (United States)

The mid-wave infrared (MWIR) portion of the electromagnetic spectrum is critically important for a variety of applications such as LIDAR and chemical sensing. Concerning the latter, the MWIR is often referred to as the “molecular fingerprint” region owing to the fact that many molecules display distinctive vibrational absorptions in this region, making it useful for gas detection. To date, steering MWIR radiation typically required the use of mechanical devices such as gimbals, which are bulky, slow, power-hungry, and subject to mechanical failure. We present the first non-mechanical beam steerer capable of continuous angular tuning in the MWIR. These devices, based on refractive, electro-optic waveguides, provide angular steering in two dimensions without relying on moving parts. Previous work has demonstrated non-mechanical beam steering (NMBS) in the short-wave infrared (SWIR) and near infrared (NIR) using a waveguide in which a portion of the propagating light is evanescently coupled to a liquid crystal (LC) layer in which the refractive index is voltage-tuned. We have extended this NMBS technology into the MWIR by employing chalcogenide glass waveguides and LC materials that exhibit high MWIR transparency.

Conference 10182: Detection and Sensing of Mines, Explosive Objects, and Obscured Targets XXII

Monday - Wednesday 10–12 April 2017

Part of Proceedings of SPIE Vol. 10182 Detection and Sensing of Mines, Explosive Objects, and Obscured Targets XXII

10182-1, Session 1

Survey of image quality metrics from the perspective of detection and classification performance

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

Detection and classification of targets is a process that we perform every day, often without even realizing it; the ability to locate and recognize a specific face in a crowd, to be able to identify a bird by its song, or to know what is for dinner simply by the aroma. Much effort has been spent in trying to replicate these uncanny abilities of our senses through purpose-built sensors. For many of these sensing modalities, automatic target recognition algorithms have been developed to automate the process of locating and recognizing the occurrence of a specific state from within the sensed data. This survey is an overview of the metrics used to assess and quantify the quality or 'goodness' of the data, mainly for imaging sensors, from the perspective of automatic target recognition performance. Digital image data go through several transformations as they are moved from the recording sensor to personal electronic devices, resulting in distortions. There has been considerable research in the area of quality assessment of digital image and video media. Often, the image quality assessment approaches rely on having the original image or at least information about the original image available for the evaluation. These approaches may also rely on knowing the source of distortion. The accuracy is typically gauged using the image quality assessment made by the human visual system. As a consequence, the metrics measure aspects of the image that are tied closely to the human perception of quality. Evaluating image quality from an automatic target recognition perspective offers many challenges, as the original data is not likely to be available. Additionally, there may be multiple unknown sources of image quality degradation forcing the need for a general solution. Finally, the human perception of 'good quality' may not necessarily correlate to optimal image quality for automatic target recognition performance, in which case metrics modeled after the human visual system may not be the best choice for image quality assessment. The goal of this survey is to provide a high-level background and overview of how image quality assessment is currently performed for different sensing modalities. Additionally, the challenges that are being addressed within the various disciplines will be discussed and commonalities will be highlighted.

10182-2, Session 1

Investigations on the detection of thin wires using MIMO SAR

Andreas Heinzel, Markus Peichl, Eric Schreiber, Stephan Dill, Florian Bischeltsrieder, Deutsches Zentrum für Luft- und Raumfahrt e.V. (Germany)

The detection of improvised explosive devices (IED) is still a challenging task. The IED is an unconventional explosive weapon which can take any form and which is usually activated in different ways. Important components of these IEDs are often thin pressure plate structures which connect the activator with the explosive device by wires. The detection of wires could therefore be useful to detect the IEDs, since the detection of the explosive itself by identifying specific characteristics is impossible for many sensor types, and quite expensive for few being able to perform this task. In this paper investigations on the detection of thin wires using a Multiple Input Multiple Output (MIMO) synthetic aperture radar (SAR) are discussed. The first part will consist of theoretical analysis on the electromagnetic behavior of wires. In the second part measurement results using our high-performance MIMO SAR system will be shown. For those experiments wires of different length and thickness were located in the ground at different poses. The radar system itself was designed for landmine and UXO (UneXploded Ordnance) detection and operates in a frequency range of 500 MHz to 3 GHz in order to guarantee sufficient penetration depth into the ground. It consists of two transmit and four receive antennas arranged in a specific pattern, which results in eight independent SAR images. The superposition of single independent images and the use of wave polarization are important tools to get sufficient clutter reduction, the latter being mandatory for proper wire detection.

10182-3, Session 1

Through-the-wall target detection using GPR A-scan data: effects of different wall structures on time-domain and frequency-domain signals

Mesut Dogan, Tolunay Aydin, Gönül Turhan-Sayan, Middle East Technical Univ. (Turkey)

Ground penetrating radar (GPR) is based on the ultra-wideband radar technology that can also be used for through-the-wall target recognition. Search for the presence of designated targets hidden behind the walls, such as stationary or moving human bodies or certain types of weapons, is addressed in various critical applications like rescue missions after earthquakes or during military operations. Interpretation of the basic A-Scan GPR signals in both time-domain and frequency-domain is critical in the fundamental through-the-wall target detection problem where the type of the wall is as important as the properties and location of the hidden target. Difficulty of this problem increases especially when the wall is constructed by bricks containing multiple hollow compartments. On the other hand, the thickness and the loss tangent of the wall material over the frequency band of operation are important factors which may cause too much absorption of the radar signal leaving too little signal power for successful target detection.

In this study, a simplified geometry will be modeled for a metallic gun using basic shapes like cylinders of different sizes. Resulting target will be placed behind wood, concrete and brick walls at different distances and at varying aspects. Received A-scan GPR signals will be simulated by a FDTD-based numerical computation tool and analyzed both in time and frequency domains for the end purpose of target recognition. Energy-based signal features such as cumulative energy curves will be used for the elimination of early time wall returns to enhance target signals in various wall/target scenarios.

10182-4, Session 1

Parallel high-resolution compact Krylov-FFT-type algorithms for subsurface scattering problems

Yuriy A. Gryazin, Ronald Gonzales, Yun Teck Lee, Idaho State Univ. (United States)

In this paper, we consider a parallel Krylov-FFT type high-resolution algorithm for the solution of a subsurface electromagnetic scattering problem. The 3D Helmholtz equation is discretized by fourth- and six-order compact finite-difference schemes. The matching order compact non-reflecting boundary conditions are applied to preserve the high accuracy of the numerical solution. The resulting systems of finite-difference equations are solved by different preconditioned Krylov subspace-based methods. The FFT-based preconditioner is used for efficient implementation of the

developed iterative approach.

The main focus of the paper is the efficient parallel implementation of the proposed algorithm in the shared (OpenMP) and distributed (MPI) memory environment. The complexity and scalability of the parallel preconditioned iterative method are analyzed on scattering problems with realistic ranges of parameters in soil and mine-like targets.

10182-5, Session 1

Using field spectroscopy combined with synthetic aperture radar (SAR) technique for detecting underground structures for defense and security applications in Cyprus

George Melillos, Kyriacos Themistocleous, George C. Papadavid, Athos Agapiou, Demetris Kouhartsiouk, Silas C. Michaelides, Diofantos G. Hadjimitsis, Cyprus Univ. of Technology (Cyprus)

The main aim of this paper is to investigate different methods for detecting underground concrete structures using as a case study an area of abandoned military bunkers. Underground structures can affect their surrounding landscapes in different ways, such as soil moisture content, soil composition and vegetation vigor. The latest is often observed on the ground as a crop mark; a phenomenon which can be used as a proxy to denote the presence of underground non-visible structures. A number of vegetation indices such as NDVI were obtained while a 'smart index' was developed. The aim of the 'smart index' is to detect underground military structures by using existing vegetation indices or other in-band algorithms. One of the techniques examined is that of the Synthetic Aperture Radar (SAR), which combined with the vegetation index measurements provided information on the vegetation height difference between areas of buried structures and reference areas. In addition, the ground penetrating capabilities of SAR were also tested. Lastly, a number of in situ measurements were conducted including the use of a thermal camera mounted on UAV for nocturnal collection of data and the installation of temperature and moisture loggers in various areas both underground and overground.

10182-6, Session 2

Backscatter imaging applied to IED detection

Travis Barker, Univ. of Florida (United States) and U.S. Army (United States); Gabriel Sandler, Shuang Cui, Christopher R. Hughes, James E. Baciak, Univ. of Florida (United States)

Current land mine detection methods predominately rely on the use of Ground Penetrating Radar (GPR) and metal detectors to scan the ground for disturbances in electromagnetic waves that would indicate a higher concentration of metal. For soldiers, these tools combined with trained observational skills, makes the rapid clearance of mine fields more of an art; one that has become a necessity with the presence of Improvised Explosive Devices (IEDs). Some of these detection methods are taught and trained to every soldier, as the principles behind IED detection are similar no matter the IED construction. Specifically, all IEDs require the use of wires in some way.

This research has expanded the use of Compton backscattering detection methods and pencil beam imaging, proven to be slow but accurate in 2008. Currently, we are investigating the use of fan beam geometries for backscatter imaging, to allow for a rapid scan of potential pressure plates, focused on detecting the signature of a wire in a mock IED, with efforts to improve imaging properties to help soldiers be successful. This has the potential to increase the accuracy of current interrogation and detection methods. This research has demonstrated some success over current interrogation methods, with the potential to allow military units to interrogate suspected IEDs through nonphysical means with greater image resolution than GPR. Ultimately, this could allow for the ability to clear suspected enemy obstacles faster, with greater accuracy, and providing more security to the soldiers on the ground.

10182-7, Session 2

Improving the design of atomic magnetometer arrays for RF interference mitigation in NQR detection of explosives

Robert J. Cooper, Brian L. Mark, David W. Prescott, Karen L. Sauer, George Mason Univ. (United States)

Nuclear Quadrupole Resonance, NQR, a type of RF spectroscopy, holds the promise of unambiguous detection of particular explosives; the associated resonant frequencies are virtually unique. This specificity is spoiled by natural and anthropogenic interference that can swamp the NQR signal. Fortunately, the spatial magnetic signature from the explosive differs significantly from that of interference, due to the proximity of the sensor to the explosive compared to that of the interference source, which can be exploited to separate the signals. An array of coils, however, cannot provide truly independent measurements, and therefore an accurate field map, due to the inductive coupling between the coils. Single coil configurations can cancel out constant interference and retain the NQR signal, but the balance between arms of the coil is compromised by the differential coupling to the environment. Atomic magnetometers, an emergent technology predicted to surpass the sensitivity of coil detection, do not suffer from such coupling and have no fundamental limitation to forming an array of independent sensors. We have demonstrated a 20x interference rejection with a 4-sensor array spanning 25 cm. The array symmetry permits rejection of linearly varying interference, which can lead to further detection gains via signal processing. The main limitation to interference rejection is scattering from the system's DC field coils that are used to set the magnetometers' resonance frequency. We will report on our progress in designing and implementing a set of field coils that minimizes this scattering, and the resulting improvement in interference rejection.

10182-8, Session 2

Methods for characterization of home-made and non-standard explosives in forensic science

Marek Kotrlý, Ivana Turková, Ivo Beroun, Institute of Criminalistics Prague (Czech Republic); Bohumil Mares, Univ. Pardubice (Czech Republic)

Availability of industrial explosives is increasingly limited. Thus, on the part of perpetrators, terrorists, ever greater attention is paid to illegal productions that are easily made from readily available raw materials. Alarming fact is the availability of information found on the internet.

In the forensic field are often faced with the problem of analysis of tiny remnants post-blast residues. Residues are analysed comprehensively both in terms of organic and inorganic contents. Organic analysis - the use of the two-stage instrumental sequence in the order - primary instrumental separation technique and secondary sensitive analytical detection.
As separation techniques will be applied methods of gas and liquid chromatography. Gas chromatography (GC) is used particularly to analyse volatile residues of explosives having a relatively high tension of vapours, characterized by a relatively high thermal stability (GC-MSD, GC-ECD). The technique of scanning electron microscopy in connection with EDS/WDS/microXRF analysis is employed to analyse samples containing inorganic components, the method allows not only a fundamental microanalysis

of particles caught on the surfaces of the reference materials after explosions, but especially their distinction from ballast particles arising from contaminants occurring in the vicinity of the explosion. There are currently devices facilitating Confocal Raman Imaging from microparticles, or their sections directly in the SEM chamber or SEM/FIB dual systems. The new data from ongoing project "Identification of improvised explosives residues using physical-chemical analytical methods under real conditions after an explosion" will be presented.

10182-9, Session 2

Laser desorption and active vortex impeller for increased contactless sampling of the gas phase analyzer

Gennadii E. Kotkovskii, Alexander A. Chistyakov, Artem E. Akmalov, Olga I. Dubkova, National Research Nuclear Univ. MEPhI (Russian Federation); Alexey V. Sychev, Diagnostika NPK (Russian Federation)

The requirements for modern methods of the detection of explosives are still important. One of the most promising areas is the use of lasers for remote detection of explosives. Thus, the laser beam was used in the gas analyzers for contactless desorption sampling of low-volatile traces of explosives from surfaces [1,2]. The "effective" sampling distance is usually limited by the diameter of orifice of sampling devices and does not exceed 10 cm.

In this work the conditions of increasing the distance of non-contact sampling up to 30-40 cm are formulated and implemented for the field asymmetric ion mobility (FAIM) spectrometer through the use of laser desorption and active shaper of the vortex flow.

It is shown that under ambient conditions the pulse intensity laser radiation (?=266nm) on the surface with traces of the most common explosives should be at least 107 W / cm2, and the pulse frequency - not less than 10 Hz.

Numerical modeling of vortex and sampling flows was made and the sampling device for FAIM spectrometer on the basis of high speed rotating impeller, located at the same axis as the ion source, was designed. The dependence of trinitrotoluene vapors signal on the rotational speed and the optimization of the value of the sampling flow were obtained.

It is shown that in the vapor registration mode the effective sampling distance is increased up to 30cm. For the use both the laser desorption mode and rotating impeller the amplitude of the signal detected at the distance of 40 cm from spectrometer reaches 25% of the signal for the sample desorbed directly at the spectrometer.

[1] Akmalov, A.E., Bogdanov, A.S., Chistyakov, A.A., Kotkovskii, G.E., Spitsyn, E.M., Sychev, A.V., Perederii, A.N., "A laser desorption ion-mobility increment spectrometer for detection of ultralow concentrations of nitro compounds," Instruments and Experimental Techniques 56 (3), 309-316 (2013).

[2] Akmalov, Artem E.; Chistyakov, Alexander A., Kotkovskii, Gennadii E.// Proceedings of SPIE , v. 9652 965206 (2015)

10182-10, Session 2

Explosive hazard detection using a portable high-flux neutron generator

Gabriel Becerra, Kevin M. Johnson, Robert O'Connell, Ross Radel, Evan Sengbusch, Phoenix Nuclear Labs. (United States)

Explosive hazards (IEDs, mines, and UXO) pose one of the greatest threats to the American warfighter today. Successful defense against these hazards requires the capability to rapidly detect and classify the hazard at safe standoff ranges. A neutron-based detection system is a viable technology solution, as described in this paper. When neutrons interact with matter, gamma radiation is emitted with characteristic energy levels that provide signature information about the elemental composition of the object being interrogated. This radiation can be detected and rapidly analyzed via a computer algorithm to generate an alert that an explosive threat is nearby and further analyzed to identify the composition of the explosive material. The speed and standoff distance of detection is directly tied to the neutron source strength, and PNL's very intense neutron generator allows neutron-based explosive detection to be a practical solution. In this paper, we present results of a quantitative analysis to determine how PNL's 1xE11 DD n/s neutron generator would improve upon past explosive detection performance. The analysis focused on the use of the Thermal Neutron Analysis (TNA) technique. TNA uses the absorption of neutrons via the (n,?) reaction of thermal neutrons (approximately 0.025 eV) and identifies the activated material with the energy of the gamma ray signature. TNA is a common strategy for neutron-based explosives detection because of the large cross section for thermal neutrons versus fast neutrons. The analysis was primarily performed using the MCNP (Monte Carlo N-Particle) code. Current progress in the validation of the MCNP modelling in a laboratory environment will be presented. This includes modelling of the laboratory and development of high throughput LaBr3 and NaI scintillation detectors using high-speed digitizers.

10182-11, Session 3

Layer tracking using image segmentation

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

Data collected by hand-held and vehicular-mounted ground penetrating radar (GPR) devices can be viewed as a sequence of A-scans grouped into frames. Sequences of frames create a three-dimensional representation of the collected area. The ground structure within this area includes: the ground layer, sub-surface layers, explosive hazards, and non-explosive (clutter) objects. In previous work, we found a wireframe view of two-dimensional layers within the three-dimensional volume. In this work, we analyze how to use image segmentation techniques to identify and view the entire three-dimensional volume of layers and objects found in the data. First, image value and contour were used to differentiate structure. This was extended to employ a multi-stage process of image segmentation, clustering analysis using Competitive Agglomeration, and optimizing a Markov Random Field (MRF). The collection sequence of hand-held system data may not always fit into a grid representation. Therefore, segmentation techniques are modified from a frame by frame grid sequence to a nearest neighborhood of three-dimensional regions. Results are displayed in an interactive viewing tool that displays each stage of the process and represents the scene elements identified.

10182-12, Session 3

Scene analysis and element classification using semi-supervised learning

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

This work performs scene analysis in order to represent and understand the elements contained in a defined area under the ground. Elements of interest are the ground layer, sub-surface layers, explosive hazards, and non- explosive (clutter) objects. The scene is composed of data collected by hand-held and vehicular-mounted ground penetrating radar (GPR) devices. In other work, we have created a scene tracking system, where elements in the scene are identified as potential layers, explosive hazards, and non-explosive (clutter) objects in the scene. Here, we analyze how to classify elements within the scene. We represent region features as Dirichlet distributions and perform semi-supervised learning on the classification. In order to assist in these steps, a tool has been created to perform truthing of sample data. Truthed data is examined to identify and allocate the scope of features. Results reduce explosive hazard miss-classification and false alarm rates.

10182-13, Session 3

A sensor fusion approach for identifying landmine regions

Mary Knox, Colin Rundel, Leslie M. Collins, Duke Univ. (United States)

Data from multiple sensors has been collected using a handheld system, and includes precise location information. These sensors include multiple ground penetrating radar (GPR) and electromagnetic induction (EMI) sensors. The performance of these sensors on different mine-types varies considerably. For example, the EMI sensor is effective at locating relatively small mines with metal while the GPR sensor is able to easily detect large plastic mines. A natural step to improving and obtaining more robust buried explosive threat detection performance is to combine information obtained from each sensor. However, there are a number of factors in the handheld data to consider when fusing sensor information: (1) the sensitivity to a landmine varies for each sensor; (2) the sensor scores have vastly different ranges; (3) the sensor scores are not independent; and (4) data from the sensors are not collocated. In this work, we focus on the sensitivity mismatch (e.g., a metal target has high EMI scores well outside the halo, whereas the high GPR scores generally fall off well within the halo). In order to account for this factor, we examine an objective function to minimize the difference in area between the halos and the high scoring regions for the sensors.

10182-14, Session 3

Fourier features for explosive hazard detection using a wideband electromagnetic induction sensor

Brendan Alvey, Univ. of Missouri (United States); Alina Zare, Univ. of Florida (United States) and Univ. of Florida (United States); Dominic K. Ho, Univ. of Missouri (United States)

Sensors which use electromagnetic induction (EMI) to excite a response in conducting bodies have been investigated for the purpose of detecting buried explosives. In particular, wide band EMI sensors which utilize a relatively low number of operating frequencies have been used to discriminate between types of objects, and to detect objects with very low metal content [1]. Fourier features are extracted using the two-dimensional Fourier transform which operates on the complex data both spatially and across operating frequencies. The Multiple Instance Adaptive Coherence Estimator (MI-ACE) [2] is used to learn cross-validated target signatures from these features. These signatures, as well as learned background statistics are used with ACE to generate confidence maps, which are clustered into alarms. Alarms are scored against a ground truth and compared to other detection algorithms.

10182-15, Session 3

A hybrid coil system for high frequency electromagnetic induction sensing

John B. Sigman, Kevin O'Neill, Benjamin E. Barrowes, Fridon Shubitidze, Thayer School of Engineering at Dartmouth (United States)

Intermediate electrical conductivity (IEC, 0.1-1000 mS/m) objects are becoming increasingly important to properly detect and classify.

For the US Military, carbon fiber (CF) "smart bomb" unexploded ordnance (UXO) are contaminating test ranges.

Home-made explosives (HME) may also fit in this conductivity range.

Objects in this conductivity range (.1 to 1000 mS/m) exhibit characteristic quadrature response peaks at high frequencies (100 kHz-15 MHz).

Previous efforts towards electromagnetic induction (EMI) sensing of IEC targets have required single-turn, small-diameter transmitter and receiver loops.

These smaller loops remain electrically short in the high frequency EMI (HFEMI) range (100 kHz-15 MHz), a necessary feature, but provide low signal-to-noise ratio (SNR), especially at low frequencies (400 Hz-10 kHz).

We propose a modification to our pre-production HFEMI instrument which has a hybrid low frequency/high frequency transmit coil.

This hybrid system uses many turns in the traditional range, and a single wire turn at HFEMI frequencies, to maximize SNR across a wider EMI band.

We take precaution that the long coil, when disconnected for HFEMI sensing, does not have mutual inductive coupling to the single turn by breaking the circuit into many shorter pieces.

The instrument uses the same calibration techniques as previously introduced, namely background subtraction and ferrite compensation.

This paper discusses engineering tradeoffs and compares results to the original HFEMI prototype, showing improved SNR at traditional EMI frequencies, and the same ability to detect IEC targets in the HFEMI band.

10182-16, Session 4

Investigation of training sample selection methods for object classification in sonar imagery

Matthew Cook, Bradley Marchand, Naval Surface Warfare Ctr. Panama City Div. (United States)

For Sonar Automatic Target Recognition problems, the number of mine-like objects is relatively small compared to the number non-mine-like objects available. This creates a heavy bias towards non-mine-like objects and increases the processing resources needed for classifier training. In order to reduce resource needs and the bias towards non-mine-like objects, we investigate selection methods for reducing the non-mine-like target samples while still maintaining as much of the original training information as possible. Specifically, we investigate methods for reducing sample size and bias while maintaining good classifier performance. Several methods are considered during this investigation that cover a wide range of techniques, including clustering and evolutionary algorithms. Each method is evaluated based on the classifier performance when trained on the chosen data samples and the execution time to select the new training set. Results on each method tested are presented using sonar data collected using a sidescan sonar system.

10182-17, Session 4

Multiple-instance learning-based sonar image classification

James T. Cobb, Naval Surface Warfare Ctr. Panama City Div. (United States); Xiaoxiao Du, Univ. of Missouri (United States); Alina Zare, Matthew S. Emigh, Univ. of Florida (United States)

An approach to image labeling by seabed context based on multiple-instance learning via embedded instance selection (MILES) is presented. Sonar images are first segmented into superpixels with associated intensity and texture feature distributions. These superpixels are defined as the "instances" and the sonar images are defined as the "bags" within the MILES classification framework. The intensity feature distributions are discrete while the texture feature distributions are continuous, thus the Cauchy-Schwarz divergence metric is used to embed the instances in a higher-dimensional discriminatory space. Results are given for labeled synthetic aperture sonar (SAS) image database containing images with a variety of seabed textures.

10182-18, Session 4

Environmentally-adaptive target recognition for SAS imagery

Xiaoxiao Du, Anand Seethepalli, Hao Sun, Univ. of Missouri (United States); Alina Zare, Univ. of Florida (United States); James T. Cobb, Naval Surface Warfare Ctr. Panama City Div. (United States)

Underwater target objects often display a variety of features and characteristics in synthetic aperture sonar (SAS) imagery depending on their environmental context, such as sea grass, sand ripple, etc. Environmentally-adaptive target detection and classification systems that take into account environmental context, therefore, have the potential for improved results by leveraging that information. This paper presents an end-to-end environmentally-adaptive target detection system for SAS imagery that performs target recognition while accounting for environmental context. First, anomalies and locations of interest are detected in the imagery using the Reed-Xiaoli (RX) Detector and a Non-Gaussian detector using the multivariate Laplacian distribution. Then, the Multiple Instance Learning via Embedded Instance Selection (MILES) approach is used to identify the environmental context of the targets. Finally, target features, such as edge histogram descriptor (EHD), hit-miss features and shape-based features, are extracted and a set of environmentally-specific k-Nearest Neighbor (k-NN) classifiers are applied. Experiments were conducted on a collection of both high and low frequency underwater SAS imagery with a variety of environmental contexts and results show improved classification accuracy between non-target, block, cone, sphere, tours, pipe, and cylinder target classes when compared with classification results with no environmental consideration.

10182-19, Session 4

Multi-band synthetic aperture sonar mosaicing

Bradley Marchand, Tesfaye G-Michael, Naval Surface Warfare Ctr. Panama City Div. (United States)

Some synthetic aperture imaging techniques have strict path requirements and need to be processed in overlapping chunks. Path adjustments applied for images can decorrelate and alter the appearance of overlapping regions, which can make mosaicing the images chunks for post mission analysis challenging.

In this paper, we investigate the methodology to generate continuous and seamless mosaicing process based on multi-stage co-registered automated change detection (ACD) techniques that alleviate the problem of high accuracy, multi-band mosaicing. This method could be integrated into image exploitation systems such as automated target recognition and ACD to improve target detection and classification.

10182-20, Session 4

Change detection in sonar images using independent component analysis

Tesfaye G-Michael, Jeannine Abiva, Naval Surface Warfare Ctr. Panama City Div. (United States); Rodney G. Roberts, Florida State Univ. (United States)

Change Detection is the process of detecting changes from pairs of multi-temporal sonar images that are surveyed approximately from the same location. The problem of change detection and subsequent anomaly feature extraction is complicated due to several factors such as the presence of random speckle pattern in the images, variability in the seafloor environmental conditions, and platform instabilities. These complications make the detection and classification of targets difficult by introducing false alarms.

In this paper, we propose false alarm reduction technique for change detection resulted from multi-temporal synthetic aperture sonar (SAS) images, based on independent component analysis (ICA). ICA is a well-established statistical signal processing technique that aims at decomposing a set of multivariate signals (in our case SAS images) into a base of statistically independent data-vectors with minimal loss of information content. Test results of the proposed method on a data set of SAS images will be presented. Results illustrating the effectiveness of ICA for false alarm reduction in change detection will be presented in terms of probability of detection and false alarm rates for various seafloor types.

10182-21, Session 5

Unsupervised feature extraction for sonar automatic target recognition

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

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

10182-22, Session 5

Towards adaptive thresholding for phase map co-registration in SAS imagery

Jeannine Abiva, Tesfaye G-Michael, Naval Surface Warfare Ctr. Panama City Div. (United States)

Co-registration is a method that ensures the areas depicted in two images coincide. The difficulty in co-registering sonar images of the seafloor can arise from a difference in vehicle trajectories, low resolution, and the presence of noise. Moreover, the temporal changing features of the sea floor can further add to the difficulty. The successful co-registration of synthetic aperture sonar (SAS) images is important when comparing images, and is thus required in areas such as change detection and mosaicking. In this effort, a three-step co-registration process is used: co-registration by navigational alignment, fine-scale co-registration using SIFT, and local co-registration that corrects navigational differences. In the first step, the pixel locations are approximated according to the navigation data, allowing for a coarse co-registration. Features are then detected and matched for a finer scale co-registration. Lastly, any difference in trajectory is corrected, where not only are the images upsampled and co-registered on a sub-pixel level but the phase data of the sonar images are also aligned. In this paper, we focus on the final step where phase alignment occurs. To eliminate unreliable unwrapped phase data, we introduce a novel histogram based adaptive thresholding technique which corrects errors in phase alignment occurring in the cross-track direction of the vehicle. We will demonstrate the effectiveness of this adaptive threshold on the phase alignment of the two images, and further demonstrate how this improvement in sub-pixel co-registration enhances results in change detection.

10182-23, Session 5

Two node vector acoustics applications for off-board passive identification and localization of individual Red Hind Grouper

Cameron Matthews, Naval Surface Warfare Ctr. Panama City Div. (United States)

Littoral regions typically offer prime breeding habitats for fish. Some fish in these regions, in particular Epinephelus Guttatus or more commonly the red hind grouper emit relatively narrowband tones in low frequencies to communicate with conspecifics in agonistic and courtship situations. The ability to track such fish for purposes of biomass measurement and conservation, particularly of interest to regulatory agencies in charge of setting catch limits is considered from the perspective of implementing individual point Acoustic Vector Sensors (AVS) for detection, bearing and elevation estimates of individual vocalizing red Hind grouper. A special two node case is presented and studied allowing for the derivation of range, track and speed estimates of shoaling or individual fish.

10182-24, Session 5

Leveraging ROC adjustments for optimizing UUV risk-based search planning

John G. Baylog, Thomas A. Wettergren, Naval Undersea Warfare Ctr. (United States)

Search scheduling for UUV's involves a complex optimization problem with multiple degrees of freedom. Typically this complexity is reduced for computational efficiency by limiting the degrees of freedom available to the optimizer. This paper addresses some of the computational aspects of collaborative search planning when multiple search agents seek to find hidden objects (i.e. mines) in adverse local operating environments where the detection process is prone to false alarms.

In search planning, the detection performance of individual searches of sub-regions is governed by the local environment and sensor settings. We apply an agnostic receiver operator characteristic (ROC) indicative of undersea search performance to construct a Bayesian cost objective function that combines the risk of missed detection and false alarm. Risk is developed as a function of the number of detections required for validation (called the r-criterion). In previous investigations, we considered the scheduling of search assets where detection event probabilities are fixed. However, this strategy yields a scheduling objective function that exhibits supermodularity only when the r-criterion does not change. This phenomenon compromises the scheduling process. In this paper we consider an expanded optimization process whereby ROC operating points are determined simultaneously for all r-criteria and the best performing combination of criterion and operating point is selected. An analysis of this new permuted optimization process is presented. Details of its application within a broader search planning context are discussed and numerical results are provided to demonstrate the effectiveness of the approach on overall search performance.

10182-25, Session 6

Spectral analysis for SAS feature extraction

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

No Abstract Available

10182-26, Session 6

Applications of speech recognition systems to sonar ATR

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

The steps performed in any acoustic pattern recognition system are to extract portions of the audio signal that identify useful content, discard the noise, and make a pattern-matching comparison and classification of the useful content with a training database. Well-established acoustic pattern recognition algorithms (typically used for speech recognition) are relative spectral transform (RASTA), mel-frequency cepstral coefficients (MFCC) and matching pursuit. RASTA uses a time-delay neural network, matching pursuit uses a sparse signal representation in conjunction with a hidden Markov model (HMM) and MFCC uses filters based on the speech patterns associated with human voices.

Due to the enormous breakthroughs in the field of speech recognition and computer vision, neural networks – particularly convolutional deep neural networks (CNNs) - have garnered a lot of attention in the pattern recognition community. Krizhevsky et al.'s results at the ILSVRC 2012 workshop are particularly interesting since they demonstrated that CNNs were capable of greatly outperforming conventional (human-trained) image recognition systems.

Hinton et al. presented a paper that has shown that it is possible to expand the applicability of a CNN beyond image pattern recognition and apply it to the realm of speech recognition. Their paper explained the then-current method of isolating phonemes in a speech dataset and the usage of mixed Gaussian models in conjunction with a HMM as a means of classifying the isolated phoneme in order to attain the goal of speech recognition. Their work described their CNN's superior classification abilities over a mixed Gaussian model as a method of enhancing the use of an HMM for speech recognition.

One key area of development that has heretofore not been fully considered is the application of the speech recognition algorithms mentioned above towards classifying objects found in sonar signals and, more specifically, towards automatic target recognition (ATR). A possible application of this technology would be providing an understanding the relevant features present in acoustic data in order to perform remediation on underwater sites contaminated by unexploded postwar ordnance.

The goal of this paper is to perform a comparison between the RASTA, MFCC, matching pursuit and CNN speech recognition algorithms by utilizing actual and simulated synthetic aperture sonar (SAS) dataset generated at the Naval Surface Warfare Center, Panama City Division (NSWC PCD). Our newly-trained speech recognition algorithms produced a high degree of classification accuracy and demonstrated how we addressed a technology gap hindering the ATR mission.

10182-56, Session 6

Signal classification using covariance matrices: A Riemannian geometry framework

Shaelyn G. Divins, Elizabethtown College (United States); Joshua S. Beard, Seattle Univ. (United States); Oluwaseun Winsala, Maxwell Ble, Anthony O. Smith, Florida Institute of Technology (United States); Dean Clauter, Air Force Technical Applications Ctr. (United States); Adrian Peter, Florida Institute of Technology (United States)

We present a novel framework for time series classification that leverages the geometric structure of covariance matrices when labeling signals. Our method maps each signal to a new multivariate localized feature signal (MLFS) representation, from which we compute a covariance descriptor. This robust MLFS covariance representation handles classification tasks

where the sampling rates of the signals vary within a class, and classes. We demonstrate that simply using the k-nearest neighbor classification rule with the Riemannian metric between the MLFS covariance matrices produces state-of-the art results on a number of standard datasets. Moreover, for the first time, we showcase results on the full Library of Typical Infrasonic Signals dataset which contains four categories of infrasound observations.

10182-27, Session 7

Investigation of buried object detection under asphalt and concrete roads using energy based preprocessing of simulated A-scan GPR signals

Mesut Dogan, Middle East Technical Univ. (Turkey); Sinem Gumus, Hacettepe Univ. (Turkey); Gönül Turhan-Sayan, Middle East Technical Univ. (Turkey)

Ground penetrating radar (GPR) is based on the ultra-wideband radar technology which is mainly used for the detection and identification of buried objects for various applications of civilian or military nature. Detection of mines or hand-made explosives buried under roadways is one of the prime applications of GPRs. While it is easier to detect large metallic objects which are buried closer to the surface, small and deeply buried objects might go almost unnoticed especially if they are made of dielectric materials. Furthermore, presence of a construction layer, made of materials such as asphalt or concrete, covering the natural ground surface may critically affect the course of the target detection problem.

In this study, we will investigate the effects of different road structures in the problem of buried object detection using GPR signals. The A-scan and B-scan type GPR signals will be simulated by an FDTD-based computation tool for different scenarios involving asphalt and concrete layers above the natural soil surface with buried objects of metallic or non-metallic nature. A-scan GPR signals will be investigated in time domain together with their spectral contents in frequency domain. In GPR problems, application of effective preprocessing techniques is very important to enhance the target signals whenever possible for higher target detection probability. In this paper, a novel energy-based preprocessing technique will be used to remove the dominant surface reflection components to reveal the relatively weak GPR signals reflected and/or scattered by the buried targets.

10182-28, Session 7

Using data compression for buried hazard detection

Ferit Toska, Joseph N. Wilson, Univ. of Florida (United States)

Ground penetrating radar (GPR) based detection systems have used a variety of di?erent features and machine learning methods to identify buried hazards and distinguish them from clutter and other objects. In this study, we describe a new feature extraction method based on Kolmogorov complexity and information theory. In particular, a three dimensional subset of GPR data centered at alarm location is partitioned into two-dimensional non-overlapping cells. Then, each cell is compressed using gzip and a feature vector is formed from the file sizes of the compressed cells. Finally, an SVM classifier is trained on compression features. The proposed method is applied to data acquired from outdoor test sites containing over 3800 buried hazards, including nonmetal and low-metal targets. The performance is measured by use of ROC curves and compared against four algorithms. These algorithms are based on geometric features and are fused with a powered geometric mean method. The compression-based algorithm outperforms the other individual methods. We also tested di?erent fusion algorithms involving combinations of these five algorithms. The best combination, the product of compression algorithm and two of the others, dominates the current state of the art solution by a significant margin.

10182-29, Session 7

Improvements to the histogram of oriented gradient (HOG) prescreener for buried threat detection in ground penetrating radar data

Daniel Reichman, Leslie M. Collins, Jordan M. Malof, Duke Univ. (United States)

To identify the presence of buried explosive threats, remote sensing technologies such as the Ground Penetrating Radar (GPR) have been utilized. In this context, the GPR is vehicle mounted and supplies data from each queried location on the vehicle's path to a computerized algorithm that can automatically detect the presence of buried threats. To achieve operationally relevant speeds, the algorithm's computational load is limited as it is used to detect the presence of a buried threat at each query location. Such an algorithm is referred to as a prescreener which, historically, has used the energy of the radar returns as a cue for target detection. One recent prescreener proposed in Torrione et al., 2014 treats the radar returns as images and uses the shape of target reflections in those images as a cue for detection. The shape is summarized with the HOG feature from the computer vision literature which has proven beneficial for object detection in natural images. In this work, we propose several modifications to the original HOG prescreener described in Torrione et al. to improve its detection performance on GPR data. We use a large collection of GPR data to demonstrate the superior performance of the proposed HOG prescreener compared to the original HOG prescreener, and the popular energy-based F1V4 prescreener.

10182-30, Session 7

Learning improved pooling regions for the histogram of oriented gradient (HOG) feature for buried threat detection in ground penetrating radar

Daniel Reichman, Leslie M. Collins, Jordan M. Malof, Duke Univ. (United States)

In recent years, the Ground Penetrating Radar (GPR) has successfully been applied to the problem of buried threat detection (BTD). A large body of research has focused on using computerized algorithms to automatically discriminate between buried threats and subsurface clutter in GPR data. For this purpose, the GPR data is frequently treated as an image of the subsurface, within which the reflections associated with targets often appear with a characteristic shape. In recent years, shape descriptors from the natural image processing literature have been applied to buried threat detection, and the histogram of oriented gradient (HOG) feature has achieved state-of-the-art performance. HOG consists of computing histograms of the image gradients in disjoint square regions, which we call pooling regions, across the GPR images. In this work we create a large body of potential pooling regions and use the group LASSO (GLASSO) to choose a subset of the pooling regions that are most appropriate for BTD on GPR data. We examined this approach on a large collection of GPR data using lane-based cross-validation, and the results indicate that GLASSO can select a subset of pooling regions that lead to superior performance to the original HOG feature, while simultaneously also reducing the total number of features needed. The selected pooling regions also provide insight about the regions in GPR images that are most important for discriminating threat and non-threat data.

10182-31, Session 7

Discriminative dictionary learning with LC-KSVD to learn effective features for detecting buried threats in ground penetrating radar data

Jordan M. Malof, Daniel Reichman, Leslie M. Collins, Duke Univ. (United States)

The ground penetrating radar (GPR) is a popular remote sensing modality for buried target detection. In this work we focus on the development of supervised machine learning algorithms that automatically identify buried targets in GPR data. An important step in many of these algorithms is feature extraction, where statistics or other measures are computed from the raw GPR data, and then provided to the machine learning algorithms for classification. It is well known that an effective feature can lead to major performance improvements and, as a result, a variety of features have been proposed in the literature. Most of these features have been hand crafted, or designed through trial and error experimentation. Dictionary learning is a class of algorithms that attempt to automatically learn effective features directly from the data (e.g., raw GPR data), with little or no supervision. Dictionary learning methods have yielded state-of-the-art performance on many problems, including image recognition, and in this work we adapt them to GPR data in order to learn effective features for target classification. We employ the LC-KSVD algorithm, which is a discriminative dictionary learning approach, as opposed to a purely reconstructive one like the popular K-SVD algorithm. We use a large collection of GPR data to show that LC-KSVD outperforms three other approaches: K-SVD, the popular Histogram of oriented gradient (HOG) with a linear classifier, and HOG with a nonlinear classifier (the Random Forest).

10182-32, Session 7

Improving convolutional neural networks for buried threat in ground penetrating radar using transfer learning via pretraining

John Bralich, Daniel Reichman, Leslie M. Collins, Jordan M. Malof, Duke Univ. (United States)

The Ground Penetrating Radar (GPR) is a remote sensing modality that has been used to collect data for the task of buried threat detection. The returns of the GPR can be organized as images and visual descriptors can be used as the basis for a buried threat detector. Recently, convolutional neural networks (CNNs) have been applied to this problem, inspired by their state-of-the-art-performance on object recognition tasks in natural images. One well known limitation of CNNs is that they require large amounts of data for training (i.e., parameter inference) to avoid overfitting (i.e., poor generalization). This presents a major challenge for target detection in GPR because of the (relatively) few labeled examples of targets and non-target GPR data. In this work we use a popular transfer learning approach for CNNs to address this problem. In this approach we train two CNN on other, much larger, datasets of grayscale imagery for different problems. Specifically, we pre-train our CNNs on (i) the popular Cifar10 dataset, and (ii) a dataset of high resolution aerial imagery for detecting solar photovoltaic arrays. We then use varying subsets of the parameters from these two pre-trained CNNs to initialize the training our buried threat detection networks for GPR data. We conduct experiments on a large collection of GPR data and demonstrate that these approaches reduce overfitting, and improve the performance of CNNs for buried target detection in GPR data.

10182-33, Session 8

Dual sensor technology of landmine clearance and its applications to survey in natural disaster

Motoyuki Sato, Tohoku Univ. (Japan)

Tohoku University has developed dual sensor ALIS for humanitarian demining. ALIS is a system combining a GPR and a metal detector, and 2 sets of ALIS are used by CAMC (Cambodian Mine Action Center) since 2009 and one team is working with them and detected more than 80 mines. Data acquisition and interpretation under strong clutter conditions is very challenging for the use of GPR and metal detector in mine fields. We use SAR (Synthetic Aperture Radar) processing for GPR imaging and it is quite successful. Based on the experience of ALIS in Cambodia, we used sensor technology for survey activities in natural disasters. In September 2014, Ontake-san volcano in Nagano, Japan erupted and 58 were killed by fallen volcanic ash. We introduced a metal detector used for humanitarian demining to the local police and one victim could be found. We could prove that the function of a metal detector reducing the response from magnetic and metallic soil worked well. In 2015, we also introduced GPR for survey under the ash. In March 2011, the east part of Japan was attacked by a huge scale Tsunami and more than 15,000 were killed and still more than 25,000 are missing. We expect that many missing victims were flashed away by Tsunami and cold be buried in sand in sand beaches or areas near the costs. We have worked together with local police stations and used metal detectors and multi-static GPR system "Yakumo" for the survey of Tsunami victims. In many beaches, we found that the semimetal layer of the Tsunami in 2011 is about 50-70cm thick, and could detect many objects buried under this sand layer. We think SAR processing in GPR is important for detecting small buried objects.

10182-34, Session 8

LBP feature for hand-held ground penetrating radar

Samuel D. Harris, Brendan Alvey, Dominic K. Ho, Univ. of Missouri (United States); Alina Zare, Univ. of Florida (United States)

Ground penetrating radar (GPR) has the ability to detect buried targets that has little or no metal content. A hand-held GPR often faces challenge in detection performance due to various factors including the quality of the data, the inconsistency of target signatures, the variety of targets and the effects of human operator. In this paper, we investigate the use of the local binary patterns (LBP) applied to the hand-held GPR data to form the feature vector for target versus non-target discrimination. The GPR B-scan at a prescreen alarm location is separated into several spatial and depth regions. LBP processing is applied to each spatial and depth cell individually and the LBP features from each cell are grouped together to form the feature vector for discrimination using a classifier. LBP feature is invariant to amplitude scaling and can represent the texture in the data well. Experimental results illustrate the ability of the LBP feature to improve the detection of buried targets, especially for low-metal or non-metal anti-tank and anti-personnel targets.

10182-35, Session 8

Void and landmine detection using the HFEMI sensor

Benjamin E. Barrowes, U.S. Army Engineer Research and Development Ctr. (United States); Fridon Shubitidze, John B. Sigman, Thayer School of Engineering at Dartmouth (United States); Jay Bennett, Janet E. Simms, Don

Yule, U.S. Army Engineer Research and Development Ctr. (United States); Kevin O'Neill, Thayer School of Engineering at Dartmouth (United States)

Electromagnetic induction instruments have been traditionally used to detect high conductivity discrete targets such as metal unexploded ordnance. The frequencies used for this electromagnetic induction regime have typically been less than 100 kHz. To detect lower conductivity objects like carbon fiber or saturated salts, we use higher frequencies up to the low megahertz range to capture the relaxation response. As a first step, we modeled the response of these intermediate electrically conducting material (IECM) targets using the Method of Auxiliary sources (MAS). We have also fabricated a benchtop high-frequency electromagnetic induction instrument capable of acquiring EMI data up to 15 MHz. We show both modeled and acquired characteristic relaxation signatures from calcium chloride saturated water and from carbon fiber. In addition, we show that the absence of conductivity (a void, e.g. a rock, a piece of wood, rubber, or other insulating material) in an otherwise conducting region can be detected using these high-frequency techniques. Finally, results from the HFEMI instrument from landmines will be presented.

10182-36, Session 8

Computation of the eddy-current modes of permeable conductors for detection using electromagnetic induction sensors

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

Electromagnetic induction (EMI) sensors are often used for subsurface detection, because of their sensitivity to even small fragments of metal buried beneath the soil surface. In certain applications, such as landmine detection, it is desirable to be able to discriminate between classes of metallic objects of interest and metallic clutter. In these applications, broadband sensors can provide additional information that can be used not only to identify targets of interest, but also to pinpoint their location and orientation underground.

In order to perform this discrimination, one prominent strategy involves inverting a pole expansion of measured frequency data, and comparing the expansion to a dictionary of known targets. This method requires a priori knowledge of the pole expansion coefficients of target classes of interest. In past papers, we have shown how the coefficients of the pole expansion for non-permeable targets can be found computationally by solving for the eigenvalues of the eddy current problem.

In this paper we will concentrate on finding the pole expansion coefficients of arbitrarily-shaped permeable conductors, which are a component of many landmines. The finite integration technique (FIT) is used in conjunction with a null-space-free Jacobi-Davidson type eigenvalue solver in order to compute the eigenpairs of interest. The circulation of eddy currents in these permeable conductors will be visualized, and expressions for the pole-expansion coefficients of different conductor shapes will be given.

10182-37, Session 8

Target location and tensor estimation for single channel EMI data

Andrew J. Kerr, Waymond R. Scott Jr., Charles E. Hayes, James H. McClellan, Georgia Institute of Technology (United States)

This work develops and tests target location, orientation, and tensor estimation techniques for two-dimensional EMI scan data collected with a single channel (head) EMI sensor. The two techniques that are presented in this work for location estimation are backprojection and least squares. For the backprojection method, the two-dimensional scan data is projected back onto a dictionary model of the measurement, effectively creating a matched filter. The backprojected image can be computed efficiently in the Fourier domain because of the shift invariant property inherent to electromagnetic problems. The least-squares solution is also used as an estimate for the target location. To compute the least-squares solution, the dictionary model is shifted to all potential target positions and a least-squares fit is computed. The residual between the estimated measurement and the true measurement is computed and the target location is estimated to be at the location with the smallest residual. While effective in quickly estimating the target location, the tensor estimate resulting from the least squares solution is generally non-physical because it is not positive semi-definite (PSD). Consequently, a PSD constraint is enforced on the least squares tensor estimate resulting in a physically possible solution. The orientation of the target can then be estimated using the geometry of the eigenvectors of the tensor estimate. These estimation techniques were tested and verified to work on both simulated data and experimental lab data.

10182-38, Session 8

Metrics for the comparison of coils used in electromagnetic induction systems

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

Many different coil head configurations are currently used in electromagnetic induction (EMI) systems for sensing buried targets. It is difficult to compare the performance of different coil head designs to one another. Comparing two particular implementations is not particularly challenging, but fairly comparing general coil head designs is nontrivial. A coil head configuration such as a dipole/quadrupole or double-D can be implemented with different wire gauges or number of turns, for example, and these choices affect the performance. It is desirable to remove influences such as these from coil performance metrics. The task of comparing coils becomes yet more difficult when a coil is designed using a stream function because the stream function can be accurately represented by many different but ultimately similar coils.

There are also multiple ways to define metrics such as the target sensitivity and the influence of the soil upon the received signal. This work details both a target sensitivity metric and soil sensitivity metric that account for differences such as overall coil size, length, and wire diameter. For example, the metric is defined so a dipole/quadrupole head can be compared to a double-D head with confidence. The metrics also allow stream function coils to be compared directly to wire coils. The metrics are then used to compare the performance of a range of coil designs, such as the dipole/quadrupole, double-D, various concentrics, and optimized stream function coils.

10182-39, Session 8

Array of broadband electromagnetic induction sensors for detecting buried objects

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

A prototype EMI sensor is built that uses a single dipole transmit coil and an array of four quadrapole receive coils. The sensor operates in the frequency domain and collects data at 15 logarithmically spaced frequencies from 1 kHz to 90 kHz, a 90 to 1 bandwidth. The system is designed to be very sensitive while making very accurate measurements. The accuracy is very important to be able to filter out soil effects and to effectively classify targets.

The coils are designed so that the inductive coupling between the transmit and receive coils is very small due to the geometry of the quadrapole receive coils. The inductive coupling between the adjacent receive coils is very small due to the overlap between the coils. The coupling effects between the receive coils are also mitigated by a feedback amplifier.

Additionally, the feedback amplifier lessens measurement errors due magnetic soils. The receive coils are resistively loaded in a manner that dampens higher-order resonances to improve the accuracy of the system. The coils are individually shielded with an anisotropic conductive shield to lessen the effects of capacitive coupling between the sensor and the targets/soil. The transmit coil is driven by a switched mode amplifier that can drive high currents efficiently.

The results of laboratory and field experiments using this sensor are presented for a variety of metallic targets. These results show that the response of the sensor varies for the different target types, so the sensor is capable of discrimination between targets.

10182-40, Session 9

Characterization of buried targets from planar electromagnetic induction sensor data in a moving reference frame

Davorin Ambrus, Darko Vasic, Vedran Bilas, Univ. of Zagreb (Croatia)

Handheld electromagnetic induction (EMI) sensors used for detection of buried landmines typically employ planar sensor head geometries comprised of a single transmitter and one or more receiver coils. Such configurations have dominant sensitivities oriented in a single direction and are therefore well-suited for metal detection. However, when one tries to characterize the target with a planar EMI sensor, e.g. reconstruct the six parameters of an induced dipole model, the problem becomes challenging, since the target needs to be interrogated by all three orthogonal field components in order to obtain unambiguous results. Sweeping the sensor over a target helps with this issue, since the target gets magnetically illuminated from different directions, however a downside is that the sensor head pose needs to be known in a ground reference frame, at each measurement point. Although various solutions for the tracking of sensor head pose have been reported, they are all more or less obtrusive when used in field conditions. Also, such systems introduce additional uncertainties, often with non-normal distributions, thus complicating the inversion procedures.

In this paper, we investigate an alternative approach to dipole-based target characterization, where the problem is analyzed in a moving, sensor-based reference frame by dynamically processing sensor data at each measurement point using the extended Kalman filter. For a chosen planar coil geometry, we first analyze the local observability of the filter for a typical scan pattern. We then show how the target's magnetic polarizabilities and sensor-target distance can be simultaneously estimated using EMI data only.

10182-41, Session 9

Ultra-wide-band EMI sensing for subsurface DU detection

Fridon Shubitidze, Thayer School of Engineering at Dartmouth (United States); Bejamin E. Barrowes, U.S. Army Engineer Research and Development Ctr. (United States); John B. Sigman, Kevin O'Neill, Thayer School of Engineering at Dartmouth (United States)

Depleted uranium (DU) has been developed as armor penetrating projectiles by the US department of defense. During DU testing and practical uses in the field, the aerosol or spallation frangible powder of DU is produced by impact and combustion, which in return contaminates wide area. Since, the DU is uranium, a toxic metal, with a lower content (less than 0.3 %) of the isotope U-235 than the natural uranium, which contains about 0.72 % of the isotope U-235, therefore there are significant concern about long-term health effects using the DU in munitions. In order to minimize the potential contamination and health concerns associated with firing of munitions that contain DU the U.S. Army Developmental Test Command (DTC) developed a Depleted Uranium Health and Environmental Management Plan. One of the main goals of DTC it to detect and identify projectiles, that contain DU-allow. For an example the M101 spotting round that is a small, about 8 inches in length and 1-inch diameter, low speed projectile weighing about one pound and containing about 6.7 ounces of DU-alloy. To address this issue, this paper investigates ultra-wide-band (from 10 th of Hertz up to 15 mega Hertz) EMI responses for DU-allow. Both computational, using the method of auxiliary sources, and experimental studies are conducted. The EMI signals sensitivities respect to DU size, material composition and depth are illustrated and reported.

10182-42, Session 9

Fusion of Choquet integrals for explosive hazard detection in EMI and GPR for handheld platforms

Ryan Smith, Derek T. Anderson, John E. Ball, Mississippi State Univ. (United States); Alina Zare, Univ. of Florida (United States); Brendan Alvey, Univ. of Missouri (United States)

Substantial interest resides in identifying sensors, algorithms and (multi-sensor) fusion theories to detect buried explosive hazards. This is a significant research effort because it impacts the safety and lives of civilians and soldiers alike. Herein, we explore the fusion of different algorithms within and across ground penetrating radar (GPR) and electromagnetic induction (EMI) sensors on a U.S. Army Night Vision and Electronic Sensors Directorate (NVESD) furnished experimental hand held demonstrator (EHHD) system. Fusing these two sensors is not trivial as they have different sampling rates, they observe different areas of interest, and they obviously span different portions of the electromagnetic spectrum. We investigate and compare the utility of different methods for conditioning/normalization, spatial resampling and interpolation, and ultimately, decision-level aggregation using the Choquet integral (CI). With respect to the CI, we explore the impact of using a global (single) aggregation strategy versus tailoring and fusing different CIs for different subsets of algorithms and sensors. Results are demonstrated in the context of receiver operating characteristic (ROC) curves on data from a U.S. Army test site that contains multiple target and clutter types, burial depths and times of day.

10182-43, Session 9

Novel model based EMI processing framework

Charles E. Hayes, James H. McClellan, Waymond R. Scott Jr., Georgia Institute of Technology (United States)

Wideband electromagnetic induction (WEMI) sensors can be used to detect, classify, and locate buried metallic targets. WEMI sensors operate by energizing eddy currents within a metallic target and then measuring the secondary magnetic fields as the target releases the energy. The traditional framework for processing the obtained WEMI data can be described as having three stages. The first stage uses a down-track filter that removes the self-response of the sensor. The second stage is responsible for finding targets and recovering the target's signature. The final stage locates the target and determines its orientation. Each of these stages is run sequentially and uses data recovered from the previous stages. If any errors occur in the upstream stages, then these errors affect the later stages and cause sub-optimal processing.

This work examines the physical models for the WEMI sensor and presents a mathematical approach for recovering the physical model from the measured data. The approach uses a low-rank approximation of the measured data obtained via a singular value decomposition. The new framework is "filterless" and allows the pre-filter, target signature recovery,

and target location to be calculated independently and in parallel. The target's orientation can then be recovered by using the target's signature and location information. This new framework is directly tied to the WEMI physical model and will allow for improved processing. Initial results for various tasks are presented to demonstrate baseline results.

10182-44, Session 10

Comparative analysis of image formation techniques for FLGPR

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

This paper discusses the application of several advanced image formation techniques to the FLGPR problem. The techniques include L_1 regularized imaging, total variation regularized imaging, coherent interferometric imaging, and coherence-factor image filtering. The technical framework and software implementation of each of these image formation techniques are presented and discussed, and results of applying the techniques to field collected data are presented. The results from the different techniques are compared to standard backprojection and compared to each other in terms of image quality and target-to-clutter ratio.

10182-45, Session 10

Multisensor fusion of FLGPR, LIDAR, and thermal and visible-spectrum cameras for standoff detection of buried objects

Anthony Pinar, Timothy C. Havens, Michigan Technological Univ. (United States); Adam J. Webb, Michigan Tech Research Institute (United States)

Buried targets pose a serious threat to modern soldiers and civilians alike, thus detecting them from a safe standoff distance is an important step in their remediation. Many successful vehicle-based detection systems have been designed to utilize forward-looking ground penetrating radar (FLGPR) for buried target detection at a distance, however, FLGPR has an inherently low signal-to-clutter-ratio (SCR) so its performance is limited. To address this limitation, suites of sensors have been added to some of these vehicle-based systems. In this work we utilize data from these various sensors to improve the buried target classification accuracy. Specifically, we present features extracted from FLGPR, lidar, and thermal- and visible-spectrum camera data, then fuse the various features using a multiple kernel learning (MKL) based classifier. Our results indicate that fusing these multimodal features yields a higher classification performance than utilizing data from the FLGPR alone. We also analyze each sensor's incremental improvement of classification accuracy by performing numerous experiments with different permutations of the sensors.

10182-46, Session 10

Regularization techniques in forward-looking GPR

Adam J. Webb, Timothy C. Havens, Timothy J. Schulz, Michigan Technological Univ. (United States)

The Forward-Looking Ground Penetrating Radar (FLGPR) collection scenario involves collection of data using a MIMO array on a moving platform targeted at a near-field region of interest. Likelihood based image formation techniques provide a flexible framework which allows for explicit modeling of the GPR environment and have demonstrated superior performance with respect to side-lobe mitigation, speckle reduction, and robustness to other undesired system limitations. Furthermore, likelihood based image formation techniques can be engineered where specific features to be used during target classification are emphasized explicitly as part of the image formation process. In this paper we present a likelihood based image formation technique applied to the Forward- Looking GPR environment. A number of different regularization techniques are compared and examples are shown emphasizing specific characteristics of the resulting images dependent on the regularization technique applied.

10182-47, Session 10

Tuning log Gabor filter bank using genetic algorithm based optimization

Pooparat Plodpradista, James M. Keller, Dominic K. Ho, Mihail Popescu, Univ. of Missouri (United States)

In an application of side-attack explosive hazard (SAEH) detection, one of the great challenges is detecting the occluded targets. Forward-looking ground penetrating radar (FLGPR) is a sensor that has the capability to handle this type of problem since it has the power to penetrate the occlusion and detect the explosive. However, the explosive can be concealed by multiple types of objects along the side of the road, such as rocks, vegetation, trash, etc. In FLGPR imaging space, these clusters of occlusion come in many shapes and sizes. The log Gabor descriptor, which has the advantage of separating different types of textures, is a potential solution for the aforementioned issue.

However, in order to fully utilize the log Gabor filter bank, there are many parameters that need to be handcrafted for each specific problem. Since the possibility of designing a filter bank is endless, brute-force search is not possible. An additional element to be considered is the size of the filter bank, since a large filter bank requires more computation time. In this paper, we propose the use of multi-objective optimization based on an evolutionary algorithm to streamline the process of designing a log Gabor filter bank. The objectives of the optimization are to design a filter bank that can well separate the location of explosive hazards from false alarm hits while keeping the size of the filter bank to the minimum. The data we use to validate our proposed method was collected on arid lanes by a MIMO FLGPR system on board of the U.S. Army prototype vehicle. The experiments are designed to measure the improvement of the optimization over the manual tuning and to demonstrate the impact of the optimization's parameters on the performance of the filter bank.

10182-48, Session 10

An improved frequency domain feature with partial least-squares dimensionality reduction for classifying buried threats in forward-looking ground-penetrating radar data

Joseph A. Camilo, Duke Univ. (United States); Miles Crosskey, CoVar Applied Technologies, Inc. (United States); Kenneth D. Morton Jr., CoVar Research (United States); Leslie M. Collins, Jordan M. Malof, Duke Univ. (United States)

The forward-looking ground penetrating radar (FLGPR) is a remote sensing modality that has recently been investigated for buried threat detection. In this context, the FLGPR sensor array is mounted on a vehicle and aimed forward in the direction of travel. The FLGPR considered in this work uses stepped frequency sensing, followed by filtered backprojection to create images of the ground. A large body of research has focused on developing effective supervised machine learning algorithms to automatically discriminate between target and non-target FLGPR imagery. An important component of these algorithms is the design of effective features (e.g., image statistics) that are extracted from the FLGPR imagery and provided

to machine learning classifiers (e.g., support vector machines). A large variety of features have been proposed for this purpose. One such feature that has recently been proposed constructs a feature from the magnitude of the two-dimensional fast Fourier transform (2D-FFT) of the FLGPR imagery. This paper presents an improvement of the previous 2D-FFT feature that substantially improves its performance. We compare the performance of this feature to many existing features, including the original 2D-FFT feature, using a large dataset of FLGPR imagery and several classifiers. We show that the improved 2D-FFT feature consistently outperforms all existing features. Further, we show that using partial least-squares discriminative dimensionality reduction, it is possible to dramatically lower the dimensionality of the new 2D-FFT feature to roughly twenty dimensions while simultaneously maintaining, or improving, its performance.

10182-49, Session 11

Multispectral signal processing of synthetic aperture acoustics for side attack explosive ballistic detection

Bryce Murray, Derek T. Anderson, Mississippi State Univ. (United States); Robert H. Luke, Kathryn A. Williams, U.S. Army Night Vision & Electronic Sensors Directorate (United States); John E. Ball, Mississippi State Univ. (United States)

Substantial interest resides in identifying sensors, algorithms and (multi-sensor) fusion theories to detect explosive hazards. This is a significant research effort because it impacts the safety and lives of civilians and soldiers alike. However, a challenging aspect of this field is we are not in conflict with the threats (objects) per se. Instead, we are dealing with people and their changing strategies and preferred method of delivery. Herein, we investigate one method of threat delivery, side attack explosive ballistics (SAEB). In particular, we explore a vehicle-mounted synthetic aperture acoustic (SAA) platform. First, a wide band SAA signal is decomposed into a higher spectral resolution signal. Next, different hyperspectral processing methods are explored and adapted for SAEB detection for band selection. Last, these bands are used by a convolutional neural network (CNN) for feature learning and classification. Performance is assessed in the context of receiver operating characteristic (ROC) curves on data from a U.S. Army test site that contains multiple target and clutter types, levels of concealment and times of day.

10182-50, Session 11

A new approach for extracting texture features to aid detection of explosive hazards using synthetic aperture acoustic sensing

Eric Brewster, James M. Keller, Mihail Popescu, Univ. of Missouri (United States)

Synthetic aperture acoustic data has a very unique appearance. Due to this unique appearance, we propose that examining the texture between targets and non-targets will prove more descriptive and improve classification performance. A few common texture feature extraction methods are those derived from grey-level co-occurrence matrix (GLCM), local binary patterns (LBP), and local directional patterns (LDP). LDP uses a set of filters to measure the local directional response around each pixel and then builds a binary code like LBP. The feature vector is a histogram of those binary codes. However, the set of filters used may not be the optimal set needed to achieve the best classification accuracy and a binary coding may not be the best aggregation method. In this paper we apply known sets of two-dimensional filters, not necessarily directional, as well as develop a new approach to aggregation. Different filter sets provide the algorithm a broader description beyond the direction of edges and thus better representation of texture. A more complex aggregation method allows for more information to be retained in the feature vector. These modifications, to the existing LDP algorithm, allow for a classifier to more accurately distinguish between the textures of targets and non-targets. A support vector machine (SVM) is used to evaluate the performance of the new feature extraction method and compare its performance to other common texture feature extraction methods. This will be used to build an online classifier system for testing on lane based data.

10182-51, Session 11

A 3D feature descriptor for high-resolution 3D radar imagery

Andrew Buck, James M. Keller, Univ. of Missouri (United States); Alina Zare, Univ. of Florida (United States); Mihail Popescu, Univ. of Missouri (United States)

Recently, the Stalker system has been developed as a high-resolution three-dimensional radar imaging system for the detection of concealed roadside explosive hazards. This system has shown considerable capability in distinguishing between true targets and false alarms using conventional processing techniques such as RX filtering on 2D projections of the data. In this paper, we develop a 3D processing method for identifying anomalous regions that are likely to contain targets and compute a novel feature descriptor that can characterize the difference between true targets and roadside clutter. We compute the 3D gradient of the beamformed Stalker data and use this information to compute multiple nested isosurfaces representing the shape of the imaged object. The normal vectors of these isosurfaces are then used to construct a discriminating feature vector. We test our approach on a real dataset collected at an arid U.S. Army test site.

10182-52, Session 11

Voxel-space radar signal processing for side attack explosive ballistic detection

Joshua L. Dowdy, Blake Brockner, Derek T. Anderson, Mississippi State Univ. (United States); Kathryn A. Williams, Robert H. Luke, U.S. Army Night Vision & Electronic Sensors Directorate (United States)

Explosive hazards in current and former conflict zones are a serious threat to both civilians and soldiers alike. Significant effort has been dedicated to identifying sensors, algorithms and fusion strategies to detect such threats. However, a challenging aspect of the field is that we are not necessarily at war with the threats (objects) we are trying to detect. Instead, we are at war with people who are constantly evolving their strategies of attack along with their preferred threat. One such method of threat delivery is side attack explosive ballistics (SAEB). In this article, we explore different 3D voxel-space Radar signal processing methods for SAEB detection on a U.S. Army provided vehicle-mounted platform. In particular, we explore the Matched Filter (MF) and the Size Contrast Filter (SCF), along with a combination of the two. Performance is assessed in the context of receiver operating characteristic (ROC) curves on data from a U.S. Army test site that contains multiple target and clutter types, levels of concealment and times of day.

10182-53, Session 11

Matched illumination waveform design for enhanced detection and imaging of tunnels

Steven R. Price, Mississippi College (United States); Carey D. Price, Clay Blount, U.S. Army Engineer Research and Development Ctr. (United States)

One promising technique of improving tunnel detection is the use of spotlight SAR in conjunction with focusing techniques. Still, clutter arises from surface variations while severe attenuation of the target signal occurs due to the dielectric properties of the soil. To combat these ill-effects, this work aims to improve imaging and detection of underground tunnels by incorporating matched illumination waveform design. Recently, matched illumination waveform design has been shown to effectively enhance the imaging capabilities of through-the-wall radar systems by designing a transmission waveform which increases the signal-to-interference-and-noise ratio (SINR) of targets in which target information is known a priori. Similarly, SINR improvement of tunnels in the context of imaging and detection can be accomplished by designing a transmission waveform which optimally places signal energy in bands that exhibit low ground attenuation and interference due to surface clutter while maximizing the level of target scattering due to the tunnel. In particular, the purpose of this work is to investigate the imaging and detection enhancement accomplished through transmission of matched illumination waveforms designed for underground tunnels.

10182-54, Session 12

Target feature extraction from simulated GPR data using time-frequency representations

Mesut Dogan, Gönül Turhan-Sayan, Middle East Technical Univ. (Turkey)

Detection and classification of buried objects using ultra-wideband ground penetrating radar (GPR) measurements have been a challenging area of research that is still open to improvements. Among the other sensor technologies, such as induction coils and infra-red imaging, down-looking and forward-looking GPRs have been known for decades to be effective sensors for automatic detection and classification of buried targets. Reducing the false alarm rates is as important as increasing the target detection probability in GPR applications where implementation of sensor fusion and feature fusion techniques has proven useful to fulfil both requirements.

Detection of a buried object requires sophisticated preprocessing techniques. Once an object is detected, it should be classified correctly to figure out if it is a target that deserves further attention or simply a cluster that can be ignored. Extraction of proper target features from measured GPR signals is the most critical step of the target recognition process. Linear and quadratic time-frequency signal representation (TFR) methods have been used for the purpose of feature extraction in automatic target recognition problems. Quadratic TFRs are found especially useful for target feature extraction as they provide detailed information about the energy distribution of A-scan GPR signals over the two-dimensional domain of time and frequency.

In this study, the A-scan and B-scan signals of a single-channel down-looking GPR are simulated for various targets of different canonical geometries having different material contents. Then, the dominating ground reflections are removed from the data by suitable preprocessing techniques. Finally, simulated GPR signals are investigated using various linear and quadratic TFRs for the ultimate purpose of buried target classification.

Conference 10183: Chemical, Biological, Radiological, Nuclear, and Explosives (CBRNE) Sensing XVIII

Tuesday 11–11 April 2017

Part of Proceedings of SPIE Vol. 10183 Chemical, Biological, Radiological, Nuclear, and Explosives (CBRNE) Sensing XVIII

10183-1, Session 1

Methodologies for using active infrared spectroscopy in standoff detection of trace explosives

Christopher J. Breshike, Christopher A. Kendziora, Robert Furstenberg, R. Andrew McGill, U.S. Naval Research Lab. (United States)

This presentation describes a methodology for the mobile stand-off detection and identification of trace amounts of hazardous materials, specifically high explosives. The technique utilizes an array of tunable infrared quantum cascade lasers as an illumination source which spans wavelengths from 6 to 11 microns, operated at eye-safe power levels. This spectral range enables excitation of a wide variety of absorption bands present in analytes of interest. The backscatter and photo-thermal signals from samples are measured via an IR focal plane array, which allows for the observation of spatial, temporal, and thermal surface processes. This information is stored in a hyperspectral image cube to allow for post processing in a detection algorithm.

Utilizing infrared quantum cascade lasers as our illumination source presents many challenges to overcome before this standoff detection method can be implemented as standard operating procedure for trace explosives detection. A discussion of specific challenges and our solutions to those challenges is presented. These challenges include atmospheric absorption, beam wander, and varying power performance and stability of the individual components in the quantum cascade laser array. In order to translate this technology into a viable field method we must calibrate, within a reasonable measure of error, where the beam is, how much light is illuminating the sample for a given time period, and what at wavelength the laser is operating at standoff distances.

10183-2, Session 1

Real-time, wide-area hyperspectral imaging sensors for standoff detection of explosives and chemical warfare agents

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

Hyperspectral imaging (HSI) can be a valuable tool for the detection and analysis of targets located within complex backgrounds. HSI is useful for the detection of threat materials on environmental surfaces, where the concentration of the target of interest is often very low and is typically found within complex scenery. Unfortunately, current generation HSI systems have size, weight, and power limitations that prohibit their use for field-portable and/or real-time applications. Current generation systems commonly provide an inefficient area search rate, require close proximity to the target for screening, and/or are not capable of making real-time measurements.

ChemImage Sensor Systems (CISS) is developing a variety of real-time, wide-field hyperspectral imaging systems that utilize shortwave infrared (SWIR) absorption and Raman spectroscopy. SWIR HSI sensors provide wide-area imagery with at or near real time detection speeds. Raman HSI sensors are being developed to overcome two obstacles present in standard Raman detection systems: slow area search rate (due to small laser spot sizes) and lack of eye-safety. SWIR HSI sensors have been integrated into mobile, robot based platforms and handheld variants for the detection of explosives and chemical warfare agents (CWAs). In addition, the fusion of these two technologies into a single system has shown the feasibility of using both techniques concurrently to provide higher probability of detection and lower false alarm rates.

This paper will discuss recent advances in our technologies, discuss the applications for these techniques, and provide an overview of novel CISS HSI sensors that will focus on sensor design and detection results.

10183-3, Session 1

High-speed mid-infrared hyperspectral imaging using quantum cascade lasers

David B. Kelley, Anish K. Goyal, Ninghui Zhu, Derek Wood, Block Engineering, Inc. (United States); Travis R. Myers, Block Engineering, Inc. (United States) and Univ. of California, Los Angeles (United States); Petros Kotidis, Block Engineering, Inc. (United States); Gil M. Raz, Cara P. Murphy, Chelsea Georgan, Systems & Technology Research (United States); Richard Maulini, Antoine Müller, Alpes Lasers SA (Switzerland)

Laser-based, mid-infrared (MIR) hyperspectral imaging (HSI) is arguably the only method that is capable of scanning surfaces for trace chemicals at high speed, with high sensitivity, and while remaining eye-safe. In this work, we utilize widely tunable external-cavity quantum cascade lasers (EC-QCLs) to illuminate target surfaces in both the mid-wave infrared (λ = 4 – 5 μm) and long-wave infrared (λ = 7.4 – 11.3 μm). Hyperspectral images (i.e., hypercubes) are acquired by synchronously operating the EC-QCLs with a LN2-cooled HgCdTe camera. By integrating lasers that can tune at high speed with a camera that is capable of high frame rates, hypercubes with 128 x 128 pixels and >100 wavelengths can be acquired in <0.1 s. To the best of our knowledge, this is the fastest acquisition to date of hypercubes using QCL illumination. Raw hypercubes are post-processed to generate a hypercube that represents the surface reflectance relative to that of a diffuse reflectance standard. Advanced detection algorithms are then applied to detect and identify the surface chemicals. Because the reflection signatures for trace chemicals on surfaces can be complex, standard detection approaches are not adequate and require the development of new approaches which will be discussed. This is especially true when the surface is rough and presents a significant amount of speckle noise. Detection results will be shown for liquids (e.g., silicone oil) and solid particles (e.g., KClO3, acetaminophen) on a variety of surfaces (e.g., aluminum, plastic, glass). We will also discuss the impact of speckle on detection capability.

10183-4, Session 1

Advanced LWIR hyperspectral sensor for on-the-move proximal detection of liquid/solid contaminants on surfaces

Jay P. Giblin, Physical Sciences Inc. (United States)

Physical Sciences Inc. is developing a long-wave infrared (LWIR, 8-10.5 microns) spatial heterodyne spectrometer (SHS) coupled with an LWIR illuminator and data fusion algorithms for the detection and identification of liquid/solid contaminants on surfaces while on-the-move. The system employs a high throughput SHS with a noise equivalent spectral radiance sufficient to support detection of liquid droplets and solid particles at dwell times associated with vehicle speeds approaching 10 mph. A modulated broadband LWIR illuminator is used to enhance thermal contrast of contaminants. The detection algorithm framework is based on a variant of the Adaptive Cosine Estimator functioning on a time series of surface reflectance spectra collected as a vehicle moves across the ground. The physical basis of detection relies on the observable modulation of a surface's apparent reflectivity due to contaminant absorption/reflectance bands prevalent in the LWIR region. The system design and architecture of the SHS-based LWIR sensor are discussed. Functional testing results of the system are presented. The ability of the system to detect 800 micron diameter triethyl phosphate particles deposited onto asphalt, concrete, and sand at areal densities of 0.5 g/m2 is discussed.

10183-5, Session 1

Measurement of infrared refractive indices of organic and organophosphorus compounds for optical modeling

Tanya L. Myers, Russell G. Tonkyn, Tyler O. Danby, Jerome L. Birnbaum, John S. Loring, Bruce E. Bernacki, Timothy J. Johnson, Pacific Northwest National Lab. (United States)

The complex optical refractive index contains the optical constants, n and k, which correspond to the dispersion and absorption of light within a medium, respectively. By obtaining the optical constants one can in principle model most optical phenomena in media and at interfaces including reflection, refraction and dispersion. We have recently developed improved protocols based on the methods of Bertie et al. [J.E. Bertie et al., Applied Spectroscopy 47, 1100-1114 (1993)] to determine the optical constants for dozens of liquids, including organic and organophosphorous compounds. Detailed description of the protocols to determine the constants will be presented, along with preliminary results using the constants with their applications to optical modeling.

10183-6, Session 1

Improved detection of chemical substances from colorimetric sensor data using probabilistic machine learning

Lasse Molgaard, Ole T. Buus, Jan Larsen, Hamid Babamoradi, Technical Univ. of Denmark (Denmark); Ida L. Thygesen, Milan Laustsen, Jens K. Munk, DTU Nanotech (Denmark) and Technical Univ. of Denmark (Denmark); Eleftheria Dossi, Cranfield Univ. (United Kingdom); Lina Lässig, Securetec Detektions-Systeme AG (Germany); Sol Tatlow, Pro Design Electronic GmbH (Germany); Lars Sandström, Gammadata Instrument AB (Sweden); Mogens H. Jakobsen, DTU Nanotech (Denmark) and Technical Univ. of Denmark (Denmark)

We present a data-driven machine learning approach to detect drug- and explosives-precursors using colorimetric sensor technology for air-sampling.

The sensing technology has been developed in the context of the CRIM-TRACK project. At present a fully-integrated portable prototype for air sampling with disposable sensing chips and automated data acquisition has been developed. The prototype allows for fast, user-friendly sampling which has made it possible to produce large datasets of colorimetric data for different target analytes in laboratory and simulated real-world air-samples.

A number of machine learning techniques are employed to make use of the highly multi-variate data produced from the colorimetric chip to provide reliable classification of target analytes from confounders found in the air streams. We demonstrate that a data-driven machine learning method using dimensionality reduction in combination with a probabilistic classifier makes it possible to produce informative features and a high detection rate for the detection of analytes. Furthermore, the probabilistic machine learning approach provides a means of automatically identifying unreliable measurements that could produce false predictions.

The robustness of the colorimetric has been evaluated in a series of experiments focusing on the amphetamine pre-cursor phenylacetone and the improvised explosives pre-cursor hydrogen peroxide. The analysis demonstrates the system's ability to detect analytes in clean air and mixed with substances that occur naturally in real-world sampling scenarios.

The technology under development in CRIM-TRACK has the potential as an effective tool to control trafficking of illegal drugs, explosive detection, or in other law enforcement applications.

10183-7, Session 2

Raman imaging using fixed narrow bandpass filter

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

By using fixed narrow band pass optical filtering and scanning the laser excitation wavelength, hyperspectral Raman imaging could be achieved. Experimental results on different Chemical Warfare Agents (CWA) as well as common simulant chemicals on different surfaces/substrates are presented and discussed.

10183-8, Session 2

Ultraviolet Raman scattering from V-agents

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

We present our latest experimental results on V-agent Raman scattering in the middle UV band. The Raman scattering was examined using a pulsed tunable laser based spectrometer system. Neat droplets of the agents were placed on a silicon surface and irradiated with sequences of laser pulses. The Raman scattering was examined as a function of laser wavelength, exposure per pulse and accumulated exposure.

10183-9, Session 2

Mobile mapping of CBRNE scenes aided with intelligent data analytics

Michel Bondy, Piotr Jasiobedzki, Ho-Kong Ng, MacDonald, Dettwiler and Associates Ltd. (Canada); Bumsoo Kim, Defence Research and Development Canada (Canada); Holly Johnson, MacDonald, Dettwiler and Associates Ltd. (Canada)

First responders teloperate CBRNE robots using camera images and live detector readings. In GPS-denied environments they rely on their memory, notes and sketches to record and understand the environment structure, distribution of hazards, traversed paths and to monitor robots' locations. Interpretation of such incomplete data is challenging, inaccurate and time consuming, and affects the response planning and execution timelines.

The Enhanced Perception Of CBRNE Hazards (EPOCH) project developed novel technologies that improve situational awareness and provide assistance to the operator with data analytics. The focus has been on chemical and radiological response in GPS-denied environments (building interiors). Field trials with first responders showed reduction of the response time by 50% comparing with state-of-the-art systems.

The rugged prototype system provides real-time camera images and CBRNE detector data from on-board sensors. Intelligent software operating creates 2D maps of the site, locates the robot and geo-locates the CBRNE data automatically in real-time. The data is presented in intuitive formats to aid the operators: augmented maps, numerical data, strip charts, and color coded paths.

Automatic radiation source localization algorithms analyze recent geo-located measurements and suggest the most likely source location to the operator. Three different algorithms have been developed for directional and standard detectors. The paper presents results on simulated data and data acquired during field trials with actual sources.

The operators can review past data stored in a database, share it over computer networks, and perform post-mission analysis by revisiting the site virtually.

10183-10, Session 2

Photo-vibrational sensing of trace chemicals and explosives by long-distance differential laser Doppler vibrometer

Yu Fu, Huan Liu, Qi Hu, Jiecheng Xie, Nanyang Technological Univ. (Singapore)

Photoacoustic/photothermal spectroscopy is an established technique for trace detection of chemicals and explosives. Normally high-sensitive microphone or PZT sensor is used to detect the signal in photoacoustic cell. In recent years, laser Doppler vibrometer (LDV) is proposed to remote-sense photoacoustic signal on various substrates. It is a high-sensitivity sensor with a displacement resolution of <10pm. In this research, the photoacoustic effect of various chemicals and explosives is excited by a quantum cascade laser (QCL) at their absorbance peak. A home-developed differential LDV at 1550nm wavelength is applied to detect the vibration signal at 100m. A differential configuration is applied to minimize the environment factors, such as environment noise and vibration, air turbulence, etc. and increase the detection sensitivity. The photo-vibrational signal of chemicals and explosives on different substrates are detected. The results show the potential of the proposed technique on detection of trace chemicals and explosives at long standoff distance.

10183-20, Session 2

Detecting unknown chemical clouds at distance with multispectral imagery

Romain Verollet, Aymeric Alazarine, Sylvain Favier, Manon Verneau, Bruno Vallayer, Bertin Technologies (France); Sébastien Blanchard, Bertin Corp. (United States)

Objective: Observing the gas absorption in infrared band III (LWIR 7.7-12?m), our multispectral infrared camera detects gas clouds up to a range of several kilometers, provides identification of gas type and follows the motion of the cloud in real time. Standoff gas detection with infrared devices traditionally relies on the comparison between measured signal with a library of signals included in a database, built following laboratory calibration. Past chemical warfare agents attacks often describe the use of mixture of chemicals or unpure-uncomplete formulation. Groups may also generate new chemical toxic agents. Those situations may generate an unknown signal and thus being undetectable by traditional method. Also, the user is asked to pre-select a short list of gases in the database which increase the risk to miss the detection of gas in real situation.

Approach: As early warning system, the detection of those unpredictable situations is the main target for chemical standoff detection. To detect unknown gases or mixture of gases with new infrared signals, our latest approach is a to develop a pattern-matching-free algorithm. The measurement principle uses the scene background as an infra-red source, and image processing algorithms highlight the presence of a gas cloud on the targeted line. The detection of gas is carried out by a three differential infra-red imaging process: spatial, spectral, and temporal fields. The approach is to develop a pattern-matching-free algorithm that enables the device to detect gas even if the measured signature is not in the database.

Results: The detection process has been evaluated in laboratory and subjected to significant experimental feedbacks. Depending on the nature of gas, distance of the gas leak, the detectable size of the gas leak ranges from few gram per second to few hundred grams per second, in match with the toxicity of the chemical compounds.

Conclusion: The results are a capability to detect new gas and gas mixtures. The algorithm is also recording the new infrared signal for updating the database of the device directly in the field or on a simulator.

10183-11, Session 3

Charge transfer in plasmonic nanoantennas: Reactivity control on the nanoscale and chemical enhancement of explosives detection

Stefan A. Maier, Emiliano Cortés, Imperial College London (United Kingdom)

Plasmonic nanoantennas have revolutionised our ability to control light on the nanoscale, via the controlled formation of electromagnetic hot spots. This has been exploited to great success in surface-enhanced spectroscopies, particularly Raman and fluorescence. Here, we want to extend the notion of a plasmonic hot spot to the realms of chemical reactivity.

When localised surface plasmons decay into electron/hole pairs, a non-equilibrium, hot-carrier distribution ensues. For the generic system of bow tie antennas, we present a methodology how to map hot spots of chemical reactivity for hot-electron emission with a spatial resolution of 15 nm, based on a six-electron reduction reaction occurring in a molecular overlayer. We provide conclusive evidence for the possibility of control of the nanoscale chemical reactivity profile of plasmonic nanoantennas.

In the second part of the talk, we present first evidence of optical control of the chemical component of Raman enhancement, via a charge-transfer reaction in a semiconductor/metal hybrid SERS substrate. We demonstrate a UV-induced increase of chemical enhancement in this system for the detection of explosives such as RDX, DNT and TNT, down to 10-8 M concentrations.

10183-12, Session 3

Performance comparison of single and dual-excitation-wavelength resonance-Raman explosives detectors

Balakishore Yellampalle, Robert B. Martin, Kenneth Witt, William McCormick, Hai-Shan Wu, Mikhail Sluch, Robert V. Ice, Brian E. Lemoff, West Virginia High Technology Consortium Foundation (United States)

Deep-ultraviolet Raman spectroscopy is a very useful approach for standoff detection of explosive traces. Using two simultaneous excitation wavelengths improves both the detection specificity and sensitivity. The High Technology Foundation developed a highly compact prototype of a resonance Raman explosives detector. The compact system was enabled by portable deep ultraviolet sources at 236.5 nm and 257.5 nm with powers of approximately 2 milliwatts each, and a highly compact dual band Raman spectrometer covering 242 nm to 272 nm range with a resolution of 30 cm-1. Solid, bulk explosives were identified or detected from distances varying from 1 m up to 15.3 m. Receiver operating characteristics were calculated from large number of measurements to assess the utility of the dual-excitation-wavelength technique. Ammonium perchlorate was detected with a probability of detection greater than 90%, and a false acceptance rate of less than 0.2% at a signal-to-noise (SNR) ratio of 1.6 using the dual-excitation detector. To achieve a similar performance using a single-excitation-wavelength detector, consisting of 30 cm-1 resolution spectrometer, an SNR of approximately 10 was needed in the experiments. We present trade space analysis comparing three Raman systems with similar size, weight, and power. The analysis considered the cost, spectral resolution, detection/identification time and the overall system benefit. The dual-excitation-wavelength detector exhibited an improvement of approximately six compared to a 10 cm-1 resolution single-excitation-wavelength detector for the identification of optically thick samples. For detection of optically thin samples, the improvement was close to two.

10183-13, Session 3

Rapid stand-off Raman detection of concealed ammonium nitrate

Jonathan A. Mills, Carlton W. Farley III, Aschalew Kassu, Paul B. Ruffin, Anup Sharma, Alabama A&M Univ. (United States)

The rapid remote detection of concealed explosive compounds is of great interest to the military and law enforcement. Fertilizers rich in nitrates, such as ammonium nitrate, can be weaponized into concealed explosive devices that are difficult to detect without direct contact. Stand-off Raman spectroscopy provides a real-time method to detect ammonium nitrate's unique spectral signature without requiring direct contact with the substance. In this paper we report the use of portable stand-off Raman spectroscopy to identify ammonium nitrate that has been concealed through cotton fabric at 5 meter distances using 10 second integration times. A portable Raman spectrometer with a 785nm laser operating at 400mW is utilized with a 2-inch refracting telescope to take 10 second measurements. The ammonium nitrate is concealed with 100% cotton fabrics of various colors at a distance of 5 meters, and the fabrics tested both dry and wet. The resultant spectral data demonstrates the ability to detect a target with concealed ammonium nitrate, with the wet fabric yielding better results.

10183-14, Session 3

Physical and environmental factors affecting the persistence of explosives particles

Michael R. Papantonakis, Viet K. Nguyen, Robert Furstenberg, U.S. Naval Research Lab. (United States); Caitlyn White, ORISE DHS Student Intern (United States); Melissa Shuey, ASEE SEAP Student Intern (United States); Christopher A. Kendziora, R. Andrew McGill, U.S. Naval Research Lab. (United States)

Knowledge of the persistence of trace explosives materials is critical to aid the security community in designing detection methods and equipment. The physical and environmental factors affecting the lifetimes of particles include temperature, airflow, interparticle distance, adlayers, humidity, particle field size and vapor pressure. We are working towards a complete particle persistence model that captures the relative importance of these effects to allow the user, with known environmental conditions, to predict particle lifetimes for explosives or other chemicals. In this work, particles of explosives are sieved onto smooth glass substrates using particle sizes and loadings relevant to those deposited by fingerprint deposition. The coupon is introduced into a custom flow cell and monitored under controlled airflow, humidity and temperature. Photomicroscopy images of the sample taken at fixed time intervals are analyzed to monitor particle sublimation and characterized as a size-independent radial sublimation velocity for each particle in the ensemble. In this paper we build on previous work by comparing the relationship between sublimation of different materials and their vapor pressures. We also describe the influence of a sebum adlayer on particle sublimation, allowing us to better model 'real world' samples.

10183-15, Session 3

Plastic fiber optic biosensor for Brazilian plant toxin

Romulo Santiago de Lima Garcia, Brazilian Army Technological Ctr. (Brazil)

A biosensor for direct analysis of toxin from a poisonous brazilian plant by use of a plastic optical fiber functionalized with sensitive enzyme is disclosed. Molecular recognizing enzymes are immobilized onto the surface of plastic optical fibers and undergo signals when the toxin is introduced into the local environment of the sensor. Recognizing events are detected by the use of a photodetector with another optoelectronic components. This analytical device finds uses in detection and screening of novel toxins from plants when they are deployed at field. Possible applications include ambiental monitoration, individual exposure sensor and pharmacological studies of antidote or decontamination effectiveness (e.g. dose-response).

10183-16, Session 4

Single-particle detection of virus simulants under microfluidic flow with two-dimensional photonic crystals

Benjamin L. Miller, James E. Baker, Rashmi Sriram, Univ. of Rochester Medical Ctr. (United States)

Because of their compatibility with standard CMOS fabrication, small footprint, and exceptional sensitivity, Two-Dimensional Photonic Crystals (2D PhCs) have been posited as attractive components for the development of real-time integrated photonic virus sensors. While detection of single virus-sized particles by 2D PhCs has been demonstrated, specific recognition of a virus simulant under conditions relevant to sensor use (including aqueous solution and microfluidic flow) has remained an unsolved challenge. This talk will describe the design and testing of a W1 waveguide-coupled 2D PhC in the context of addressing that challenge.

10183-17, Session 4

Thermal bioaerosol cloud tracking with Bayesian classification

Christian W. Smith, Julia R. Dupuis, Elizabeth C. Schundler, William J. Marinelli, Physical Sciences Inc. (United States)

The development of a wide area, bioaerosol early warning capability employing existing uncooled thermal imaging systems used for forward operating base perimeter surveillance will be discussed. The capability exploits other available data streams including meteorological data and employs a recursive Bayesian classifier to detect, track, and classify observed thermal objects with consistent attributes to a bioaerosol plume. Target detection is achieved based on similarity to a phenomenological model which predicts the scene-dependent thermal signature of bioaerosol plumes. Change detection in thermal sensor data is combined with local meteorological data to locate targets with the appropriate thermal characteristics. Target tracking utilizes a Kalman filter and nearly constant velocity motion model for cloud state estimation. Track management is performed using a logic-based upkeep system, and data association is accomplished using a combinatorial optimization technique. Bioaerosol threat classification is determined using a recursive Bayesian classifier to determine the threat probability of each tracked object. The classifier can accept additional inputs from visible imagers, acoustic sensors, and point

biological sensors to improve classification confidence. This capability was successfully demonstrated for bioaerosol simulant releases during government sponsored field tests. Standoff detection at a range of 1km was achieved for as little as 500g of anthrax simulant. Developmental test results will be reviewed for a range of simulant releases and future development and transition plans for the bioaerosol early warning platform will be discussed.

10183-18, Session 4

Performance characterization of scintillators using a method of enhanced layered wavelength shifting coatings

Amanda C. Madden, Shawn Tornga, Daniel Wakeford, Jillian Adams, Olivia Trautschold, Markus P. Hehlen, Los Alamos National Lab. (United States)

Many application areas, including space-based and compact fieldable devices, use scintillator systems that require high quantum efficiency and small size, weight, and power consumption (SWAP). Advancements in semiconductor readout devices, such as silicon Avalanche Photodiodes (APD) provide a low SWAP alternative to conventional photomultiplier tubes (PMTs) and provide larger quantum efficiency over a broader spectral range. Direct replacement of PMTs by APDs can degrade system performance because the optimal detection sensitivity of APDs (~700 nm) is poorly matched to the emission of most scintillators (~300-500 nm). Wavelength-shifters can mitigate this performance degradation, however there are many parameters that must be optimized.

We will describe our generalized method of applying layers of wavelength shifting dyes to scintillators coupled with state-of-the-art APD readout devices. We will present recent results using single dye layers (YSO:Ce), multiple dye layers (LiCaF:Ce), neutron sensitive scintillators (LiCaF:Ce), and hygroscopic scintillators (CsI:Na) to provide a robust proof of concept of this method for other high performance scintillators (e.g. LaBr3 and CLYC). Improvements in the measured light collection efficiency and energy resolution are supported by photoluminescence, radioluminescence, and absolute quantum efficiency measurements. Additional considerations such as the effect of the wavelength shifter on the decay time of the crystal, optimization studies of dye thickness

10183-19, Session 4

Development of a large area microstructure photomultiplier assembly (LAMPA)

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

Large area (> m2) position-sensitive readout of scintillators is important for passive/active gamma and neutron imaging for counter-terrorism applications. The goal of the LAMPA project is to provide a novel, affordable, large-area photodetector (8" x 8") by replacing the conventional dynodes of photomultiplier tubes (PMTs) with electron multiplier microstructure boards (MSBs) that could be produced using industrial manufacturing techniques. The square, planar format of the LAMPA assemblies enables tiling of multiple units to support large area applications. The LAMPA performance objectives include comparable gain, noise, timing, and energy resolution relative to conventional PMTs, as well as spatial resolution in the few mm range.

The current LAMPA prototype is a stack of 8" x 8" MSBs made commercially by chemical etching of a molybdenum substrate and coated with boron-doped diamond for high secondary emission yield (SEY). The layers of MSBs are electrically isolated using ceramic standoffs. Field-shaping grids are located between adjacent boards to achieve good transmission of electrons from one board to the next. The spacing between layers and the design of the microstructure pattern and grids were guided by simulations performed using electro-optics code. A position-sensitive anode board at the back of the stack of MSBs provides 2-D readout.

This presentation will discuss the trade studies performed in the design of the MSBs, the measurements of SEY from various electro-emissive materials, the electro-optics simulations conducted, the design of the 2-D readout, and the mechanical aspects of the LAMPA design, in order to achieve a gain of > 104 in an 8-stage stack of MSBs, suitable for use with various scintillators when coupled to an appropriate photocathode.

Conference 10184: Sensors, and Command, Control, Communications, and Intelligence (C3I) Technologies for Homeland Security, Defense, and Law Enforcement Applications XVI

Monday - Tuesday 10–11 April 2017

Part of Proceedings of SPIE Vol. 10184 Sensors, and Command, Control, Communications, and Intelligence (C3I) Technologies for Homeland Security, Defense, and Law Enforcement Applications XVI

10184-1, Session 1

Updates on NLW technologies for defense and security missions *(Invited Paper)*

David B. Law, Joint Non-Lethal Weapons Directorate (United States)

No Abstract Available

10184-2, Session 1

Ranged eye-safe laser induced flashbang enabling system (RESLIFE)

Ninad P. Patnekar, Physical Optics Corp. (United States)

No Abstract Available

10184-3, Session 1

Updates to radiabeam high-power and gain s-band and w-band steerable antennas

Alexei Smirnov, RadiaBeam Technologies, LLC (United States)

No Abstract Available

10184-4, Session 1

An integrated human test surrogate to assess injury risk and measure non-lethal exposure

Keith Sedberry, CFD Research Corp. (United States)

No Abstract Available

10184-5, Session 1

SSADT autonomous module with enhanced electronic steering program

Ken Brown, Raytheon Co. (United States)

No Abstract Available

10184-6, Session 1

Toyon Research Corporation's compact lightweight modular prime power for directed energy systems

Eric Sandoz, Toyon Research Corp. (United States)

No Abstract Available

10184-7, Session 2

Counter unmanned aerial system testing and evaluation methodology

Camron G. Kouhestani, Gabriel C. Birch, Bryana L. Woo, Sandia National Labs. (United States)

Unmanned aerial systems (UAS) are increasing in flight times, ease of use, and payload sizes. Detection, classification, tracking, and neutralization of UAS is a necessary capability for infrastructure and facility protection. We discuss the Sandia National Laboratories (SNL) test and evaluation methodology to establish a consistent, defendable, and unbiased means for evaluating counter unmanned aerial systems (CUAS) technologies. The test approach described identifies test strategies, performance metrics, UAS types tested, key variables, and the necessary data analysis to accurately quantify the capabilities of CUAS technologies. The tests being conducted, as defined by this approach, will allow SNL to determine the quantifiable limitations, strengths, and weaknesses in terms of detection, tracking, classification, and neutralization. Communicating the results of this testing in a manner that informs decisions by government sponsors and stakeholders is intended to guide future investments and inform procurement, deployment, and advancement of such systems into their specific venues.

10184-8, Session 2

Maximizing PPV in C3I systems

Tomasz P. Jannson, Wenjian Wang, Andrew A. Kostrzewski, Physical Optics Corp. (United States); Pedram Boghrat, Physical Optics Corp (United States)

In this paper, discussion of PPV (Positive Predictive Value) is presented in the context of C3I systems. PPV is inverse conditional probability in a Bayesian system, namely, probability of correct alarm. This paper summarizes results of nine (9) previous papers about so-called binary sensors. Binary sensor is a binary decision system which has only two alarms: true and false, and binary target: target or no-target (noise). With such a simple system, it is possible to develop quite a comprehensive conglomerate, which is a decision system itself. In this paper, a large number of statistically independent binary sensors is discussed and PPV maximization procedure is analyzed.

Typically, PPV-value for single-sensor is low, i.e. 20%, i.e.80% is the chance that the alarm is false. However, when the number of sensors grows, the situation can change, especially for these sensors which are similar statistically, leading to quite large PPV-numbers, for so-called joint PPV, or JPPV. It should be emphasized that the binary sensors can be physical such as IR, or non-physical (cyber).

Very important is the fact that this decision process can be mathematically

formulated, so, we can give exact numbers of PPV in various stages. For example, we can obtain k-number of binary sensors in order to obtain JPPV = 99.99%, or other number. Keep in mind that such numbers as JPPV = 99.99%, means almost certainty, which is decisive factor in automatic decision process. Those considerations can be very important in C3I systems "decision process."

10184-9, Session 2

Emergency positioning system accuracy with visible and infrared LEDs in high-security facilities

Sierra Knoch, Charles Nelson, Owens Walker, U.S. Naval Academy (United States)

Instantaneous personnel location presents a challenge in Department of Defense applications where high levels of security restrict real-time tracking of crew members. During emergency situations, command and control requires immediate accountability of all personnel. Current radio frequency (RF) based indoor positioning systems can be unsuitable due to security vulnerabilities associated with RF leakage and electromagnetic interference with sensitively calibrated machinery on various platforms such as ships, submarines and high-security facilities. Infrared and visible light provide a potential solution to this problem. This paper proposes and evaluates an indoor line-of-sight positioning system that is comprised of IR and visible light transmitters and high-sensitivity CMOS camera receivers. In this system the movement of the LEDs is captured by the camera, uploaded and analyzed; the highest point of power is located and plotted to create a blueprint with beacons designating crew members' locations. Results provided evaluate accuracy of the LED transmitter and CMOS camera receiver system as a function of both wavelength and environmental conditions as well as target movement profiles. Transmissions in both the 780 and 850nm IR bands as well as the visible light spectrum are investigated and analyzed.

10184-10, Session 2

A random walk approach for robustness analysis of control systems

Xinjia Chen, Northwestern State Univ. (United States)

A persistent concern of control engineer is whether a controller designed based on a nominal model will perform satisfactorily in an uncertain environments. This issue has been addressed in the worst-case deterministic framework. However, the existing methods in this framework suffer from the drawback of very high computational complexity. In this paper, we propose to treat uncertainties as random variables and formulate such issue of control systems as a problem of parameter estimation in the context of random walk. We develop a theory of stopped random walk which demonstrates the credibility and computational efficiency of the proposed approach for resolving such issue of control systems.

10184-11, Session 3

The development of modern small arms

Slobodan Rajic, Panos G. Datskos, Oak Ridge National Lab. (United States)

No Abstract Available

10184-12, Session 3

Employing wavelet-based texture features in ammunition classification

Angelo M.C. R. Borzino, Instituto Militar de Engenharia (Brazil); Robert C. Maher, Montana State Univ. (United States); José A. Apolinário Jr., Instituto Militar de Engenharia (Brazil); Marcello L. R. de Campos, Univ. Federal do Rio de Janeiro (Brazil)

Ammunition classification - its type or caliber - from a gunshot audio signal can be a deciding factor in a criminal investigation. Knowing automatically which armament a shooter uses may give knowledge of its identity, help a forensic analyst solve a crime, aid to find a weapon stolen from a government agency, or alert an operative for a change of threats during real action in a combat field or in a routine police operation. It is assumed known that well-trained humans are able to recognize the weapon type when listening to a firing. Nevertheless, in order not to depend on this ability of a few skilled and trained people, we may use a machine learning approach to ammunition classification. This paper uses pattern recognition to identify which kind of ammunition was used when a bullet was fired based on a carefully constructed set of gunshot sound recordings. To do this task, we show that texture features obtained from the wavelet transform of a component of the gunshot signal, treated as an image, and quantized in gray levels, are good ammunition discriminators. We test the technique with eight different calibers and achieve a classification rate better than 95%. We also compare the performance of the proposed method with results obtained by standard temporal and spectrographic techniques.

10184-13, Session 3

AFRL Commander's Challenge 2015: stopping the active shooter

John P. McIntire, Jonathon Boston, Brandon Smith, Pete Swartz, Amy Whitney-Rawls, Julian Martinez Calderon, Jon Magin, Air Force Research Lab. (United States)

In this work, we describe a rapid-innovation challenge to combat and deal with the problem of internal, insider physical threats (e.g., active shooters) and associated first-responder situation awareness on military installations. Our team's research and development effort described within focused on several key tech development areas: (1) indoor acoustical gunshot detection, (2) indoor spatial tracking of first responders, (3) bystander safety and protection, (4) two-way mass alerting capability, and (5) spatial information displays for command & control. The technological solutions were specifically designed to be innovative, low-cost, and (relatively) easy-to-implement, and to provide support across the spectrum of possible users including potential victims/bystanders, first responders, dispatch, and incident command.

10184-14, Session 3

Airborne DoA estimation of gunshot acoustic signals using drones with application to sniper localization systems

Rigel Fernandes, Instituto Militar de Engenharia (Brazil); António L. L. Ramos, Univ. College of Southeast Norway (Norway); José A. Apolinário Jr., Instituto Militar de Engenharia (Brazil)

Shooter localization systems have been subject of a growing attention lately owing to its wide span of possible applications, e.g., civil protection, law enforcement, and support to soldiers in missions where snipers might

pose a serious threat. These devices are based on the processing of electromagnetic or acoustic signatures associated with the firing of a gun. This work is concerned with the latter, where the shooter's position can be obtained based on the estimation of the direction-of-arrival (DoA) of the muzzle blast. A major limitation of current commercially available acoustic sniper localization systems is the impossibility of finding the position of the shooter when one of these acoustic signatures is not detected. This is very likely to occur in real-life situations, especially when the microphones are not in the field of view of the shockwave or in urban environments where the presence of obstacles like buildings can prevent a direct-path to sensors for one or both signals. This work addresses the problem of DoA estimation of the muzzle blast using a planar array of sensors deployed in a drone. The solution copes with the well-known ambiguity of a planar array given the low-rank matrix from coplanar sensors. Results supported by actual gunshot data from a realistic setup are very promising and pave the way for the development of enhanced sniper localization systems featuring two main advantages over stationary ones: (1) wider surveillance area; and (2) increased likelihood of a direct-path detection of at least one of the gunshot signals, thereby adding robustness and reliability to the system.

10184-16, Session 4

Sketches for solving graph centrality problems

Benjamin Priest, George Cybenko, Thayer School of Engineering at Dartmouth (United States)

New algorithms for computing various graph properties from streaming data will be presented. The algorithms are space bounded and time efficient.

10184-17, Session 4

Operational cyber vulnerability analysis and management

Katheryn Farris, John Sullivan, George Cybenko, Thayer School of Engineering at Dartmouth (United States)

This paper will present novel techniques for analyzing cyber vulnerability scan data with a focus on temporal and semantic trend analysis.

10184-18, Session 4

High-speed streaming algorithms for learning behaviors

George Cybenko, Thayer School of Engineering at Dartmouth (United States)

This paper describes novel algorithms for learning behaviors from streaming data at scale.

10184-19, Session 5

Automated and anticipatory high-performance computations at the in situ sensors: technical challenges *(Invited Paper)*

Guna Seetharaman, U.S. Naval Research Lab. (United States)

No Abstract Available

10184-20, Session 5

Novel procedure for characterizing nonlinear systems with memory

Tariq Manzur, Naval Undersea Warfare Ctr. (United States)

No Abstract Available

10184-21, Session 5

Transparent spinel windows and domes for imaging applications

Jasbinder S. Sanghera, Shyam Bayya, Woohong Kim, Guillermo Villalobos, Michael Hunt, Jonathan M. Nichols, U.S. Naval Research Lab. (United States)

No Abstract Available

10184-22, Session 5

Hybrid on-chip microwave photonic signal processor architecture

Yifei Li, Univ. of Massachusetts Dartmouth (United States)

No Abstract Available

10184-23, Session 5

MWIR uncooled SiC detector with optical signal output

Geunsik Lim, CREOL, The College of Optics and Photonics, Univ. of Central Florida (United States)

No Abstract Available

10184-24, Session 5

Atmospheric transitional and turbulent boundary layer effects near the ocean

Tariq Manzur, Naval Undersea Warfare Ctr. (United States)

No Abstract Available

10184-41, Session 5

Nondestructive evaluation enhanced accelerated life testing

Patric Lockhart, Thomas Ramotowski, Naval Undersea Warfare Ctr. Newport (United States); Adam Duszkiewicz, Jay Melillo, Naval Undersea Warfare Ctr. (United States)

Accelerated life tests, or ALTs, are used to study system or component failure mechanisms which occur on time scales that are longer than is acceptable to wait. ALTs use accelerating variables to speed up the time to failure allowing faster study of failure mechanisms. Terahertz (THz) imaging is an imaging technology capable of nondestructively generating millimeter-resolution images of objects or defects inside and through non-metallic materials and coatings. This study explores the potential

to use a Nondestructive Evaluation (NDE) technique to enhance an ALT through reduced costs, space, testing time, prescreening for defective samples, verifying the expected failure mode occurs, improved failure mode understanding, and allowing evaluation of multiple concurrent failure modes. During the test in this study, samples were imaged throughout the span of an ALT using THz imaging for in-situ study of the failure mode as it occurred. The THz imaging results showed that the actual ALT failure mode was different than the expected delamination failure mode (confirmed with pull tests), and the THz images also revealed additional insight into the failure process by recording an unexpected phenomenon that occurred during the ALT. As this unexpected phenomenon formed and resolved before failure occurred, it could easily have been missed during standard ALTs.

10184-25, Session 6

Estimating distance to an object on the horizon using wave motion

Anthony Spears, Darsan Patel, Steven Bishop, Walter Hunt, Prioria Robotics, Inc. (United States)

No Abstract Available

10184-26, Session 6

Advanced wireless mobile collaborative sensing network for tactical and strategic missions

Hao Xu, Univ. of Nevada, Reno (United States)

In most military tactical and strategic missions, (1) How to effectively sense and collect real-time data in uncertain environment and (2) How to quickly and efficiently transmit the collected data back to remote command station are two major challenges that have been investigated for a long while and still not completely solved. In this paper, an advanced wireless mobile collaborative sensing network will be developed. Through properly combining wireless sensor network, emerging mobile robots (e.g. unmanned aircraft systems (UAV), unmanned ground vehicles (UGV), etc.) and multi-antenna sensing/communication techniques, we could demonstrate superiority of developed sensing network. In the proposed advanced wireless mobile cooperative sensing platform, heterogeneous mobile robots including UAV and UGV are equipped with multi-model sensors (e.g. infrared cameras, passive emitter sensors) and wireless transceiver antennas. Through real-time collaborative formation control, multiple mobile robots can team the best formation that can provide most accurate sensing results. Also, formatting multiple mobile robots can also construct a multiple-input multiple-output (MIMO) communication system that can provide a reliable and high performance communication network. Eventually, two specific military missions will be considered to validate the proposed system, i.e. (1) IED detection and localization, and (2) Target objects (e.g. tank, military trucks) detection and location.

10184-27, Session 6

Real-time implementations of acoustic signal enhancement techniques for aerial based surveillance and rescue applications

António L. L. Ramos, Aleksander Holthe, Mathias F. Sandli, Univ. College of Southeast Norway (Norway)

The introduction of the System-on-Chip (SoC) technology has brought exciting new opportunities for the development of smart low cost embedded systems spanning a wide range of applications. Currently available SoC devices are capable of performing high speed digital signal processing tasks in software while featuring relatively low development costs and reduced time-to-market. Unmanned aerial vehicles (UAV) are an application example that has shown tremendous potential in an increasing number of scenarios, ranging from leisure to surveillance as well as in search and rescue missions. Video capturing from UAV platforms is a relatively straightforward task that requires almost no preprocessing. However, that does not apply to audio signals, especially in cases where the data is to be used to support real-time decision making. In fact, the enormous amount of acoustic interference from the surroundings, including the noise from the UAV's propellers, becomes a huge problem.

This paper discusses a real-time implementation of the NLMS adaptive filtering algorithm applied to enhancing acoustic signals captured from UAV platforms. The model relies on a combination of acoustic sensors and a computational inexpensive algorithm running on a digital signal processor. Given its simplicity, this solution can be incorporated into the main processing system of an UAV using the SoC technology, and run concurrently with other required tasks, such as flight control and communications. Simulations and real-time DSP-based implementations have shown significant signal enhancement results by efficiently mitigating the interference from the noise generated by the UAV's propellers as well as from other external noise sources.

10184-28, Session 6

Anti-icing coatings for UAV's

Georgios Polizos, Panos G. Datskos, Oak Ridge National Lab. (United States)

No Abstract Available

10184-29, Session 7

Finite element method framework for RF-based through-the-wall mapping

Rafael Campos, CEFET/RJ (Brazil); Lisandro Lovisolo, Univ. do Estado do Rio de Janeiro (Brazil); Marcello L. R. Campos, Univ. Federal do Rio de Janeiro (Brazil)

Radiofrequency (RF) Through-the-Wall Mapping (TWM) employs techniques originally applied in X-Ray Computerized Tomographic Imaging to map obstacles behind walls. It provides valuable information for rescuing efforts in damaged buildings, as well as for military operations in urban scenarios. This work defines a Finite Element Method (FEM) based framework to allow fast and accurate simulations of the reconstruction of floor blueprints, using Ultra High-Frequency (UHF) signals at three different frequencies (500 MHz, 1 GHz and 2 GHz). This framework allows quick evaluation of different algorithms – already in use or yet to be proposed – without the need to assemble a full test setup, which might not be available due to budgetary and/or time constraints. This work evaluates a collection of reconstruction methods (Filtered Backprojection Reconstruction, Direct Fourier Reconstruction, Algebraic Reconstruction and Simultaneous Iterative Reconstruction) under a parallel-beam acquisition geometry for different spatial sampling rates, number of projections, antenna gains and operational frequencies. The use of multiple frequencies assesses the trade-off between higher resolution at shorter wavelengths and lower through-the-wall penetration. Considering all the drawbacks associated to such a complex problem, a robust and reliable computational setup based on a flexible method such as FEM can be very useful. To the best of our knowledge, this is the first use of FEM in a TWM scenario.

10184-30, Session 7

Demonstration of a broadband anti-UAV RF front-end based on GaN HEMT technology

Erdin Ture, Markus Musser, Axel Hülsmann, Rüdiger Quay, Oliver Ambacher, Fraunhofer-Institut für Angewandte Festkörperphysik (Germany)

The alarmingly-increasing number of unmanned aerial vehicles (UAV) in recent years has raised concerns regarding the security of the lower airspace where challenges are faced in deterring the so-called drones before potentially possessing a threat to the urban environment. Thereupon, the effectiveness of the developed jammer front-end on blocking the communication link of a commercial drone vehicle has been demonstrated in this work. Correspondingly, a brute-force jamming approach has been taken in a broadband fashion by using GaN HEMT technology. Equipped with a modulated-signal generator, a broadband power amplifier, and an omni-directional antenna, the proposed system is capable of producing jamming signals in a very wide frequency range between 0.1 – 3 GHz. The maximum RF output power of the amplifier module has been software-limited to 27 dBm (500 mW) due to the spectral regulations within the 2.4 GHz ISM band. A baseband white noise signal modulated by a Sinc function with a bandwidth of 100 MHz has been deployed to be able to counter the frequency hopping spread spectrum (FHSS) principle used by radio-controlled UAVs which allows dynamically alternating the transmission frequency within 2.4 – 2.485 GHz. In order to test the proof of concept, a real-world scenario has been prepared in which a commercially-available quadcopter UAV is flown in a controlled environment while the jammer system has been placed in a distance of about 10 m from the drone. It has been proven that the drone of interest can instantly be neutralized as soon as it falls within the range of coverage (~3 m) which endorses the promising potential of the broadband jamming approach.

10184-31, Session 7

EO and IR reconnaissance and surveillance system

Qingzeng Xue, Weiwei Zhu, China North Vehicle Research Institute (China)

Some panorama system use 6 or 8 staring CCDs, which increases the cost of the system. And the multi-CCD system can not see far such as 3 km away,and need very high stabilization.With the development of the linear scan array,their resolution and sensitivity are improved. The linear scan arrays have advantages in some ways,such as remote sensing system,multi-spectral imaging system. An EO linear scan arrays is used in search and tracking system. The array is fitted together into a gyro-stabilization rotating platform.The platform rotates in 1 Hz. Optical lens and platform are designed according to integration time of the linear array and the revisit time. Some Target detection methods based on the scan image are discussed. And display modes of such high resolution image are analyzed.

10184-32, Session 7

Silicon-based optically read MEMS gyroscope

Panos G. Datskos, Nickolay V. Lavrik, Oak Ridge National Lab. (United States)

No Abstract Available

10184-33, Session 7

Sonic anemometers in battlefield applications

Tomas R. Bober, David M. Rophael, U.S. Army Armament Research, Development and Engineering Ctr. (United States)

No Abstract Available

10184-34, Session 8

Temperature sensing in defense applications

Jonathan A. Jablonski, Melissa N. Jablonski, U.S. Army Armament Research, Development and Engineering Ctr. (United States)

No Abstract Available

10184-35, Session 8

Explosive detection technology

Steven C. Doremus, Robin M. Crownover, U.S. Army Armament Research, Development and Engineering Ctr. (United States)

No Abstract Available

10184-36, Session 8

Modeling of turbulence in the marine boundary layer for optimizing optical beam propagation

Jeffrey Davis, College of Optical Sciences, The Univ. of Arizona (United States); Tariq Manzur, Richard Katz, Naval Undersea Warfare Ctr. (United States); Joshua L. Olson, Arturo Chavez-Pirson, Nasser N. Peyghambarian, College of Optical Sciences, The Univ. of Arizona (United States)

No Abstract Available

10184-37, Session 8

Capturing a Commander's decision making style

Jacob A. Russell, Thayer School of Engg at Dartmouth (United States); Eugene S. Santos Jr., Dartmouth College (United States); Hien Nguyen, Univ. of Wisconsin-Whitewater (United States); Keumjoo Kim, Thayer School of Engg at Dartmouth (United States); Ramnjit S. Boparai, Luke Veenhuis, Thomas K. Stautland, Bryan Brandt, Univ. of Wisconsin-Whitewater (United States)

A Commander's decision making style represents how he weighs his choices and evaluates possible solutions with regards to his goals. Specifically, in the naval warfare domain, it relates the way he processes a large amount of information in dynamic, uncertain environments, allocates resources,

and chooses appropriate actions to pursue. In this paper, we describe an approach to capture a Commander's decision style by creating a cognitive model that captures his decision making process and evaluate this model using a set of scenarios using an online naval warfare simulation game. In this model, we use the Commander's past behaviors and generalize Commander's actions across multiple problems and multiple decision making sequences in order to recommend actions to a Commander in a manner that he may have taken. Our approach builds upon the Double Transition Model to represent the Commander's focus and beliefs to estimate his cognitive state. Each cognitive state reflects a stage in a Commander's decision making process, each action reflects the tasks that he has taken to move himself closer to a final decision, and the reward reflects how close he is to achieving his goal. We then use inverse reinforcement learning to compute a reward for each of the Commander's actions. These rewards and cognitive states are used to compare between different styles of decision making. We construct a set of scenarios in the game where analytical, directive and emotional decision making styles will be evaluated.

10184-38, Session PSTue

A calibration method of non-orthogonal redundant ring laser gyro inertial navigation system

Chunfeng Gao, Qi Wang, Guo Wei, Zhihui Ying, Xing W. Long, National Univ. of Defense Technology (China)

As a highly reliable positioning and orientation equipment, the redundant inertial navigation system (INS) is widely used in aerospace and other fields. For INS, high-precision calibration is the basis of high-precision navigation. Different from the calibration error modeling methodof traditional orthogonal system, the non-orthogonal redundant ring laser gyro INS is installed with multi-device obliquely, and with the complexity of the configuration, the difficulty of separating the calibration parameters is also increased. Therefore, it is very significant to find a high precision calibration scheme for the non-orthogonal redundant INS. In this paper, the high precision calibration of non-orthogonal redundant INS in laboratory is studied, and a new calibration model of redundant system is summarized. A regular tetrahedral configurationprototype consisting of four Ring Laser Gyro and four Quartz Accelerometer is designed, and the calibration error modeling method and calibration accuracy are verified.

10184-39, Session PSTue

High-Accuracy self-calibration method for dual-axis rotation-modulating RLG-INS

Guo Wei, Chunfeng Gao, Qi Wang, Xingwu Long, National Univ. of Defense Technology (China)

Inertial navigation system has been the core component of both military and civil navigation systems. Dual-axis rotation modulation can completely eliminate the inertial elements constant errors of the three axes to improve the system accuracy. But the error caused by the misalignment angles and the scale factor error cannot be eliminated through dual-axis rotation modulation. And discrete calibration method cannot fulfill requirements of high-accurate calibration of the mechanically dithered ring laser gyroscope navigation system with shock absorbers. This paper has analyzed the effect of calibration error during one modulated period and presented a new systematic self-calibration method for dual-axis rotation-modulating RLG-INS. Procedure for self-calibration of dual-axis rotation-modulating RLG-INS has been designed. The results of self-calibration simulation experiment proved that: this scheme can estimate all the errors in the calibration error model, the calibration precision of the inertial sensors scale factor error is less than 1ppm and the misalignment is less than 5?. These results have validated the systematic self-calibration method and proved its importance for accuracy improvement of dual -axis rotation inertial navigation system with mechanically dithered ring laser gyroscope.

10184-40, Session PSTue

Online calibration technique for LDV in SINS/LDV integrated navigation systems

Qi Wang, Chunfeng Gao, Guo Wei, Xingwu Long, National Univ. of Defense Technology (China)

There are the scale factor error of LDV (laser Doppler velocimeter) and the misalignment between the SINS (Strapdown inertial navigation system) and the vehicle in a SINS/LDV integrated navigation system. In this paper, the effects of these errors on the attitude, velocity and position of dead reckoning are derived, and a new online calibration method aiming to calibrate the scale factor of LDV and the misalignment between the SINS and the vehicle for the integrated system is put forward. This method, which is utilize the velocity and position of DGPS as references, use the velocity error and position error of dead reckoning to estimate these errors. Through simulation and experiment, the validity and feasibility of the method are verified. The results show that the scale factor and the misalignment can be calibrated with satisfying accuracy, and the related research can provide technical support for high precision navigation of SINS/LDV integrated navigation systems.

10185-1, Session 1

Modeling approaches for intrusion detection and prevention system return on investment

Nandi O. Leslie, U.S. Army Research Lab. (United States) and Raytheon Co. (United States); Lisa M. Marvel, U.S. Army Research Lab. (United States); Joshua Edwards, Kyra Comroe, Gregory Shearer, Lawrence Knachel, U.S. Army Research Lab. (United States) and ICF International (United States)

Making decisions about intrusion detection and/or prevention system (IDPS) enhancements depend largely on system effectiveness, efficiency, and ease of use. However, in many cases, the tools in an IDPS with a modular tool framework are based on signature, behavior or anomaly-based, or hybrid detection algorithms, where the ground truth (on whether input data is malicious) is unknown, computational resources are limited, and malicious behavior is difficult to discern. We develop three IDPS performance modeling approaches that are motivated by the return on investment (ROI) metric from the investment industry and combined with simple IDPS metrics: 1) a practical, static ROI approach that at the system level, is a weighted average over each tool's contributions to statistical accuracy and efficiency of the system; 2) a theoretical modeling approach that leverages deterministic difference equations, where IDPS future performance is completely determined by its previous values; and 3) a theoretical modeling approach that is based on stochastic difference equations which, along with capturing temporal dynamics as in (2), this modeling approach also introduces uncertainty into the predictions for IDPS performance. Our practical and theoretical IDPS ROI modeling approaches are non-financial, and these approaches are designed to compare the relative performance of IDPSs over extended time periods and multiple IDPS configurations. In addition, we provide three novel IDPS ROI modeling approaches for measuring and predicting IDPS performance which combine statistical accuracy metrics (e.g., precision, recall) and computational resource costs into a single model and facilitate decision making on IDPS configurations based on these trade-offs.

10185-2, Session 1

Computer security and the OS friendly microprocessor architecture

Patrick Jungwirth, U.S. Army Research Lab. (United States)

We examine how the hardware level security features in the OS Friendly Microprocessor Architecture improves cybersecurity against a rootkit attack. A rootkit (root + kit) is a malicious program or tool-"kit" of programs designed to obtain "root" level (root for Unix, admin level for Windows) privileges. Rootkits operate at the same security ring level as an operating system. This gives rootkits access to kernel level data structures and makes it very difficult to detect a rootkit even with state-of-the-art technologies. Rootkits have been used for digital rights management and copy protection; however, the 2005 CD copy protection scandal illustrates how poor computer security can leave an open door for other malware.

We present a security model of the OS Friendly Microprocessor Architecture and we present a short introduction to rootkits. For this paper, we will focus on OS-kernel level rootkits. We will illustrate how the hardware security features of the OS Friendly Microprocessor Architecture increases the difficulty for rootkit malware to compromise a computer system.

10185-3, Session 1

Machine learning for intrusion detection in mobile tactical networks

Ken F. Yu, U.S. Army Research Lab. (United States) and ICF International (United States); Kerry Wood, Richard E. Harang, U.S. Army Research Lab. (United States)

Previous work has demonstrated that machine learning-based network intrusion detection systems (IDS) can be constructed to provide a significant proportion of the accuracy of a conventional signature-based IDS while using a fraction of the resources. Such systems are ideally suited to mobile tactical networks, which typically require much denser sensor coverage to ensure complete network protection and have relatively limited size, weight, and power budgets within which to both protect and operate the network. In this study, we extend previous work on the Extremely Lightweight Intrusion Detection system (ELIDe) and examine its ability to both store a wide range of signatures and generalize to new data. We also demonstrate the following: (1) ELIDe weight vectors are capable of storing multiple signatures while not significantly affecting the false-positive rate; (2) such weight vectors can detect packets that match the signatures on which they were trained with a high degree of accuracy (low false-negative rate); and (3), in addition to approximating the output of a conventional set of signatures, ELIDe weight vectors can also weakly generalize to novel malicious traffic. We show that, despite the significant challenges mobile tactical networks pose for intrusion detection, the use of machine learning allows the deployment of approximate signature-based intrusion detection in such networks.

10185-4, Session 1

Using deep learning to detect network intrusions and malware in autonomous robots

Andrew Jones, North Dakota State Univ. (United States); Jeremy Straub, Univ. of North Dakota (United States)

Cybersecurity threats to autonomous robots present a particular danger, as a compromised robot can directly affect its surrounding environment in potentially catastrophic ways. This paper analyzes the use of deep learning to detect suspicious autonomous robotic activity. To this end, the behavior of the autonomous robot is analyzed and deviations from expected behavior are identified. Complementing this, completely abnormal behavior is also (separately) identified. Any deviation from expected behavior can be classified as suspicious. These behaviors are logged and a knowledge-based system combines the detected issue with analysis relevant to other signs of unexpected activity to determine if an attack or compromise has occurred.

Two deep neural networks that are trained using semi-supervised training are used to determine when/if deviations occur. The first deep neural network is trained to know the expected behavior. This training continues over time to refine detection of and adapt to minor changes in expected patterns of normal operations. A second deep neural network is trained to detect specific types of signatures of particular attacks and maloperation. Data from both neural networks will be provided to and assessed by the knowledge-based system.

Several implementation challenges exist for this system. One prospective issue is distinguishing intended objective changes from the machine's owner/operator from unwanted commands. Another issue is correctly recognizing when an otherwise normal behavior would be considered abnormal, given other conditions. This paper presents ongoing work on the development and testing of this system and concludes with a discussion of directions for future work.

10185-5, Session 1

Extraction and validation of algorithms based on analog side-channels

Ronald A. Riley, James T. Graham, Ryan M. Fuller, Rusty O. Baldwin, Ashwin Sampathkumar, Riverside Research (United States)

The Internet of Things (IoT) and Internet of Everything (IoE) drive the proliferation of processors into every powered device around us: from thermostats to refrigerators to light bulbs. IoT/IoE creates a new layer of signals and processors that can be exploited to gain access to supporting network layers. Our research focuses on leveraging the analog side-channels of processors commonly used in IoT/IoE devices. We collect the RF emissions near the processing elements of several different processors and apply machine-learning techniques to detect if software running on the processor has been modified (corrupted or injected with malware).

The paper describes our process for positioning a 1-GHz bandwidth RF probe over the device under test (DUT). Linear classifiers are implemented for identifying the code running on the device. We demonstrate the ability to detect, identify, and isolate individual instructions based on signatures learned during initial DUT characterization. The probe is positioned to capture RF signals that a support-vector machine (SVM) classifier can accurately discriminate between different instructions, rather than relying on raw power leakage. At this selected location, the signatures of each instruction are extracted by separating its signal into components (fetch, opcode, operands, and values) by applying principal component analysis (PCA). These signatures are used to identify instructions in the test code. Additionally, this paper discusses the potential of applying our methodology to entire blocks of code/algorithms using sequence learning algorithms. Plans to extend this approach to other analog domains, including acoustic, thermal, and optical will also be discussed.

10185-6, Session 1

Characterization of Riscure 1-GHz low sensitivity probe for side channel analysis (SCA)

James T. Graham, Rusty O. Baldwin, Ashwin Sampathkumar, Riverside Research (United States)

Side-channel attacks are most known for their utility in cryptanalytics; however, they can also be used to fingerprint devices or even determine the digital state of the system. For RF-SCA, the ultimate limits of signal sensitivity and frequency response are determined by the antenna characteristics. We present our characterization of a GHz-probe using a 418-MHz antenna that operates in the license-free industrial FCC band. We present the measured frequency response and signal attenuation as a function of SRD, spatial amplitude and phase maps, as well as the corresponding theoretical responses of the antenna.

10185-7, Session 2

High-performance computing for automatic target recognition in synthetic aperture radar imagery

Uttam K. Majumder, Air Force Research Lab. (United States); Erik Christiansen, Univ. of Florida (United States)

No Abstract Available

10185-8, Session 2

Jaccard similarity-based quantification of the neighborhood stability of a node in mobile sensor networks

Natarajan Meghanathan, Quavanti Hart, Jackson State Univ. (United States)

We propose to apply the Jaccard Similarity measure to quantify the extent of change in the neighborhood of a node in mobile sensor networks (MSNs) whose topology changes dynamically with time. If Ni(t-s) and Ni(t) denote respectively the set of neighbors of a node i at two successive sampling time instants t-s and t (where 's' is the time between two successive sampling instants), then the Jaccard Similarity of the neighborhood sets of node i with respect to time instants t-s and t is given by: JS(i, t-s, t) = Ni(t-s) n Ni(t) / Ni(t-s) U Ni(t). We propose to determine a weighted average of the Jaccard Similarity score for a node i at time instant t as follows: WJS(i, t) = h*WJS(i, t-s) + (1-h)*JS(i, t-s, t), where $0 \leq h \leq 1$ is the weight assigned for the importance to be given to the history. To begin with, for every node i: WJS(i, 0) = 1.0. We hypothesize that nodes with larger WJS values ($0 \leq$ WJS ≤ 1) are more likely to have a stable neighborhood and could be preferred for inclusion as intermediate nodes in communication topologies (like paths, trees, connected dominating sets, etc) for MSNs. Through simulation studies, we illustrate the strongly negative correlation between the WJS scores and node velocities (a fast moving node is more likely to have a low WJS score and vice-versa) as well as illustrate the use of the WJS scores to determine stable paths between any two nodes in a MSN.

10185-9, Session 2

Security in cloud computing based cognitive radio networks

Yenumula B. Reddy, Grambling State Univ. (United States)

Cloud computing based cognitive radio networks (CCCRN) is an eye-catching research area in recent years to improve the spectrum sensing and spectrum management. Cognitive radio networks (CRN) are capable of adaptive learning and reconfiguration to provide consistent communications in dynamic environments. The adoption and learning in CRN demand fast process of big data. The performance and security in CRN do not meet such requirements due to its low computational power capabilities, particularly in low computational power devices. The advent of cloud capabilities mitigate these constraints. Due to this reason, we suggest the steganography with Advanced Encryption Standard (AES) cryptography technique to protect the cloud data. We identify the critical issues and challenges to implementing CCCRN and provide possible solutions. Even though, both techniques have the same objective, the cloud data in cognitive radio network requires a combination to keep the hackers away from the classified and unclassified data.

Integration of cloud computing and cognitive radio increases the performance with added security threats of cloud computing. If the integration overcome these security threats, CCCRN will replace traditional methods of radio operation. The proposed security model incorporated in CCCRN can help the primary user emulation and many other jamming problems. Integrating cognitive radio in cloud arrives secure problems along with real-time processing and energy supply problems. Cloud integration provides resource pooling with additional antennas to meet the real-time performance. Therefore, the cloud is one of the solutions that is facing by CRN. We discuss these problems in the current research paper.

10185-10, Session 3

Multispectral very wide-view sensing concept

Anatoliy Boryssenko, Nuvotronics, LLC (United States)

Major features and system-level design considerations for 3-D array apertures with hemispherical coverage are presented. First, an ideal 3-D dome-like hemispherical aperture is simulated using physical optics. Second, 3-D smooth aperture shape is approximated by several planar facets each presenting identical 2-D aperture arrays. Optimal division of hemispherical field of view into sectors of regards with similar maximum angular scan extent is discussed along with optimization of major electrical features of planar array facets, their number and total component count.

10185-11, Session 3

Optimization of RF components in omnidirectional sensor

Anatoliy Boryssenko, Nuvotronics, LLC (United States)

Subarray modules are introduced for face arrays used to create 3-D aperture antenna systems. Several representative topologies and major electrical features are reviewed for beam-forming networks of subarray modules. Major performance measures such as Gain to Temperature ratio (G/T) are discussed. Three key components are identified and their impact on G/T is studied using circuit models.

10185-12, Session 3

Machine learning algorithm to detect unknown malicious codes

Simon Khan, Uttam K. Majumder, Air Force Research Lab. (United States)

No Abstract Available

10185-13, Session 3

Detecting poisoning attacks on hierarchical malware classification systems

Dan Guralnik, Omur Arslan, Univ. of Pennsylvania (United States); Ali Pezeshki, Colorado State Univ. (United States); Bill Moran, RMIT Univ. (Australia)

Anti-virus software based on unsupervised hierarchical classification (HC) of malware samples has been shown to be vulnerable to poisoning attacks. In this kind of attack, a malicious player degrades anti-virus performance by submitting to the database samples specifically designed to collapse the classification hierarchy utilized by the anti-virus or otherwise deform it in a way that would render it useless. Though each poisoning attack needs to be tailored to the particular HC scheme deployed, existing research seems to indicate that no particular HC method is immune.

We present results on applying a new notion of entropy for combinatorial dendrograms, as well as some novel tree dissimilarity measures, to the problem of controlling the influx of samples into the data base and deflecting poisoning attacks. In a nutshell, effective and tractable measures of change in hierarchy complexity are derived from the above, enabling on-the-fly flagging and rejection of potentially damaging samples. The information-theoretic underpinnings of these measures makes them indifferent to which particular poisoning algorithm is being used by the attacker, making them particularly attractive in this setting.

10185-14, Session 3

Classification and automatic recognition of objects using H2o package

Yenumula B. Reddy, Grambling State Univ. (United States)

Deep learning (DL) is a set of methods that automatically classify the raw data fed into the machine. Deep Convolutional nets composed of multiple processing layers to learn and representation of data with multiple levels of abstraction to process images, video, speech and audio. H2o deep learning architecture has many features that include supervised training protocol, memory efficient Java implementation, adaptive learning, and with related CRAN packages. H2o uses supervised training protocol with a uniform adaptive option which is an optimization based on the size of the network. It can take clusters of computing nodes to train on the entire data set but automatically shuffling the training examples for each iteration locally. The framework supports regularization techniques to prevent overfitting. H2o R has intuitive web interface using localhost and IP address. Using the H2o package in R is easy. The computations are performed in the H2o cluster and initiated by REST calls (in highly optimized Java code) from R. Since SPARK is available in R, H2o uses a single R session and communicates to the H2o Java cluster via REST calls. H2o runs inside the Spark executor JVM. Using these packages in R, we demonstrate the classification and automatic recognition of objects. Further, we use the H2o deep learning package in R Language to classify the NOAA VIIRS Night fires data to detect the persistent fire activity at a given location around the globe.

10185-15, Session 4

Apply analytical grid processing to sensor data collections

Gregory Shlyuger, St. Sinai PPS (United States)

Non-event based raw data (NERD) is a passive feed activity in relatively static properties for modern cyber domain network architecture. Some of NERD segments are system processes, storage, user activity, network topology or application(s). For each type of cyber domain such as Software Defined Networks, Virtualization, Service Orchestration or Cloud/Elastic Computers, NERD carryover essential characteristics, but each cyber domain might have slightly different properties. Enrichment NERD model with Raw Activity Event Data allowed transformation the raw sensor flowing through the system into enriched data elements that are both descriptive and predictive in nature, Automation and remote management of these sensors allows for efficient operation and flexible response mid-incident if greater data volume or fidelity is required. This paper detail some scenarios for evidence collection with the ability of robust and secure data bus to move through potentially untrusted networks with empathizing on data flow management and the full chain of custody of information generation of data provenance. A proof of concept, results indicates this is a viable approach towards collecting sensor data in modern volatile, uncertain, complex and ambiguous environment.

10185-16, Session 4

Fusion of cyber sensors on a network for improved detection and classification

Mark E. Oxley, Air Force Institute of Technology (United States); Igor V. Ternovskiy, Air Force Research Lab. (United States)

This paper investigates the fusion process of combining cyber sensors on a network to detect and classify cyber behaviors – good and bad. Some bad cyber activity can be confused as appropriate (good) activity and vice versa. To wrongly block good activity is an error. Also, to allow bad cyber activity to continue believing it to be good activity is also an error. We wish to minimize these errors. Some bad cyber activity can be classified according to its severity. Confusing an extremely severe cyber activity for a mildly bad cyber activity can be a costly mistake also. We assume there are several classification systems present on the network, that is, a sensor, processor and exploiter at a minimum for each system. Also, the sensors may be disparate. Assume each system has a ROC manifold that is known, or has a good approximation. The goal of this paper is to demonstrate that there a best combining rule. We seek to demonstrate a feedback transformation exists that update the rule such that a performance functional (criterion) is satisfied.

10185-17, Session 4

Efficient non-resonant absorption of electromagnetic radiation in thin cylindrical targets: experimental evidence

Andrey Akhmeteli, LTASolid, Inc. (United States); Nikolay G. Kokodiy, Boris 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) 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. Experimental confirmation of the above results is presented [Akhmeteli, Kokodiy, Safronov, Balkashin, Priz, Tarasevitch, arXiv:1109.1626 and 1208.0066, Proc. SPIE 9097, Cyber Sensing 2014, 90970H (June 18, 2014); doi:10.1117/12.2053482].

10185-18, Session 4

Unauthorized transmission detection and blocking in cyberspace communications

Ahmeen Muhammad, Wei Wayne Li, Bobby Wilson, Texas Southern Univ. (United States)

Cybersecurity refers to the technologies and processes designed to protect computers, networks and data from unauthorized access, vulnerabilities and attacks delivered via the Internet by cyber criminals. Current dynamic routing protocol has been promoted to improve network throughput and network security all the time. However, it is still a challenging issue to efficiently detect the transmission rate which is what the network engineer and security inspector always care about. The major objective of this research is to identify the transmission rate from an unauthorized wireless device to a secured cloud system and then to block this unauthorized transmission. Vice versa, we also conduct the research on the identification of the transmission from an unknown system to a secured device and on the blocking methodology for this malicious transmission. After comparing the current tools in the literature, an optimal method, based on the wireshark application, is proposed to conduct the measurement of the unauthorized and malicious transmissions. It is worthy to point out that instead of the traditional method of test throughputs, we purpose to add real-time interval measurement in finding a sensitive and comparatively objective solution to evaluate the network performance. As for the blocking techniques, we enlisted the Kali Linux operating system running on VMWare software to virtualize the environment. After comparing the different applications offered by Kali Linux, the aircrack, airmon, and airodump suites in conjunction with aireplay and Websploit, we propose an efficient method to deal with the transmission blocking. By using a stochastic queueing model, as a byproduct, we have also demonstrated the probability of network hardware delay which may make transmission data loss. Our results have efficiently improved the performance of monitoring the whole network circumstance and hardware delay.

10185-19, Session 4

On some optical properties of Lobster Eye inspired network sensing

Igor V. Ternovskiy, Air Force Research Lab. (United States)

No Abstract Available

10185-20, Session 4

Applying self-structured data learning algorithm to aerial infrared and visual images

Jenfeng S. Li, Georgia Institute of Technology (United States); James T. Graham, Riverside Research (United States); Roman Ilin, Air Force Research Lab. (United States)

No Abstract Available

Conference 10186: Ocean Sensing and Monitoring IX

SPIE. DCS DEFENSE+ SECURITY

Tuesday - Wednesday 11–12 April 2017

Part of Proceedings of SPIE Vol. 10186 Ocean Sensing and Monitoring IX

10186-1, Session 1

Creation and exploitation of orbital angular momentum for maritime environments *(Invited Paper)*

Eric G. Johnson, Jerome K. Miller, Richard J. Watkins, Indumathi Raghu Srimathi, Joshua Baghdady, Wenzhe Li, Yuan Li, Clemson Univ. (United States)

No Abstract Available

10186-2, Session 1

Experimental measurements of backscattered light underwater with beams carrying orbital angular momentum (OAM)

Brandon Cochenour, Lila Rodgers, Linda Mullen, Naval Air Warfare Ctr. Aircraft Div. (United States); Kaitlyn Morgan, Jerome K. Miller, Eric G. Johnson, Clemson Univ. (United States)

Orbital Angular Momentum (OAM) is a unique property of light that is characterized by a helical phase structure and a vortex intensity distribution. The propagation of beams carrying OAM have recently been examined in scattering environments such as turbid water in an effort to determine if the unique spatial properties of OAM beams can be exploited for sensing and communication applications.

This effort experimentally examines the properties of backscattered light carrying OAM. In this geometry, several modalities can be investigated. In the first modality, OAM is induced at the transmitter. By observing the return, one may be able to discriminate target photons (that which maintains the vortex) from backscatter clutter (light outside the vortex). The second modality using OAM as an analyzer, which separates coherent returns (eg, object, surface flash, etc.) from non-coherent returns (eg., backscatter, solar ambient, etc). The third modality examines encoding and decoding OAM at both the transmitter and receiver. This modality provides insight as to how spin is maintained or 'transferred' between modes in scattering environments. It may also be used as a way to discriminate against solar ambient, as the encoding/decoding procedure is 'blind' to non-coherent solar background.

Our investigation across these modalities aim to help understand the nature of OAM in scattering environments for oceanographic sensing, imaging, and LIDAR.

10186-3, Session 1

Diffractive optics for the detection of Interfering orbital-angular-momentum beams in underwater environments

Kaitlyn Morgan, Jerome K. Miller, Eric G. Johnson, Wenzhe Li, Clemson Univ. (United States)

Previously, we have demonstrated the dynamic control of the intensity profile of a beam underwater through the use of interfering orbital-angular-momentum modes. By controlling the relative phase between the two interfering modes, we are able to spatially modulate the intensity profile. The beam shaping capabilities demonstrated are explored as an alternative to amplitude modulation of a visible light source in determining underwater channel properties. This work demonstrates the use of diffractive optics to detect the spatial modulation as an alternative to detection through the use of masks or image processing. The setup utilizes a blue-green laser source. Different orbital-angular-momentum modes are generated by passing the coherent beams through diffractive vortex phase plates. The beams are then superimposed using a mach-zehnder interferometry setup. These beams are then sent through a controlled underwater environment where they are then passed through the detection optics. Two detection channels are used to provide both I and Q modulation information. This enables detection of alternative channel properties where amplitude modulation is ineffective or lacks precision. Additionally, we demonstrate the spatial demultiplexing capability of these optics. This data provides the foundations necessary to develop a method for channel characterization of underwater communication links with these dynamically controlled coherent orbital-angular-momentum modes.

10186-4, Session 1

Beam wander due to optical turbulence in water

Gero A. Nootz, Silvia C. Matt, Andrey V. Kanaev, Ewa Jarosz, Weilin W. Hou, U.S. Naval Research Lab. (United States)

Optical methods to communicate or sense in the ocean environment can be effected inhomogeneities in the index of refraction called optical turbulence. Beam wander introduced by optical turbulence is of particular interest for optical means relying on the propagation of a well-defined laser beam such as free space communication and laser line scan. Here we present a comprehensive study of beam propagation simulations, lab experiments, and field measurements of laser beams propagating through varying degrees of optical turbulence. For the computational part of the investigation a true end to end simulation was performed. Starting with a CFD simulation of Rayleigh–Bénard convection the temperature fields where converted to index of refraction phase screens which then where used to simulate the propagation of a focused Gaussian laser beam via the split-step Fourier method. Lab experiments where conducted using the same parameters as in the simulation using a good quality TEM00 beam and a CCD camera to record data. For the field experiments a Telescoping Ridged Underwater Sensor Structure (TRUSS) was equipped with a transmitter and a receiver capable of analyzing a multitude of laser beams simultaneously. The TRUSS was deployed in the Bahamas to record beam wander under weak optical turbulence conditions above and stronger optical turbulence conditions inside the thermocline. The data from the experimental and lab experiments are compared and the strength of the optical turbulence in terms of the structure parameter Cn2 are extracted. We also extract Cn2 from the TRUSS experiments and in doing so provide, for the first time, a quantitative estimate for the strength of optical turbulence in the ocean.

10186-5, Session 2

Undersea narrow-beam optical communications field demonstration

Scott A. Hamilton, MIT Lincoln Lab. (United States)

Optical propagation through the ocean encounters significant absorption and scattering; the impact is exponential signal attenuation and temporal broadening, limiting the maximum link range and the achievable data rate, respectively. MIT Lincoln Laboratory is developing narrow-beam lasercom for the undersea environment, where a collimated transmit beam is precisely pointed to the receive terminal. This approach directly contrasts with the more commonly demonstrated approach, where the transmit light is sent

over a wide angle, avoiding precise pointing requirements but reducing the achievable range and data rate. Two advantages of narrow-beam lasercom are the maximization of light collected at the receiver and the ability to mitigate temporal broadening by spatial filtering. Precision pointing will be accomplished by bi-directional transmission and tracking loops on each terminal, a methodology used to great effect in atmospheric and space lasercom systems. By solving the pointing and tracking problem, we can extend the link range and increase the data throughput.

In FY16, MIT Lincoln Laboratory deployed a narrow-beam optical measurement and communication experiment over several days at the Naval Undersea Warfare Center (NUWC) harbor in the shallow, turbid water of Narragansett Bay, Rhode Island. The transmitter's optical power was kept low at 0.25 mW. The receiver operated continuously in real time and included a high-sensitivity photon-counting photomultiplier tube (PMT) and a high-speed linear avalanche photodiode (APD). The PMT also included strong forward error correction (FEC) and demonstrated near-theoretical channel performance at all data rates, error-free output after FEC, and robust operation during day and night.

10186-6, Session 2

Deployable wavelength optimizer for multi-laser sensing and communication undersea

Burton Neuner III, Alexandru Hening, B. Melvin L. Pascoguin, Brian Dick, Martin Miller, Nghia Tran, Michael Pfetsch, SPAWARSYSCEN Pacific: San Diego (United States)

This effort develops and tests algorithms and a man-portable optical system designed to autonomously optimize the laser communication wavelength in open and coastal oceans. In situ optical meteorology and oceanography (METOC) data gathered and analyzed as part of the auto-selection process can be stored and forwarded. The system performs closed-loop optimization within one minute by probing the water column via passive retroreflector and polarization optics, selecting the ideal wavelength, and enabling high-speed communication. Backscattered and stray light is selectively blocked by employing polarizers and waveplates, thus increasing the signal to noise ratio. As an advancement in instrumentation, we present autonomy software and portable hardware, and demonstrate this new system in natural subsea environments. Once miniaturized, the optical payload and software will be ready for deployment on manned and unmanned platforms such as buoys, UUVs, and gliders for world-wide coverage. Gathering timely and accurate ocean sensing data in situ will dramatically increase the knowledge base and capabilities for defense, environmental sensing, and industrial applications. Furthermore, communicating on the optimal channel increases transfer rates, propagation range, and mission length, all while reducing power consumption in unmanned undersea platforms.

10186-7, Session 2

Advances in underwater C2 optical communications

Dave Rolandelli, Northrop Grumman Systems Corp. (United States)

No Abstract Available

10186-8, Session 2

Environmental effects on underwater optical transmission in the Arabian Gulf and the Gulf of Oman

Peter C. Chu, Thai Q. Phung, Ross F. Hammerer, Tetyana Margolina, Chenwu Fan, Naval Postgraduate School (United States)

Optical communication/detection systems have potential to get around some limitations of current acoustic communications and detection systems especially increased fleet and port security in noisy littoral waters. Identification of correlation functions between underwater hydrographic and optical parameters is the key to understand the ocean environmental effects on optical communication and detection. In this paper, we use the data collected by Naval Oceanographic Office with the High Intake Defined Excitation (HIDEX) photometer at 459 stations in the Arabian Gulf from June 1993 to September 2000 to analyze temporal and spatial variability of hydrographic and optical variables such as temperature, salinity, bioluminescence, fluorescence, and transmissivity at two different wavelengths (TRed at 670 nm, TBlue at 490 nm), and in turn the transfer and correlation functions between the hydrographic and optical parameters. The T-S diagrams show seasonal spreading of the Persian Gulf Water into Gulf of Oman through the Strait of Hormuz. Vertical temperature profiles show evident thermocline formation in the summer months in the Arabian Gulf. Bioluminescence and fluorescence maxima, transmissivity minimum with their corresponding depths, red and blue laser beam peak attenuation coefficients are identified from the optical profiles. Mixed layer depth, thermocline depth and strength are determined from (T, S) profile. Evident correlations are found between the ocean mixed layer depth and the blue laser beam peak attenuation coefficient, red laser beam peak attenuation coefficient, bioluminescence and fluorescence maxima in the Gulf of Oman in September and in the Arabian Gulf in June.

10186-9, Session 2

Biomimetric sentinel reef structures for optical sensing and communications

David Fries, Tim Hutcheson, Noam Josef, Florida Institute for Human & Machine Cognition (United States)

No Abstract Available

10186-10, Session 3

Workbench for the computer simulation of underwater gated viewing systems

Katrin Braesicke, Daniel Wegner, Endre Repasi, Fraunhofer-Institut für Optronik, Systemtechnik und Bildauswertung (Germany)

In this paper we introduce a software tool for image based computer simulation of an underwater gated viewing system. This development is helpful as a tool for the discussion of a possible engagement of a gated viewing camera for underwater imagery. We show the modular structure of implemented input parameter sets for camera, laser and environment description and application examples of the software tool. The whole simulation includes the scene illumination through a laser pulse with its energy pulse form and length as well as the propagation of the light through the open water taking into account complex optical properties of the environment.

The scene is modeled as a geometric shape with diverse reflective areas and optical surface properties submerged in the open water. The software is based on a camera model including image degradation due to diffraction,

lens transmission, detector efficiency and image enhancement by digital signal processing. We will show simulation results on some example configurations.

Finally we will discuss the limits of our method and give an outlook to future development.

10186-11, Session 3

In situ particle characterization and evidence of ubiquitous particle orientation in the ocean using a submersible holographic imaging system

Aditya R. Nayak, Malcolm N. McFarland, Nicole D. Stockley, Michael S. Twardowski, James M. Sullivan, Harbor Branch Oceanographic Institute (United States)

Field experiments with the goal of characterizing aquatic particle properties, including size distributions and orientations in their natural environment, were conducted using a submersible holographic imaging system (HOLOCAM). Digital holography is a non-intrusive technique that allows particle fields to be mapped within a 3-D sampling volume at high resolution. The HOLOCAM was deployed at East Sound, a fjord in the US Pacific Northwest, and Lake Erie over three separate deployments from 2013 to 2015. A database of more than a million particles in the 100-10000 μm size range of varying shape and orientation was created after processing > 50,000 holograms. Furthermore, simultaneous, co-located acoustic Doppler velocimeter measurements of small-scale shear and turbulence structure were used to study the effects of the ambient flow field on particle orientation. Several interesting features presented themselves, with a Microcystis bloom dominating the surface layer of Lake Erie, while 'thin layers' of high particle concentrations dominated by colonial diatoms were seen in East Sound. Particle size distribution (PSD) slopes in the 50-250 μm size range were ~1.7-1.9, while for particles > 250 μm, the slopes were significantly higher. Clear evidence of ubiquitous particle alignment to the horizontal flow field in regions of low shear and turbulent dissipation was seen. This result, obtained under flow conditions representative of coastal and open oceans, can have significant consequences to ocean optics as random particle orientation is inherently assumed in theory and models. Preferential alignment can increase/decrease optical properties such as backscattering and attenuation relative to random distributions.

10186-12, Session 3

Statistical signal processing technique to reduce effects of forward scatter on underwater modulated pulse lidar

David W. Illig, Robert W. Lee, Linda Mullen, Naval Air Systems Command (United States)

Lidar sensors offer the potential for high-resolution, high-accuracy ranging in the underwater environment. Such optical systems experience challenges due to the properties of the underwater channel, namely absorption and scattering. Absorption reduces received signal power, while scattering can have several negative effects on the received signal. Previous work explored the use of statistical signal processing techniques to suppress the "clutter" return resulting from photons that scatter in the backwards direction without reaching the object of interest in the scene. Many approaches have been investigated to reduce backscatter, with forward scattering remaining a significant challenge, which causes blurring of target features and can result in reduced range accuracy. In this work we will explore the potential for statistical processing approaches to suppress forward scattering using a modulated pulse waveform in a ranging application. For the modulated pulse lidar rangefinder, performance becomes limited in turbid waters primarily due to forward scatter decreasing range resolution and range accuracy. This work will demonstrate the ability of statistical signal processing to reduce range error for systems operating in these turbid conditions. Both simulated and experimental results will be presented using a state of the art underwater optical channel model and a custom modulated pulse laser source.

10186-13, Session 4

Optimizing the performance of modulated pulse laser systems for imaging and ranging applications

Linda Mullen, Robert W. Lee, David W. Illig, Naval Air Warfare Ctr. Aircraft Div. (United States)

Blue-green laser systems are being developed for optical imaging and ranging in the underwater environment. The imaging application requires high range resolution to distinguish between multiple targets in the scene or between multiple target features, while the ranging application benefits from measurements with high range accuracy. The group at the Naval Air Warfare Center Aircraft Division (NAWCAD) in Patuxent River, MD has been investigating the merging of wideband radar modulation schemes with a pulsed laser system for underwater imaging and ranging applications. For the imaging application, the narrow peak produced by pulse compression at the receiver offers enhanced range resolution relative to traditional short pulse approaches. For ranging, the selection of modulation frequency bands approaching 1GHz provides backscatter and forward scatter suppression and enhanced range accuracy. Both passband and baseband digital processing have been applied to data collected in laboratory water tank experiments. The results have shown that the choice of processing scheme has a significant impact on optimizing the performance of modulated pulse laser systems for either imaging or ranging applications. These different processing schemes will be discussed, and results showing the effect of the processing schemes for imaging and ranging applications will be presented.

10186-14, Session 4

Adaptive underwater channel estimation for hybrid lidar/radar

Robert W. Lee, David W. Illig, Naval Air Systems Command (United States); Linda Mullen, Naval Air Warfare Ctr. Aircraft Div. (United States)

Researchers from the Naval Air Warfare Center Aircraft Division (NAWCAD) in Patuxent River MD have been working to show that wideband modulation can be applied to blue-green laser systems designed to measure the range to underwater objects. These modulation techniques provide improved range accuracy and resolution due to pulse compression, time-bandwidth product gain, and the ability to discriminate against backscatter without gating the optical receiver. It has been previously observed that the scattering of optical signals in turbid environments causes frequency dependent attenuation of received wideband waveforms. As the channel becomes increasingly turbid or the propagation distance increases, these effects become even more prominent. The frequency dependent attenuation caused by forward scattered photons affects both range accuracy and resolution of pulse compression systems due to the mismatch between the comparator and the observed signal. It is proposed that adaptive filtering techniques make it possible to iteratively learn the frequency dependent nature of a channel, and provide an estimate for the frequency response of the environment. This estimation can be used to reduce the effects of filter mismatch, and provides insight into the underwater channel characteristics. The application of adaptive filters to wideband intensity modulated laser systems will be discussed, and the iterative learning process will be applied to results generated using an underwater optical impulse response model. These adaptive techniques will also be applied to data collected in laboratory water tank experiments, and results will be presented comparing the learned response with the observed results.

10186-15, Session 4

Experimental study of an underwater pulsed compressive line sensing imaging system

Bing Ouyang, Harbor Branch Oceanographic Institute (United States); Cuiling Gong, Texas Christian Univ. (United States); Weilin W. Hou, U.S. Naval Research Lab. (United States); Fraser R. Dalgleish, Frank M. Caimi, Anni K. Vuorenkoski, Harbor Branch Oceanographic Institute (United States)

Compressive Line Sensing (CLS) imaging system A type of compressive sensing (CS) based imaging system concept was proposed with the objective to enable resource efficient sensors that is optimum for power-constraint unmanned platforms such as UUVs and UAVs. 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. Several different CLS prototypes have been developed using both CW laser and passive spatial light modulator (SLM) such as digital micromirror device (DMD) or active SLM device such as the individually addressable laser diode array. In this paper, we will present the lasted CLS prototype that relies on a pulsed laser diode source and DMD light engine. The challenges of implementing this prototype will be discussed. This performance of this prototype in various test tank conditions such as in the turbid water, through turbulence and in a combination of the two types of image degradation interference will be analyzed. The comparison between CW CLS system and pulsed CLS system will be presented.

10186-16, Session 4

Study of underway salinity monitoring device based on optical refractive index measurement

Long Yu, School of optical and electronic information (China); Wenping Guo, Junyao Chen, Kecheng Yang, Min Xia, Wei Li, Huazhong Univ. of Science and Technology (China)

In ocean optics, salinity is an important inherent optical parameter to be measured. Salinity reflects the state of the Marine environment. The variation on the ocean salinity is an important factor of Marine growth. Thus, monitoring of the salinity is of great significance for the study of Marine ecological environment. In the field of optics, refractive index (RI) is closely related to salinity. It attracted general attentions, as it provide a much accurate method to obtain the absolute salinity. Through the real-time detection of the refractive index, we achieved the purpose of real-time monitoring of the salinity.

We designed a refractive index measurement system based on optical total internal reflection. It adopted a divergent light source and a CCD camera. The divergent light source sent out a bunch of tapered beam, exposure to the interface of optical prism and the sea water. Light intensity distribution reflected from the interface could be detected by the CCD camera and then sent to an embedded system. In the DSP embedded system, we obtained the critical edge position through image processing algorithm. Through the relation we concluded between refractive index and the critical angle edge position, we get the refractive index. In this system, the detecting precision of the refractive index of the sea water reached 10-4. Finally, through the conversion of the refractive index, we achieved in-situ measurement of the salinity. In 2016 summer, we joined the cruise survey in China Bo-Hai and Huang-Hai Sea. We achieved the underway monitoring of the refractive index. The trends of the results are basically agreed with the salinity measurements. And for the measurement of station, data is also consistent with the data of salinity.

10186-17, Session 4

Laboratory observations of sediment transport using combined particle image and tracking velocimetry

Donya Frank, Joseph Calantoni, U.S. Naval Research Lab. (United States)

Improved understanding of coastal hydrodynamics and morphology will lead to more effective mitigation measures that reduce fatalities and property damage caused by natural disasters such as hurricanes. We investigated sediment transport under oscillatory flow over flat and rippled beds with phase-separated stereoscopic Particle Image Velocimetry (PIV). Standard PIV techniques severely limit measurements at the fluid-sediment interface and do not allow for the observation of separate phases in multi-phase flow (e.g. sand grains in water). We have implemented phase-separated Particle Image Velocimetry by adding fluorescent tracer particles to the fluid in order to observe fluid flow and sediment transport simultaneously. While sand grains scatter 532 nm wavelength laser light, the fluorescent particles absorb 532 nm laser light and re-emit light at a wavelength of 584 nm. Optical long-pass filters with a cut-on wavelength of 550 nm were installed on two cameras configured to perform stereoscopic PIV to capture only the light emitted by the fluorescent tracer particles. A third high-speed camera was used to capture the light scattered by the sand grains allowing for sediment particle tracking via particle tracking velocimetry (PTV). Together, these overlapping, simultaneously recorded images provided sediment particle and fluid velocities at high temporal and spatial resolution (100 Hz sampling with 0.8 mm vector spacing for the 2D-3C fluid velocity field). Measurements were made under a wide range of oscillatory flows over flat and rippled sand beds. The set of observations allow for the investigation of the relative importance of pressure gradients and shear stresses on sediment transport.

10186-18, Session 4

The impact of optical turbulence on particle image velocimetry

Silvia C. Matt, Gero A. Nootz, U.S. Naval Research Lab. (United States); Samuel Hellman, Dantec Dynamics Inc. (United States); Weilin W. Hou, U.S. Naval Research Lab. (United States)

Particle image velocimetry (PIV) is a well-established tool in the oceanographic community to collect high-resolution velocity and turbulence data in the laboratory. PIV measurements are based on using a laser sheet to illuminate a flow seeded with small particles and taking quick successive images or image pairs of the illuminated particle field with a CCD camera. The movement of the particles between images can be used to infer flow velocities. During experiments at the Simulated Turbulence and Turbidity Environment (SiTTE) laboratory tank, we observed a marked influence of optical turbulence, i.e. strong temperature gradients leading to changes in the index of refraction, on particle imaging in PIV. The particles look smeared and have a “shooting star” appearance. PIV is routinely used in flows with very high temperature gradients, such as nuclear reactor cooling rods, but generally the optical path length is very short (on the order of cms), and no such effect has previously been reported.

We investigated the effect of optical turbulence on PIV imaging for various optical path lengths (0.5m to 2.5m) and turbulence strengths. Velocities from the PIV measurements were calculated using the sophisticated algorithms provided within Dantec Dynamic Studio and compared to velocities from concurrent velocity point measurements with a Laser Doppler Velocimetry system. The results indicate that optical turbulence can affect PIV measurements, and that depending on the strength of the optical turbulence and path length, care needs to be taken to mediate this effect using appropriate post-processing techniques when inferring velocities from PIV data.

10186-19, Session 5

Temporal monitoring of vessels activity using day/night band in Suomi NPP on South China Sea

Takashi Yamaguchi, Ichio Asanuma, JongGeol Park, Kenneth J. Mackin, Tokyo Univ. of Information Sciences (Japan); John Mittleman, U.S. Naval Research Lab. (United States)

In this research, we focus on vessel detection using the satellite imagery of day/night band (DNB) on Suomi NPP in order to monitor the change of vessel activity on the region of South China Sea (SCS). In this paper, we consider the relation between the temporal change of vessel activities and the events on maritime environment based on the vessel traffic density estimation using DNB.

DNB is a moderate resolution (350-700m) satellite imagery but can detect the fishing light of fishery boats in night time for every day. The advantage of DNB is the continuous monitoring on wide area compared to another vessel detection and locating system. However, DNB gave strong influence of cloud and lunar refection. Therefore, we additionally used Brightness Temperature at 3.7μm(BT3.7) for cloud information.

In our previous research, we construct an empirical vessel detection model that based on the DNB contrast and the estimation of cloud condition using BT3.7. Moreover, we proposed a vessel traffic density estimation method based on empirical model. In this paper, we construct the time temporal density estimation map on SCS and East China Sea (ECS) in order to extract the knowledge from vessel activities change. From the vessel traffic density maps in 2016, we can see that the vessel distribution is moved to ECS from SCS as if to response an events reported on news medium. Finally, we plan to construct the maps over 2 years for the distinction of seasonal change and the other.

10186-20, Session 5

Neural network retrievals of phytoplankton absorption and Karenia brevis harmful algal blooms in the West Florida Shelf

Samir Ahmed, Ahmed El-Habashi, The City College of New York (United States)

We describe the application of a Neural Network (NN) for the detection of phytoplankton absorption at 443 nm (aph443) from Visible Infrared Imaging Radiometer Suite (VIIRS) satellite observations at the 486, 551 and 671 nm channels in coastal waters of the West Florida Shelf (WFS). The aph443 in the VIIRS images can in turn be correlated to chlorophyll-a concentrations [Chla] and KB cell counts. To retrieve KB values, the VIIRS NN retrieved aph443 images are filtered by applying limiting constraints, defined by (i) low backscatter at Rrs 551 nm and (ii) a minimum aph443 value known to be associated with KB HABs in the WFS. The resulting filtered residual images, are then used to delineate and quantify the existing KB HABs. Results are presented of comparisons with KB HABs satellite retrievals obtained using other techniques, notably those from the Moderate Resolution Imaging Spectro-radiometer Aqua (MODIS-A) satellite that depended on the remote sensing chlorophyll fluorescence reflectance signal at the 678 nm band, absent on VIIRS, but needed for both the normalized fluorescence height (nFLH) and Red Band Difference algorithms (RBD) that proved effective in retrieval of KB HABs. Comparisons with other retrieval techniques are also reported against in situ measurements over a four year period (2011-2016). These confirm the viability of the NN retrieval approach for retrievals in challenging coastal waters. They also underline the importance of short term temporal as well as intra pixel variations on the accuracy and interpretation of retrievals.

10186-21, Session 5

A study on bulk and skin temperature difference using observations from Atlantic and Pacific Coastal regions of United States

Denny P. Alappattu, Naval Postgraduate School (United States) and Moss Landing Marine Labs. (United States); Qing Wang, Ryan Yamguchi, Dick Lind, Naval Postgraduate School (United States); Michael Reynolds, Remote Measurement & Research Co. (United States); Adam Christman, Univ. of Notre Dame (United States)

Sea surface temperature (SST) is the key variable required for a number of oceanographic and atmospheric science applications. Satellite remote sensing of the oceans helped to improve our understanding on the SST variability of the global oceans and air-sea interaction. Satellites measure the radiation leaving from the surface skin layer using the onboard infrared radiometer. The temperature retrieved from the radiation measurements is representative of the surface skin layer referred to as skin SST. However, bulk SST observations made in the layer deeper (generally varies from one to five meter) in the water are conventionally used to validate satellite measurements. Bulk SST can differ by tenth of a degree from the skin SST. The difference between bulk and skin temperature is known as cool skin, skin effect or cool skin effect. Understanding of the cool skin effect is imperative to properly validate the schemes that use surface skin temperature to infer bulk temperatures. Our current understanding on the cool skin effect is based on the simultaneous measurements of skin and bulk SST using shipborne measurements from research vessels fitted with infrared radiometers and bulk SST sensors. Parameterization of cools skin effect based on these measurements chiefly considers the observations from open ocean and may not be representative of the cool skin behavior of coastal regions. Skin SST retrieved over coastal waters may show different patterns to those retrieved over the open ocean due to differences in the properties of oceanic mixed layer and atmospheric boundary layer.

In this study, we use the bulk and skin SST observations from two field experiments, each from East (Duck, North Carolina) and West (Moss Landing, California) coast of USA covering a broad range of oceanic and atmospheric conditions. This investigation sheds light on the relationship of bulk-skin SST difference with the wind speed and its diurnal variability in the coastal regions. Moreover dependence of skin temperature on downwelling longwave radiation is also examined. Our data shows an average cool skin effect of ~0.4°C with a standard deviation of around 0.2°C. When wind speed was less than 4 m s-1 the skin temperature is oscillated and greatly increased the uncertainty of skin effect reported over the study region. We found that the cool skin models based on the open ocean observations systematically underestimates the cool skin effect observed in the present study. This indicates that the assumptions used for the skin effect behavior over open ocean may not be appropriate over coastal regions.

10186-22, Session 5

Mueller matrices of hydrosols and their impact on the polarized light fields from the ocean water

Robert Foster, Anna McGilloway, Alexander Gilerson, The City College of New York (United States)

Polarimetric characteristics of light from ocean water in a combination with standard remote sensing reflectance provide important information about water constituents; they are useful in retrieval of additional water parameters like attenuation-to-absorption ratio and attenuation coefficients and/or establishing additional constraints for retrieval algorithms. The Stokes vectors of light above and below water surface, which fully represent polarimetric characteristics of water leaving radiance, strongly depend on the particle size distribution and related Mueller matrices of water particulates. The goal of this work is to investigate the effect of various hydrosol mixtures which include chlorophyllous and mineral particles on the polarized light field. The Stokes vectors of scattered light and the degree of polarization (DOP) are generated as outputs of vector radiative transfer simulations using RayXP code for various water compositions. Mie theory as well as other approaches are used for the generation of the scattering matrices and the impact of their variability on the retrieval algorithms is analyzed. Results are validated by the comparison of the simulated hyperspectral polarized light fields with the polarimetric observations from the recent cruises supported by NASA and NOAA.

10186-23, Session 5

Monitoring abnormal bio-optical and physical properties in the Gulf of Mexico

Robert A. Arnone, Brooke Jones, Inia Soto, The Univ. of Southern Mississippi (United States)

The dynamic bio-optical and physical ocean properties within the Gulf of Mexico (GoM) have been identified by the Ocean Weather Laboratory as interaction of the river discharge and the offshore currents. Ocean properties derived from VIIRS satellite ocean color (Chlorophyll and Bio-Optics) and Sea Surface Temperature (SST) products and physical properties from ocean-circulation models (currents, SST and salinity) were used to identify regions of dynamic changing properties. Monitoring the degree of environmental changes was defined by the Dynamic Anomaly of bio-optical and physical environmental properties. Locations where these normal and abnormal ocean properties occur, determine ecological and physical hotspots in the GoM which can be used for adaptive sampling of ocean processes. Methods are described to characterize activity of the abnormal environmental properties using differences between daily, weekly and previous 2 month mean with a 2 week lag. The intensity of the product anomaly using levels of the standard deviation of the mean and can be used to recognize ocean events and provide decision support for adaptive sampling. The similarities of the locations of different environmental property anomalies suggest interaction between the bio-optical and physical properties. The locations of environmental anomalies changes throughout the year and help demonstrate the evolution of ecosystem to events. Results identify ocean regions for sampling to reduce data gaps and provide improve monitoring of bio-optical and physical properties.

10186-24, Session 6

Modeling and measurements of depolarization rates in ocean water with an airborne imaging LIDAR system

Michael DeWeert, BAE Systems (United States)

Ocean LIDAR is one of the few methods capable of 24-hour imaging of submerged objects from an airborne platform. In this technology, a laser pulse is emitted, and reflected/backscattered light is collected at known time lapses, allowing both imaging and depth estimation of submerged objects. The advantages of dual-polarization LIDAR include enabling the cross-polarized channel to operate near-to or straddling the sea surface without LIDAR glint interference, as well as superior discrimination of objects of interest and clutter types, and separation of artificial objects from the ocean background return.

A key parameter for estimating polarized-LIDAR performance is the rate at which the transmitted laser beam and the reflected light de-polarize with range. We report here on recent experiments testing a polarized-LIDAR imaging system to characterize a real ocean environment. The LIDAR system tested used a high-pulse-energy doubled-YAG laser with a single polarized mode. The receiver included a linear-polarization-based beam splitter directing orthogonal polarizations to separate range-gated focal planes. In ocean-characterization mode, the LIDAR steps range gates for both channels down from the surface in controlled increments, allowing for characterization of the attenuation rate of the laser and computation of the degree of linear polarization versus depth. Imaging data, in conjunction with modeling/simulation, also allows estimation of the total scattering via analysis of wave-focal caustics versus depth. We compare the results to computations from the most-recent upgrade to the 3DLASEM (3-Dimensional LIDAR Airborne System Emulator-Maritime), and discuss 3DLASEM as a tool for predicting and improving polarized-LIDAR system performance.

10186-25, Session 6

Assessment of lidar remote sensing capability of Raman water temperature from laboratory and field experiments

Damien B. Josset, Weilin W. Hou, Wesley Goode, Silvia C. Matt, U.S. Naval Research Lab. (United States); Yongxiang Hu, NASA Langley Research Ctr. (United States)

Lidar remote sensing based on visible wavelength is one of the only way to penetrate the water surface and to obtain range resolved information of the ocean surface mixed layer at the synoptic scale. Accurate measurement of the mixed layer properties is important for ocean weather forecast and to assist the optimal deployment of military assets. Turbulence within the mixed layer also plays an important role in climate variability as it also influences ocean heat storage and algae photosynthesis (Sverdrup 1953, Behrenfeld 2010).

As of today, mixed layer depth changes are represented in the models through various parameterizations constrained mostly by surface properties like wind speed, surface salinity and sea surface temperature. However, cooling by wind and rain can create strong gradients (0.5C) of temperature between the submillimeter surface layer and the subsurface layer (Soloviev and Lukas, 1997) which will manifest itself as a low temperature bias in the observations.

Temperature and salinity profiles are typically used to characterize the mixed layer variability (de Boyer Montégut et al. 2004) and are both key components of turbulence characterization (Hou 2009). Recently, several research groups have been investigating ocean temperature profiling with laser remote sensing based either on Brillouin (Fry 2012, Rudolf and Walther 2014) or Raman scattering (Artlett and Pask 2015, Lednev et al. 2016). It is the continuity of promising research that started decades ago (Leonard et al. 1979, Guagliardo and Dufilho 1980, Hirschberg et al. 1984) and can benefit from the current state of laser and detector technology.

One aspect of this research that has not been overlooked (Artlett and Pask 2012) but has yet to be revisited is the impact of temperature on vibrational Raman polarization (Chang and Young, 1972).

The TURBulence Ocean Lidar is an experimental system, aimed at characterizing underwater turbulence by examining various Stokes parameters. Its multispectral capability in both emission (based on an optical parametric oscillator) and detection (optical filters) provide flexibility to measure the polarization signature of both elastic and inelastic scattering.

We will present the characteristics of TURBOL and several results from our laboratory and field experiments with an emphasis on temperature profiling capabilities based on vibrational Raman polarization. We will also present other directions of research related to this activity.

10186-26, Session 6

Ocean atmospheric horizontal visibility measuring by a self-designed Mie-scattering Lidar

Yinghui Ge, Xianjiang Zeng, Min Xia, Wenping Guo, Wei Li, Kecheng Yang, Huazhong Univ. of Science and Technology (China)

Sea fog is a dangerous weather phenomenon over ocean and costal areas. Fog and haze led to the reduction of the atmospheric visibility. In particular, poor visibility conditions have frequently caused the collision of ships. At the same time, fog and haze usually carries lots of harmful granules which may cause terrible respiratory diseases when breathed into the lungs by humans living in costal areas. The monitor and prediction of sea fog has significant contributions to maritime safety and human's daily life in costal areas. As we know, we can monitor the sea fog by measuring the atmospheric visibility.

In this paper, we designed a compact Mie scattering lidar system for ocean atmospheric horizontal visibility measuring. This system was based on an air-cooled 532nm Nd-YAG pulsed laser as a source for the benefit of system size shrink. A Cassegrain telescope was engaged to collect the echo of the atmosphere and a Hamamatsu photomultiplier tube (PMT) was used in converting the optic signal to electric signal. The slope method needs to be used to retrieve the AEC (atmosphere extinction coefficient) which used to calculate the visibility. But slope method involves significant uncertainty as this algorithm is based on the hypothesis that either molecule or aerosol components exists in the atmosphere. To reduce the uncertainty, an algorithm based on two components fitting was applied for AEC retrieval in our system which replaced the algorithm based on the slope method. The whole system was powered by electricity supply which made it easy mounting on a ship or observation station by the sea. Lots of experiments were conducted laboratory to ensure the veracity and stability. In 2016 summer, we joined the cruise survey in China Bo-Hai and Huang-Hai Sea. Site experiments were carried out on the research vessel 'Dongfanghong 2'. The results showed that the visibility values obtained by our system are in good agreement with the value set by the visibility meter.

10186-27, Session 7

Simulating biogeo-optical dynamics in the bottom boundary layer: northern Gulf of Mexico test case

Jason Jolliff, Sherwin D. Ladner, Travis Smith, Allison Penko, Ewa Jarosz, U.S. Naval Research Lab. (United States); Todd Lovitt, Vencore, Inc. (United States)

Interdisciplinary coastal observations over a two-week period in the northern Gulf of Mexico reveal a complex and dynamic bottom boundary layer (BBL) that is characterized by both biological and suspended sediment (biogeo-) optical signals. Much of the BBL optical variance is concealed from remote sensing by the opacity of the nearly omnipresent surface river plume, however, the BBL physical dynamics and resulting optical excitation are indeed responding to surface wind stress forcing and surface gravity wave-induced turbulence. Here we present a series of numerical modeling efforts and approaches aimed towards resolving and simulating these observed biogeo-physical and –optical processes. First, we present results from the Coupled Ocean-Atmosphere Prediction (COAMPS) system that has been modified to include surface-gravity wave simulations, a coupled seafloor boundary layer model, an ocean biological model, and an associated optical module. Results from this complex numerical modeling prototype are used to examine the benthic-pelagic coupling processes that were observed during the field experiment, particularly the optical excitation of the BBL during anomalous significant wave heights in excess of 3.5 meters. Second, we examine results from the Tactical Ocean Data System (TODS), which combines daily satellite imagery with numerical circulation model results to render a three-dimensional estimate of the optical field and then execute a reduced-order complexity advection-diffusion-reaction model to render hourly forecasts. Whereas the TODS system has the advantage of effectively assimilating both glider data and satellite images, the 3D generation algorithms still have difficulty in the northern Gulf's complex 3-layered system (surface plume, geostrophic interior, BBL). In contrast, the COAMPS system can begin to resolve this complexity but is computationally expensive and remains unconstrained by optical observations. The combined analysis of these systems suggests the potential way forward to develop appropriate optical forecast models with U.S. Naval applications.

10186-28, Session 7

Recent warming in the San Francisco Bay and the California coastal ocean

Yi Chao, John Farrara, Remote Sensing Solutions, Inc. (United States); Hongchun Zhang, Univ. of California, Los Angeles (United States); Fei Chai, The Univ. of Maine (United States)

Exceptionally warm water temperatures developed in the San Francisco Bay as well as the California coastal ocean during 2014-2016. Observations are first used to document this anomalous warming. The warming is realistically simulated by both the structured grid California coastal ocean model and the unstructured grid San Francisco Bay modeling system. The model simulations are used to study the origin of the 2014-2016 warming. The warming in San Francisco Bay originates in the adjacent California coastal ocean and propagates through the Golden Gate into San Francisco Bay. The 2014-2015 warming is associated with the North Pacific warm blob, while the 2015-2016 warming is associated with the tropical Pacific ENSO. Such warming events could have significant impact on the foodweb structure and health of the San Francisco Bay ecosystem. Coupling the physical circulation with a biogeochemical model to assess this impact on ecosystem is currently in progress.

10186-29, Session 7

Effect of Yellow Sea inter- and intra-annual thermohaline variability on acoustic propagation

Peter C. Chu, Colleen M. McDonald, Tetyana Margolina, Naval Postgraduate School (United States)

This paper is to answer the question "How can inter- and intra-annual variability in the ocean be leveraged by the submarine Force?" through quantifying inter- and intra-annual variability in (T, S) fields and in turn underwater acoustic characteristics such as transmission loss, signal excess, and range of detection. The Navy's Generalized Digital Environmental Model (GDEM) is the climatological monthly mean data and represents mean annual variability. An optimal spectral decomposition method (Chu et al. 2015, 2016) is used to produce a synoptic monthly gridded (SMG) (T, S) dataset for the world oceans with 1o?1o horizontal resolution, 28 vertical levels (surface to 3,000 m depth), monthly time increment from January 1945 to December 2014 now available at the NOAA/NCEI website: http://data.nodc.noaa.gov/cgi-bin/iso?id=gov.noaa.nodc:0140938. The sound velocity decreases from 1945 to 1975 and increases afterwards due to global climate change. Effect of the inter- and intra-annual (T, S) variability on acoustic propagation in the Yellow Sea is investigated using a well-developed acoustic model (Bellhop) in frequencies from 3.5 kHz to 5 kHz with sound velocity profile (SVP) calculated from GDEM and SMG datasets, various bottom types (silty clay, fine sand, gravelly mud, sandy mud, and cobble or gravel) from the NAVOCEANO's High Frequency Environmental Algorithms (HFEVA), source and receiver depths. Acoustic propagation ranges are extended drastically due to the inter-annual variability in comparison with the climatological SVP (from GDEM). Submarines' vulnerability of detection as its depth varies and avoidance of short acoustic range due to inter-annual variability are also discussed.

10186-30, Session 7

Regularized learning of linear ordered-statistic constant false alarm rate filters

Timothy C. Havens, Ian Cummings, Michigan Technological Univ. (United States); Jonathan Botts, Jason E. Summers, Applied Research in Acoustics LLC (United States)

The linear ordered statistic (LOS) is a parameterized ordered statistic (OS) that is a weighted average of a rank-ordered sample. LOS operators are useful generalizations of aggregation as they can represent any linear aggregation, from minimum to maximum, including conventional aggregations, such as mean and median. In the fuzzy logic field, these aggregations are called ordered weighted averages (OWAs). Here, we present a method for learning LOS operators from training data, viz., data for which you know the output of the desired LOS. We then extend the learning process with regularization, such that a lower complexity or sparse LOS can be learned. Hence, we discuss what 'lower complexity' means in this context and how to represent that in the optimization procedure. Finally, we apply our learning methods to the well-known constant-false-alarm-rate (CFAR) detection problem, specifically for the case of background levels modeled by long-tailed distributions, such as the K-distribution. These backgrounds arise in several pertinent imaging problems, including the modeling of clutter in synthetic aperture radar and sonar (SAR and SAS) and in wireless communications.

10186-31, Session 7

Three-dimensional model of hydro acoustic channel for research MIMO systems

Valentin P. Fedosov, Andrei Legin, Southern Federal Univ. (Russian Federation); Vyacheslav V. Voronin, Don State Technical Univ. (Russian Federation); Anna V. Lomakina, Southern Federal Univ. (Russian Federation)

Nowadays active development hydroacoustic wireless modems that are used for effective data transmission in the underwater channel. These developments are relevant today, as are used in various fields of science and spheres of activity. An example is the relationship with the underwater vehicles for scientific, research, search and rescue purposes. Development of this kind of communication systems (modems) is a difficult task because signal propagation is affected by various factors. The acoustic channel, especially in the shelf zone, is subject to multipath propagation of signals from the receiver to the transmitter, reverb, attenuation range, the frequency of the emitted signal and etc. Also, when moving the mobile and/or base station signal propagation constantly varies, there are the effects of signal fading, Doppler effect, which leads to a distortion of the transmitted information. The task of the developers of underwater communication systems is to create systems that can work in a changing transmission channel.

To solve the problems of development and research of algorithms of forming and signal processing, the choice of methods of coding is necessary to have a model of hydroacoustic channel. To date there is no comprehensive standards that describe the hydroacoustic channel, because the characteristics of underwater channels in various parts of the world are different and it is difficult to develop a suitable standard that would cover all the possible features of the aquatic environment.

As a result of research has been developed and investigated a three-dimensional model of hydroacoustic channel, describing the propagation of signals in the shelf zone, the data transmission system based on MIMO technology. Model considers the volume, surface and bottom reverberation, reflections from local objects. As the movement of the base stations and / or mobile station relative to each other, the signal attenuation caused by absorption of range and frequency, consider the effect of the antenna systems of transmitting and receiving stations, which may have a different structure (for a three-dimensional model uses a square array to form patterns in the azimuth plane and the elevation angle). Also consider the effect of directional diagrams forms depending on the signals at the outputs of antenna elements algorithms, in the case of forming algorithms and adaptive processing of spatiotemporal signals.

10187-1, Session 1

Lessons learned in the execution of advanced x-ray material discrimination *(Invited Paper)*

Sharene Young, DHS, S&T Div. (United States)

Advanced X-ray Material Discrimination (AXMD) or BAA 13-05 was a broad agency announcement which was initiated in order to develop solutions to the following problem. The emergence of improvised explosive threats and their use by terrorists has placed many challenges on the aviation security screening layers. EDS and AT X-ray equipment have been presented with considerable challenges in developing a broad detection capability for improvised explosive threats during security screening of checked bags and carry-on items.

Technologies are needed that increase the measurement or mathematical discrimination between improvised explosive threats and stream-of-commerce clutter in checked baggage and carry-on items. Conventional EDS utilizes two basic discriminating signatures: effective atomic number and density of screened objects. R&D is needed to identify additional discriminating signatures between improvised explosive threats and stream-of commerce clutter to improve detection capability with reduced false alarm rates.

DHS S&T EXD along with stakeholders at the TSA, TSL, and the UK Home Office have been successful in funding efforts to address and potentially provide operational solutions which can be deployed as part of the Next Generation of X-ray Technologies.

10187-2, Session 1

Prospects for using coherent x-ray scatter for material discrimination at a checkpoint

Edward D. Franco, Rapiscan Systems Labs. (United States)

Rapiscan has developed a pre-prototype of a system that combines dual-energy radiography and coherent x-ray scatter for material discrimination. This system was used to collect data with explosives in bags and bins under a wide range of clutter conditions. The performance of this system and the implications of moving this technology to the checkpoint will be presented.

10187-3, Session 1

Simulations of phase imaging with polycapillary optics

Jonathan C. Petruccelli, Univ. at Albany (United States); Bushra Kanwal, Punjab Univ. (Pakistan); Carolyn A. MacDonald, Univ. at Albany (United States)

X-ray phase imaging is known to enhance contrast, particularly for low atomic number materials, for which absorption contrast is low. However, it requires spatial coherence which is typically achieved with a small (10 to 50 μm) source, or a grating placed in front of the source to essentially break it into multiple small sources. In a previous experiment, polycapillary focusing optics were shown to improve coherence when employed to focus x rays from a large spot rotating anode to a smaller secondary source. Edge-enhancement to noise ratios up to a value of 6.5 were obtained, and sufficiently high quality data was obtained from a single image to allow for phase reconstruction using a phase attenuation duality approach. Alternatively, polycapillary optics might operate in place of a source grating to effectively divide the source into a very large number of small channels. In order to examine the potential use of polycapillary optics to enhance phase imaging, the phase and coherence properties of the optic were modeled by observing the fringe visibility in a simulated Young's double slit experiment. The optic was modeled using simple ray tracing in a Monte Carlo simulation, with the phase advance associated with each photon path computed from the path length and phase changes upon each reflection through the polycapillary tube. Fringes, which disappeared with a large source, were maintained after the optics, implying that beam coherence was observed for both the collimating and focusing polycapillary optics.

10187-4, Session 1

X-ray coherent scattering tomography of textured material

Zheyuan Zhu, Shuo Pang, CREOL, The College of Optics and Photonics, Univ. of Central Florida (United States)

Small-angle X-ray scattering (SAXS) measures the signature of angular-dependent coherently scattered X-rays, which contains richer information in material composition and structure compared to conventional absorption-based computed tomography. SAXS image reconstruction method of a 2 or 3 dimensional object based on computed tomography, termed as coherent scattering computed tomography (CSCT), enables the detection of spatially-resolved, material-specific isotropic scattering signature inside an extended object, and provides improved contrast for medical diagnosis, security screening, and material characterization applications. However, traditional CSCT methods assumes materials are fine powders or amorphous, and possess isotropic scattering profiles, which is not generally true for all materials. Anisotropic scatters cannot be captured using conventional CSCT method and result in reconstruction errors. To obtain correct information from the sample, we designed new imaging strategy which incorporates extra degree of detector motion into X-ray scattering tomography for the detection of anisotropic scattered photons from a series of two-dimensional intensity measurements. Using a table-top, narrow-band X-ray source and a panel detector, we demonstrate the anisotropic scattering profile captured from an extended object and the reconstruction of a three-dimensional object. For materials possessing a well-organized crystalline structure with certain symmetry, the scatter texture is more predictable. We will also discuss the compressive schemes and implementation of data acquisition to improve the collection efficiency and accelerate the imaging process.

10187-5, Session 1

Monte Carlo simulations of a novel coherent scatter materials discrimination system

Laila Hassan, Sean Starr-Baier, Jeremy Wittkopp, Jonathan C. Petruccelli, Carolyn A. MacDonald, Univ. at Albany (United States)

X-ray coherent scatter imaging has the potential to improve the detection of liquid and powder materials of concern in security screening. While x-ray attenuation is dependent on atomic number, coherent scatter is highly dependent on the characteristic angle for the target material, and thus offers an additional discrimination. Conventional coherent scatter analysis requires pixel-by-pixel scanning, and so could be prohibitively slow for security applications. A novel slot scan system has been developed to provide rapid imaging of the coherent scatter at selected angles of interest, simultaneously with the conventional absorption images. Prior experimental results showed promising capability. In this work, Monte Carlo simulations were performed to assess discrimination capability and provide system optimization. Simulation analysis performed using the measured ring profiles for an array of powders and liquids, including water, ethanol and

peroxide. For example, simulations yielded a signal-to-background ratio (SBR) of 2.4 for a sample consisting of two vials, one containing ethanol (signal) and one water (background). This high SBR value is due to the high angular separation of the coherent scatter between the two liquids. The results indicate that the addition of coherent scatter information to single or dual energy attenuation images improves the discrimination of materials of interest.

10187-6, Session 2

Sparse view Compton scatter tomography with energy resolved data: experimental and simulation results *(Invited Paper)*

Brian H. Tracey, Eric L. Miller, Abdulla Desmal, Hamideh Rezaee, Tufts Univ. (United States); Jeffrey R. Schubert, Jeff Denker, Aaron Couture, American Science and Engineering, Inc. (United States)

The use of energy selective detectors for Compton Scatter Tomography holds the hope of enhancing imaging performance, especially for problems with limited view in presence of highly attenuating materials. We present a broken-ray forward model mapping mass density and photoelectrical coefficients into observed scattered photons, as well as an iterative reconstruction method. An experimental testbed was developed to test out the proposed scatter tomography concepts, providing both few-view transmission images as well as scatter data, and the testbed system was carefully calibrated. We present both simulation and experimental results demonstrating the impact of including measured scatter data in the tomographic reconstruction process.

10187-7, Session 2

Design and implementation of a fan beam coded aperture x-ray diffraction tomography system for checkpoint baggage scanning *(Invited Paper)*

Joel A. Greenberg, Mehadi Hassan, Duke Univ. (United States); Scott D. Wolter, Elon Univ. (United States)

X-ray diffraction tomography (XRDT) makes it possible to detect concealed targets based solely on their material properties. We have previously shown that coded aperture XRDT allows one determine the XRD form factor at each point throughout an object using a single measurement with no moving parts. Furthermore, by making use of broadband illumination and high-transparency codes, one can perform real-time tomography with off-the-shelf components.

While a wide range of system geometries are possible, we focus here on fan beam coded aperture XRDT systems, wherein a planar slice of the object is imaged in each measurement. After describing the basic system architecture and key components, we discuss the impact of design choices on image fidelity. In addition, we demonstrate the importance of combining transmission and scatter data to improve the overall detection performance. The results presented are based both on numerical simulations and experimental measurements made using our prototype checkpoint baggage scanner, which supports both coded aperture XRDT and multi-energy transmission imaging.

10187-8, Session 2

Creating an experimental testbed for information-theoretic analysis of architectures for x-ray anomaly detection

David Coccarelli, Joel A. Greenberg, Duke Univ. (United States); Sagar Mandava, The Univ. of Arizona (United States); Qian Gong, Duke Univ. (United States); James Huang, The Univ. of Arizona (United States); Amit Ashok, College of Optical Sciences, The Univ. of Arizona (United States); Michael E. Gehm, Duke Univ. (United States)

Anomaly detection requires a system that can reliably convert measurements of an object into knowledge about that object. Previously, we have shown that an information-theoretic approach to the design and analysis of such systems provides insight into system performance as it pertains to architectural variations in source fluence, view number/angle, spectral resolution, spatial resolution, etc. However, this work was based on simulated measurements which, in turn, relied on assumptions made in our simulation models and virtual objects.

In this work, we describe our experimental testbed capable of making transmission x-ray measurements. The spatial, spectral, and temporal resolution is sufficient to validate aspects of the simulation-based framework, including the forward models, bag packing techniques, and performance analysis. In our experimental CT system, designed baggage is placed on a rotation stage located between a tungsten-anode source and a spectroscopic detector array. The setup is able to measure a full 360 rotation with 18,000 views, each of which defines a 10 ms exposure of 1,536 detector elements, each with 64 spectral channels. During the presentation, we will show example reconstructions that highlight the capabilities of the spectral CT testbed.

Measurements were made of 1,000 bags that comprise 100 clutter instantiations each with 10 different target materials. In addition, hundreds of bags were scanned at fixed view positions with increased exposure time and higher temporal resolution. Moreover, we developed a systematic way to generate bags representative of our desired clutter and target distributions. This gives the dataset a statistical credibility valuable in future investigations.

10187-9, Session 2

Adaptive x-ray threat detection using sequential hypotheses testing with fan-beam experimental data

Ratchaneekorn Thamvichai, Liang-Chih Huang, The Univ. of Arizona (United States); Amit Ashok, College of Optical Sciences, The Univ. of Arizona (United States); Qian Gong, David Coccarelli, Joel A. Greenberg, Michael E. Gehm, Duke Univ. (United States); Mark A. Neifeld, The Univ. of Arizona (United States)

We employ an adaptive measurement system, based on sequential hypotheses testing (SHT) framework, for detecting material-based threats using experimental data acquired on an X-ray experimental testbed system. This testbed employs 45-degree fan-beam geometry and 15 views over a 180-degree span to generate energy sensitive X-ray projection data. Using this testbed system, we acquire multiple view projection data for 200 bags. We consider an adaptive measurement design where the X-ray projection measurements are acquired in a sequential manner and the adaptation occurs through the choice of the optimal “next” source/view system parameter. Our analysis of such an adaptive measurement design using the experimental data demonstrates a 3x-7x reduction in the probability of error relative to a static measurement design. Here the static measurement design refers to the operational system baseline that corresponds to a

sequential measurement using all the available sources/views. We also show that by using adaptive measurements it is possible to reduce the number of sources/views by nearly 50% compared a system that relies on static measurements.

10187-10, Session 2

Interior tomographic imaging for x-ray coherent scattering

Sean Pang, Zheyuan Zhu, CREOL, The College of Optics and Photonics, Univ. of Central Florida (United States)

Conventional computed tomography reconstructs the attenuation only high-dimensional images. Coherent scatter computed tomography, which reconstructs the angular dependent scattering profiles of 3D objects, can provide molecular signatures that improves the accuracy of material identification and classification. Coherent scatter tomography are traditionally acquired by setups similar to x-ray powder diffraction machine; a collimated source in combination with 2D or 1D detector collimation in order to localize the scattering point. In addition, the coherent scatter cross-section is often 3 orders of magnitude lower than that of the absorption cross-section for the same material. Coded aperture and structured illumination approaches has been shown to greatly improve the collection efficiency. In many applications, especially in security imaging and medical diagnosis, fast and accurate identification of the material composition of a small volume within the whole object would lead to an accelerated imaging procedure and reduced radiation dose. Here, we report an imaging method to reconstruct the material coherent scatter profile within a small volume. The reconstruction along one radial direction can reconstruct a scalar coherent scattering tomographic image. Our methods takes advantage of the finite support of the scattering profile in small angle regime. Our system uses a pencil beam setup without using any detector side collimation. Coherent scatter profile of a 10 mm scattering sample embedded in a 30 mm diameter phantom was reconstructed. The setup has small form factor and is suitable for various portable non-destructive detection applications.

10187-11, Session 3

System modeling, computing architecture, and reconstructions for a carry-on luggage scanner employing coherent x-ray scatter detection *(Invited Paper)*

Kenneth P. MacCabe, Physical Numerics (United States); Edward D. Franco, Jonathan Kerner, Rapiscan Systems Labs. (United States)

We adapt coherent x-ray scatter imaging to carry-on luggage scanners through co-design of detection hardware and software. Previous laboratory experiments have shown great promise for coded aperture systems to rapidly recover coherent momentum transfer spectra. Until now, these demonstrations have involved relatively small scan volumes. Scalability to real-size scanners is achieved by defining a basic design unit: a scatter "module" consisting of a coded aperture, a detector panel, and a (shared) x-ray generator. Through careful placement of multiple modules, scatter measurements are collected from the entire reconstruction volume. As is the case for transmission-based imaging, for the scatter system a second x-ray generator provides a near-orthogonal "view" which improves the reconstruction results by better localization of the electron density through parallax. Unlike transmission imaging, however, a 3D (plus momentum) tomographic image may be reconstructed using only one x-ray emitter location due to the spatial resolving power of the coded apertures in the scatter configuration. The modular design of the measurement system is mirrored by the reconstruction software, which partitions the problems of forward projection and back-projection accordingly. Details on the physics model developed for this system are included, as well as approximations used to accelerate calculations. Progress toward real-time processing is presented, as well as reconstruction performance on CPU and GPU hardware. Additionally, we demonstrate scalable distributed processing with multiple computers on a TCP/IP network.

10187-12, Session 3

Multi-energy penalized maximum-likelihood reconstruction for x-ray security imaging

David G. Politte, Jingwei Lu, Joseph A. O'Sullivan, Washington Univ. in St. Louis (United States); Eric Johnson, Carl Bosch, SureScan Corp. (United States)

X-ray imaging for security screening is a challenging application that requires simultaneous satisfaction of seemingly incompatible constraints, including low cost, high throughput, and reliable detection of threats. The marketplace has provided a variety of proposed solutions which differ greatly in their technological approaches, including the design and configuration of hardware and of implementation of algorithms for detecting threats. We maintain that these stringent requirements are best met by taking a principled computational imaging approach to system design. Mathematical models of the underlying physics and a Huber-class penalty function yield a penalized maximum-likelihood problem. We've previously implemented an iterative algorithm on multiple GPUs to rapidly reconstruct accurate image volumes of linear attenuation coefficients (LACs). The SureScan x1000 is capable of collecting photon counting data in multiple energy bins; currently 3 bins are used. The x1000 has an unconventional, fixed-source geometry without circular symmetry for which algorithms like filtered backprojection cannot be applied. Current extensions to the reconstruction utilize all the energy bins to jointly reconstruct into various bases, such as LACs at different energies, effective atomic number and electron density, or material decompositions. The goal is to maintain spatial resolution of the existing single-energy reconstruction while providing information for material characterization which can be used for detection of threats. Performance is demonstrated on sample bags containing NIST phantoms.

10187-13, Session 3

Representation-learning for anomaly detection in complex x-ray cargo imagery

Jerone T. A. Andrews, Univ. College London (United Kingdom); Edward J. Morton, Rapiscan Systems Ltd. (United Kingdom); Lewis D. Griffin, Univ. College London (United Kingdom)

Previous approaches to automated security image analysis focus on the detection of particular classes of threat. However, this mode of inspection is ineffectual when dealing with mature classes of threat, for which adversaries have refined effective concealment techniques. To detect these hidden threats, customs officers often observe anomalies of shape, texture, weight, feel or response to perturbation. Inspired by the practice of customs officers, we are developing algorithms to discover visual anomalies in X-ray images.

This paper investigates an anomaly detection framework, at X-ray image patch-level, for the automated discovery of absolute-, positional-, and relative-anomalies. The framework consists of two main components: (i) automated feature-learning, and (ii) the detection of anomalies relative to those features.

The development of discriminative features is problematic; as only normal data is available. Therefore, we pursue automatically learnt features that have been optimised for a related, very general, task on similar data. The features, for each patch, are then scored using an Isolation Forest – a machine learning algorithm for general-purpose anomaly detection in data. The Forest is constructed under the working assumption that anomalies are 'few and different'. Therefore, patches that are more readily separated from the main cluster, by randomly selected criteria, give rise to higher anomaly scores. The patch-level results are then fused into an overall anomaly heat map of the entire container, to facilitate human inspection. Lastly, our system is evaluated qualitatively using illustrations of example outputs and test cases with real and contrived anomalies.

10187-14, Session 3

Image reconstruction for view-limited x-ray CT in baggage scanning

Sagar Mandava, The Univ. of Arizona (United States); Amit Ashok, College of Optical Sciences, The Univ. of Arizona (United States); Ali Bilgin, The Univ. of Arizona (United States)

X-ray CT based baggage scanners are widely used in security applications. Recently, there has been increased interest in view-limited systems which can potentially improve the scanning throughput while maintaining the threat detection performance. However as very few view angles are acquired in these systems the image reconstruction problem is challenging. Standard reconstruction algorithms like the filtered backprojection create strong artifacts when dealing with view limited data. In this work, we study the performance of a variety of reconstruction algorithms for both single and multi-energy view-limited systems.

10187-15, Session 4

Towards brilliant, compact x-ray sources: a new x-ray photonic device *(Invited Paper)*

Brian Scherer, Sudeep Mandal, Joshua Salisbury, Susanne M. Lee, Peter M. Edic, Forrest Hopkins, GE Global Research (United States)

Commercially available x-ray optics are not suitable for applications like baggage scanning that require concentration of polychromatic x-rays having energies greater than 100 KeV. To fill this need and move towards x-ray sources that are brilliant and compact, General Electric has designed an innovative x-ray photonic device that concentrates a polychromatic beam of diverging x-rays into a less divergent, parallel, or focused beam of x-rays over a wide operating range of 20-300 KeV. The photonic device consists of multiple, thin film multilayer stacks. X-rays incident on a given multilayer stack propagate within a high refractive index transmission layer while undergoing multiple total internal reflections off a novel, engineered lower refractive index multilayer. This talk will begin with discussing how the solid phase nature of GE's x-ray photonic device and the total internal reflection physics enables operation over a wide energy range. The talk will conclude with a discussion of key materials engineering challenges and GE's progress towards fabricating prototype devices.

10187-16, Session 4

The acceleration of electrons with light and x-ray generation in nanostructures *(Invited Paper)*

Kenneth J. Leedle, Huiyang Deng, Yu Miao, James S. Harris Jr., Jack M. Jiang, Stanford Univ. (United States)

High energy particle beams and their generation of X-rays have been foundational elements in physics research the past 7 decades [1] and medical therapy [2]. The acceleration is achieved by high power radio frequency (RF) fields. Unfortunately, their widespread availability is seriously limited by their enormous size and huge cost, creating a strong need for alternatives. Over the past 5 years, a new breed of accelerator nanotechnologists using technologies driven by advances in semiconductor fabrication and "Moore's Law" have now demonstrated several KeV acceleration on micron scale dimensions using high peak power lasers in dielectric nano- structures—a Dielectric Laser Accelerator (DLA)–whose near fields synchronously accelerate charged particles. [4,5,6] To realize a practical "accelerator on a chip", we are developing an integrated system with several crucial elements: dielectric nano-structures serve as phase masks for sustained energy gain, self-focusing structures to keep the beam well collimated, waveguides for efficient energy coupling and dielectric "undulators" for the generation of X-rays.

We have demonstrated these essential elements with sub-relativistic electron beams and will describe progress in laser electron acceleration with silicon dual-pillar grating structures with record high acceleration gradients [5] and optically-driven transverse self-focusing of the electron beam [6].

[1] Lee, S. Y., Accelerator Physics, World Scientific Publishing Co. Ptc. Ltd. Singapore (2012). [2] McNeil, B. W. J. et. al., Nature Photonics 4, 814 (2010).

[3] Wilson, R. R., Radiology 47, 487 (1946).

[4] Peralta, E. A. et al. Nature 503, 91-94 (2013).

[5] Leedle, K., et. al., Optica 2 158-161 (2015). [6] Leedle, K. J. et al. Opt. Lett. 40, 4344 (2015).

10187-17, Session 4

Multi-energy x-ray detectors to improve air-cargo security

Caroline Paulus, Vincent Moulin, CEA-LETI (France); Didier Perion, Patrick Radisson, Multix (France); Loïck Verger, CEA-LETI (France)

X-ray based systems have been used for decades to screen luggage or cargo to detect illicit material. The advent of energy-sensitive photon-counting x-ray detectors mainly based on Cd(Zn)Te semi-conductor technology enables to improve discrimination between materials compared to single or dual energy technology. The presented work is part of the EUROSKY European project to develop a Single European Secure Air-cargo Space.

Firstly, a comparison on simulated measurements shows the performances improvement of the new multi-energy detectors compared to the current dual-energy one. The relative performances are evaluated according to different criteria of separability or contrast-to-noise ratio and the impact of different parameters is studied (influence of channel number, type of materials and tube voltage).

Secondly, performances of multi-energy detectors for overlaps processing in a dual-view system is accessed. "Cargo" context implies the presence of relatively heavy objects and with potentially high atomic number. Therefore, calibration and processing based on bi-material decomposition have been adapted for this purpose. For the dual view approach, the case of orthogonal projections has been studied, one giving dimensional values, the other one providing spectral data to assess effective atomic number. A method of overlap correction has been proposed and extended to multi-layer objects case.

All the study is conducted on simulations with three different detectors: a typical dual energy sandwich detector, a realistic model of the commercial ME100 multi-energy detector marketed by MULTIX, and a ME100 "Cargo": a not yet existing modified multi-energy version of the ME100 more suited to air freight cargo inspection).

10187-19, Session 4

Impact of sub-pixelation within CdZnTe detectors for x-ray diffraction imaging systems

Joachim Tabary, Caroline Paulus, Guillaume Montémont, Loïck Verger, CEA-LETI (France)

X-ray diffraction is known to be an effective technique for illicit materials detection in baggage screening, as it can reveal molecular structural information of any solid substances but also of liquids, aerosols and gels. Some x-ray diffraction systems using 2D pixelated spectrometric detectors, such as CdZnTe detectors, are then able to perform 3D baggage scanning in time compatible with bag throughput constraints of airports. However, as this technique often requires use of thick collimations to preserve angular resolution, it suffers from poor sensitivity and bad spatial resolution (several cm) in the x-ray beam direction.

The CEA-LETI designs CdZnTe detectors in which it implements some specific detector-level signal processing in order to optimize both energy and spatial resolution thanks to subpixel positioning. Using sub-pixelation along the scatter angle dimension enables to improve trade-off between angular resolution and sensitivity and also the spatial resolution along the depth direction of the imaged baggage.

To make the most of this sub-pixelation, an original reconstruction processing has been developed to restore the diffraction profiles of the different materials of the baggage from the measured diffraction spectra on each subpixels. This reconstruction algorithm removes the different factors which degrade the scatter spectra. In particular, the attenuation object is corrected thanks to the transmitted spectrum simultaneously measured with another spectrometric CdTe detectors, dedicated to high count rates. An experimental demonstration will be presented, with a 2D XRD image of a realistic baggage performed with only one single pixel from our own CdZnTe based imager.

10187-20, Session 5

Classification-free threat detection based on material-science-informed clustering

Scott D. Wolter, Elon Univ. (United States); Joel A. Greenberg, Duke Univ. (United States)

Transmission-based imaging has been the workhorse of modern X-ray baggage scanners. Depending on the configuration used, one can obtain estimates of the density (rho) and effective atomic number (Z) of baggage objects, which enables some degree of materials-based threat detection. Nevertheless, typical uncertainties associated with these measurements and proximity of many threat and non-threat materials in Z-rho feature space make it impossible to perform threat detection with a sufficiently low probability of error. To remedy this, additional degrees of freedom have been previously studied; in particular, the diffracted X-rays (i.e. those that undergo coherent scatter in the target material) contain information about the micro-molecular structure of an object. By measuring the spatio-spectral distribution of scattered X-rays, one maps out the scatter form factor [f(q)] as a function of photon momentum transferred to the material and introduces many additional degrees of freedom by which to distinguish different materials. Once the material of interest is known, its threat status can be determined. This method, however, is inefficient and potentially problematic: determining the specific material may require extra resources (e.g. time or source brightness) and classification is impossible for materials not present in a reference library. In this talk, we work with a large material database (over 400 materials) and investigate the ability to determine the threat status of a target object without first requiring material classification. Our approach is based on a combination of conventional cluster analysis techniques and material science insights to identify the key distinguishing features in Z-rho-f(q) space.

10187-21, Session 5

A deep learning framework for the automated inspection of complex dual-energy x-ray cargo imagery

Thomas W. Rogers, Nicolas Jaccard, Univ. College London (United Kingdom); Edward J. Morton, Rapiscan Systems Ltd. (United Kingdom); Lewis D. Griffin, Univ. College London (United Kingdom)

Previously, we investigated the use of Convolutional Neural Networks (CNNs) to detect so-called Small Metallic Threats (SMTs) hidden amongst legitimate goods inside a cargo container. We trained CNNs using a Threat Image Projection (TIP) framework that generates realistic variation to robustify performance. We achieved 90% detection of containers that contained an SMT, while raising 6% false positives on benign containers. Moreover, the full cargo image was processed in 3.5s - much faster than a human operator. The best CNN architecture used the raw high energy image (single-energy) and its logarithm as input channels. Use of the logarithm improved performance, thus echoing findings in human operator performance. However it is an unexpected result with CNNs.

We use this finding as motivation to improve SMT detection performance by investigating (i) common single-energy image manipulations (e.g. square-root, histogram equalisation) used by operators when searching for SMTs, (ii) the use of full dual-energy images which encode information about material type, and (iii) different CNN architectures for exploiting multiple input channels. To our knowledge this is the first time that CNNs have been applied to dual-energy X-ray imagery, in any field. To exploit dual-energy, we experiment with adapting several physics-derived approaches to material discrimination from the cargo literature. Such methods have been shown to perform well at material discrimination in laboratory set-ups, however researchers have struggled to fully exploit dual-energy in commercial systems due to noise. We investigate whether a learning-based approach can better exploit the material information encoded within dual-energy images.

10187-23, Session 5

Performance estimation for material discrimination in CT systems *(Invited Paper)*

Trent Montgomery, Clem Karl, David Castanon, Boston Univ. (United States)

Detecting the presence of hazardous materials in suitcases and carry-on luggage is an important problem in aviation security. As the set of threats is expanding, there is a corresponding need to increase the capabilities of explosive detection systems to address these threats. However, there is a lack of principled tools for predicting the performance of alternative designs for detection systems. In this paper, we describe an approach for computing bounds on the achievable classification performance of material discrimination systems based on empirical statistics that estimate the f-divergence of the underlying features. Our approach can be used to examine alternative physical observation modalities and measurement configurations, as well as variations in reconstruction and feature extraction algorithms.

10188-1, Session 1

Passive coherent location direct signal suppression using hardware mixing techniques

Sean A. Kaiser, The Pennsylvania State Univ. (United States); Andrew J. Christianson, Naval Surface Warfare Ctr. Crane Div. (United States); Ram M. Narayanan, The Pennsylvania State Univ. (United States)

Passive coherent location (PCL) is a radar field, in which the system uses reflections from opportunistic illumination sources in the environment for detection and tracking. Typically PCL uses civilian communication transmitters not ideally suited for radar. The physical geometry of PCL is developed on the basis of bistatic radar without control of the transmitter antenna or waveform design. This poses the problem that often the receiver is designed with two antennas and channels, one for reference and one for surveillance. The surveillance channel is also contaminated with the direct signal and thus direct signal suppression (DSS) techniques must be used. This paper proposes an analytical solution based around hardware for DSS and is compared to other methods available in the literature. The methods are tested in varying bistatic geometries and with varying target RCS and SNR.

10188-2, Session 1

Multistatic passive coherent location resource optimization

Sean A. Kaiser, The Pennsylvania State Univ. (United States); Andrew J. Christianson, Naval Surface Warfare Ctr. Crane Div. (United States); Ram M. Narayanan, The Pennsylvania State Univ. (United States)

Passive Coherent Location (PCL) is a developing radar field, in which the system processes reflections from opportunistic illumination sources in the environment for detection and tracking. Many developments and improvements of PCL implement pseudo-monostatic and bistatic radar configurations; however, with the proliferation of commercial communication systems, the spectrally dense environment proves to be in favor of a heterogenous multistatic PCL system. This paper develops error minimization criteria to adjust and optimize available resources to a wideband PCL receiver. The method introduces the concept of self ambiguity as an error metric and implements this as a criteria to test varying PCL scenarios with different transmitter modulation waveforms. The paper compares this to available techniques and the global minimum error available.

10188-3, Session 1

Continuous high pulse repetition frequency (HPRF) mode for challenging environments

Steven Jaroszewski, Allan F. Corbeil, Technology Service Corp. (United States); David Sobota, Air Force Research Lab. (United States)

Novel methods of increasing the detection sensitivity of air-to-air radar are being investigated and tested to address challenging environments. The time-on-target (TOT) of HPRF air-to-air waveforms is typically divided into multiple short coherent processing intervals (CPIs) that employ PRF and frequency diversity. This prevents the possibility that targets are range eclipsed, allows target slant range estimation and provides multiple independent looks to improve the detection performance for high SNR targets. However, such waveforms are not optimal for detecting lower RCS or long range targets. The Continuous HPRF approach extends the CPI over the full TOT to greatly improve the SNR and improve detection performance of low SNR targets. Simultaneously, these techniques overcome the range eclipsing, target range estimation and multiple look drawbacks of a single long CPI. Increasing the CPI of HPRF radar also increases the target to clutter ratio (TCR) and improves detection performance of targets in sidelobe clutter. We present an overview of Continuous HPRF techniques; summarize target detection/tracking performance improvement and computational complexity. Continuous HPRF technology can greatly improve the detection range, angle measurement accuracy, velocity resolution, and overall tracking performance of airborne radars against small targets in sidelobe clutter, such as look-down encounters.

10188-4, Session 1

Automatic change detection using very high-resolution SAR images and prior knowledge about the scene

Carlos Villamil Lopez, Deutsches Zentrum für Luft- und Raumfahrt e.V. (Germany) and Technische Univ. München (Germany); Timo Kempf, Rainer Speck, Deutsches Zentrum für Luft- und Raumfahrt e.V. (Germany); Uwe Stilla, Technische Univ. München (Germany)

Change detection using very high resolution SAR images is an important source of information for reconnaissance applications. Modern SAR sensors are capable of acquiring many images in short periods of time, which creates the need for a reliable automatic change detection method. In this paper, we will describe a new automatic change detection approach that combines very high resolution SAR images with prior knowledge about the imaged scene. In this case, the prior knowledge about the scene will come from vector maps, which can be obtained from a Geographic Information System (GIS) or from the classification of an optical image. These vector maps will allow us to determine which regions are of interest for the change detection, and what kind of changes/objects can be expected there. Besides, this knowledge can also help to set the thresholds used for the change detection, and it also makes it possible to set different thresholds for different regions of the image. Results obtained using a time series of high resolution TerraSAR-X images will be shown for different scenes of interest, like a port with military shipyards. In this case, the vector maps were obtained from a Geographic Information System (GIS) containing map data from OpenStreetMap.

10188-5, Session 1

On results using automated wideband instrumentation for radar measurements and characterization

Mark A. Govoni, U.S. Army CERDEC Intelligence and Information Warfare Directorate (United States)

Experiences are shared from our recently established radar measurement and characterization capability (MC2). Results will show that despite chamber size and absorptive material limitations, high quality measurements are still achievable. By adhering to a regimented collection procedure including the use of calibrated hardware and efficient signal processing, the author will present findings that circumvent the preconceived notion that one absolutely needs a sophisticated collection environment for high quality, radar measurements. Data products including radar cross section (RCS) measurements, high-range resolution (HRR) profiles, and tomographic images will be included in the discussions.

10188-6, Session 1

Mapping detailed 3D information onto high-resolution SAR signatures

Harald Anglberger, Rainer Speck, Deutsches Zentrum für Luft- und Raumfahrt e.V. (Germany)

Due to challenges in the visual interpretation of radar signatures or in the subsequent information extraction, a fusion with other data sources can be beneficial. The most accurate basis for a fusion of any kind of remote sensing data is the mapping of the acquired 2D image space onto the true 3D geometry of the scenery. In the case of radar images this is a challenging task because the coordinate system is based on the measured range which causes ambiguous regions due to layover effects. This paper describes a method that accurately maps the detailed 3D information of a scene to the slant-range-based coordinate system of an imaging radar. Due to this mapping all the contributing geometrical parts of one resolution cell can be determined in 3D space. The proposed method is highly efficient, because computationally expensive operations can be directly performed on graphics card hardware. The described approach builds a perfect basis for sophisticated methods to extract data from multiple complimentary sensors like from radar and optical images, especially because true 3D information from whole cities will be available in the near future. The performance of the developed methods will be demonstrated with high resolution radar data acquired by the space borne SAR-sensor TerraSAR-X.

10188-7, Session 2

A low-cost through-the-wall FMCW radar for stand-off operation and activity detection

Kevin Chetty, Qingchao Chen, Matthew Ritchie, Karl Woodbridge, Univ. College London (United Kingdom)

We present a new through-the-wall (TTW) FMCW radar. The system architecture enables both high signal-to-noise ratios (SNR) and range resolutions of <1.5m. Moreover, the radar employs novel signal processing to remove the problematic primary wall reflection, allowing higher SNR's, which can be traded-off for increased operational stand-off. The system is an order of magnitude lower in cost than competitor UWB TTW systems.

The TTW radar operates at 5.8GHz with a 200MHz bandwidth. Its dual-frequency design minimises interference from signal leakage, and permits a baseband output after deramping which is digitized using an inexpensive 24-bit COTS sound card. The high sensitivity afforded by this wide dynamic range has allowed us to develop a software-based wall removal technique whereby high-order digital filters provide a flexible means of filtering based on the phases of echoes.

Experimental data demonstrates detection of people in a standard brick-walled house at various standoff distances, and undergoing different types of activities. Target positions were located to within ±1.25m in range, allowing us distinguish between two closely separated targets. Furthermore, at 8.5m standoff, our wall mitigation technique is able to recover target responses that would have otherwise been masked.

The TTW radar has the capability to measure micro-motions of objects using phase processing of the recorded signals. Examination of our experimental data illustrates a clear difference in the micro-Doppler signatures between single and multiple personnel targets, and across various types of actions. A multiple antenna configuration is also being examined for selectively probing different sectors of a room.

10188-8, Session 2

A coherent through-wall MIMO phased array imaging radar based on time-duplexed switching

Qingchao Chen, Kevin Chetty, Paul Brennan, Matthew Ritchie, Lai Bun Lok, Karl Woodbridge, Univ. College London (United Kingdom)

Through-Wall (TW) radar sensors are gaining increasing interest for security, surveillance and search & rescue applications. Additionally, the integration of Multiple-Input, Multiple-Output (MIMO) techniques with phased array radar is allowing higher performance at lower cost. In this paper we present a 4-by-4 TW MIMO phased array imaging radar operating at 2.4 GHz with 200 MHz bandwidth. To achieve high imaging resolution in a cost-effective manner, the 4 Tx and 4 Rx elements are used to synthesize a uniform linear array of 16 virtual elements. Furthermore, the transmitter is based on a single-channel 4-element time-multiplexed switched array. In transmission, the radar utilises frequency modulated continuous wave (FMCW) waveforms that undergo de-ramping on receive to allow digitisation at relatively low sampling rates, which then simplifies the imaging process. This architecture has been designed for the short-range TW scenarios envisaged, and permits sufficient time to switch between antenna elements. The paper first outlines the system characteristics before describing the key signal processing and imaging algorithms which are based on Multiple Signal Classification (MUSIC), and the custom and intelligent signal processing methods to suit the proposed system. These techniques are implemented in LabVIEW software. Finally, we report results from an experimental campaign that investigated the imaging capabilities of the system through various types of walls, and demonstrated the detection of personnel targets. Moreover, we show that multiple targets within a room with greater than approximately 1 meter separation can be distinguished from one another.

10188-9, Session 2

Theoretical considerations for a dynamic calibration device for through-wall and through-rubble radar

Michael J. Harner, Matthew J. Brandsema, Ram M. Narayanan, The Pennsylvania State Univ. (United States); John R. Jendzurski, Nicholas G. Paulter, National Institute of Standards and Technology (United States)

This paper discusses the theoretical considerations for a monostatic radar calibration device used for human detection in through-wall and through-rubble settings. Proper calibration of radar equipment, in regards to human detection, is problematic because of the human-body's complex and ever-changing radar cross section. The RCS depends heavily on a variety of factors such as height, body composition, orientation angle, and breathing rate; all of which will vary tremendously from person to person. Thus, typical calibration devices such as flat-plates and corner reflectors prove to be ineffective in this scenario. The solution to this problem is to use a large, dynamic, conducting sphere for calibration. A sphere is ideal due to its aspect independence which eliminates the issue of maintaining a precise orientation angle. The calibration target must be dynamic in that it must be able to expand and contract radially to simulate breathing while maintaining its aspect independent spherical structure. It turns out that the change in the radius to simulate breathing is quite small compared to the actual radius of the sphere whose radar cross section (RCS) is equivalent to that of a typical human. Various design options for the calibration target will be investigated through extensive simulations and their ability to mimic the breathing RCS of the human will be quantified.

10188-10, Session 2

Detection and tracking of human targets in indoor and urban environments using through-the-wall radar sensors

Vincent Radzicki, Univ. of California, Santa Barbara (United States); David Boutte, AKELA, Inc. (United States)

Radar based detection of human targets behind walls or in dense urban environments is an important technical challenge with many practical applications in security, defense, and disaster recovery. Typical radar reflections from a human can be orders of magnitude weaker than those from objects encountered in urban settings such as walls, cars, or possibly rubble after a disaster. Furthermore, these objects can act as secondary reflectors and produce multipath returns off of a person. To mitigate these issues, processing of radar return data needs to be optimized for recognizing human motion features such as walking, running, or breathing. This paper will present a theoretical analysis on the modulation effects human motion has on the radar waveform and how high levels of multipath can distort these motion effects. From this analysis, an algorithm will be optimized for tracking human motion in heavily clutter environments. The tracking results will be used as the fundamental detection/classification tool to discriminate human targets from others by identifying human motion traits such as predictable walking patterns and periodicity in breathing rates. The theoretical formulations will be tested against simulated and measured data collected using a low power, portable see-through-the-wall radar system that could be practically deployed in real-world scenarios. Lastly, the overall detection performance will be evaluated in a series of carefully designed experiments where both a single person and multiple people are moving in an indoor, cluttered environment.

10188-11, Session 3

Polarization effects in quantum radar cross sections

Matthew J. Brandsema, Ram M. Narayanan, The Pennsylvania State Univ. (United States); Marco O. Lanzagorta, U.S. Naval Research Lab. (United States)

The quantum radar cross section (QRCS) is a representation of how visible a target appears to a quantum radar. This visibility is due to the way in which photons are scattered from the target after an impingement from an incoming cluster of photons. The mechanism by which this operates is the interaction between the photons polarization and the electric dipole moments of the atoms in the target. This paper derives a new QRCS equation that properly takes into account these polarization effects. It will be shown that under the right circumstances, this scattering mechanism can be exploited to produce some very interesting results that have no classical equivalent. Furthermore, the new equation will be general to any bistatic radar scenario.

10188-12, Session 3

The lemur conjecture

Marco O. Lanzagorta, U.S. Naval Research Lab. (United States); Jeffrey Uhlmann, Univ. of Missouri (United States); Oliverio Jitrik, The Ranken Institute (Mexico)

In previous research we used quantum radar principles to design an interferometric quantum seismograph that uses entangled photon states to enhance sensitivity in an optomechanic device. However, a spatially-distributed array of such sensors, with each sensor measuring only nm-vibrations, may not provide sufficient sensitivity for the prediction of major earthquakes because it fails to exploit potentially critical phase information. We conjecture that relative phase information can explain the anecdotal observations that animals such as lemurs exhibit sensitivity to impending earthquakes earlier than can be done confidently with traditional seismic technology. More specifically, we propose that lemurs use their limbs as ground motion sensors and that relative phase differences are fused in the brain in a manner similar to a phased-array or synthetic-aperture radar. In this paper we will describe a lemur-inspired quantum sensor network for early warning of earthquakes. The system uses 4 interferometric quantum seismographs (e.g., analogous to a lemur's limbs) and then conducts phase and data fusion of the seismic information. Although we discuss a quantum-based technology, the principles described can also be applied to classical sensor arrays.

10188-13, Session 3

Quantum radar for tectonic geodesy

Marco O. Lanzagorta, U.S. Naval Research Lab. (United States); Jeffrey Uhlmann, Univ. of Missouri (United States); Oliverio Jitrik, The Ranken Institute (Mexico)

The study of plate tectonic motion is important to generate theoretical models of the structure and dynamics of the Earth. In turn, understanding tectonic motion provides insight to develop sophisticated models that can be used for earthquake early warning systems and for nuclear forensics. Tectonic geodesy uses the position of a network of points on the surface of earth to determine the motion of tectonic plates and the deformation of the earth's crust. GPS and interferometric synthetic aperture radar are commonly used techniques used in tectonic geodesy. In this paper we will describe the feasibility of interferometric synthetic aperture quantum radar and its theoretical performance for tectonic geodesy.

10188-14, Session 3

Synthetic aperture quantum radar

Marco O. Lanzagorta, U.S. Naval Research Lab. (United States); Jeffrey Uhlmann, Univ. of Missouri (United States)

Synthetic aperture radar (SAR) uses sensor motion to generate finer spatial resolution of a given target area. In this paper we explore the theoretical potential of quantum synthetic aperture quantum radar (QSAR). We provide theoretical analysis and simulation results which suggest that QSAR to provide improved detection performance over classical SAR in the high-noise low-brightness regime. Practical applications are discussed.

10188-15, Session 3

Quantum imaging for underwater arctic navigation

Marco O. Lanzagorta, U.S. Naval Research Lab. (United States)

The precise navigation of underwater vehicles is a difficult task due to the challenges imposed by the variable oceanic environment. It is particularly difficult if the underwater vehicle is trying to navigate under the Arctic ice shelf. Indeed, in this scenario traditional navigation devices such as GPS, compasses and gyrocompasses are unavailable or unreliable. In addition, the shape and thickness of the ice shelf is variable throughout the year. Current Arctic underwater navigation systems include sonar arrays to detect the proximity to the ice. However, these systems are undesirable in a wartime environment, as the sound gives away the position of the underwater vehicle. In this paper we briefly describe the theoretical design of a quantum imaging system that could allow the safe and stealthy navigation of underwater Arctic vehicles.

10188-16, Session 3

Quantum ghost imaging in the oceanic environment

Marco O. Lanzagorta, U.S. Naval Research Lab. (United States); Jeffrey Uhlmann, Univ. of Missouri (United States); Oliverio Jitrik, The Ranken Institute (Mexico)

We examine the use of quantum radar and ghost imaging to identify differences between an underwater region of interest and a reference region with similar optical transmission characteristics. The goal is to determine whether "ghost imaging" can be used to improve the detection threshold of a target within the region of interest. We also consider the use of compressed sensing to reduce the computational complexity of the system. Analysis and simulation results are provided.

10188-17, Session 3

Enhanced sensing and communication via quantum networks

James F. Smith III, U.S. Naval Research Lab. (United States)

A network based on quantum information has been developed to improve sensing and communications capabilities. Quantum teleportation offers features for communicating information not found in classical procedures. It is fundamental to the quantum network approach. A version of quantum teleportation based on hyper-entanglement is used to bring about these improvements. Recently invented methods of improving sensing and communication via quantum information based on hyper-entanglement are discussed. These techniques offer huge improvements in the SNR, signal to interference ratio, and time-on-target of various sensors including RADAR and LADAR. Hyper-entanglement refers to quantum entanglement in more than one degree of freedom, e.g. polarization, energy-time, orbital angular momentum (OAM), etc. The quantum network makes use of quantum memory located in each node of the network, thus the network forms a quantum repeater. The quantum repeater facilitates the use of quantum teleportation, and superdense coding. Superdense coding refers to the ability to incorporate more than one classical bit into each transmitted qubit. The network of sensors and/or communication devices has an enhanced resistance to interference sources. The repeater has the potential for greatly reducing loss in communications and sensor systems related to the effect of the atmosphere on fragile quantum states. Measures of effectiveness (MOE) are discussed that show the utility of the network for improving sensing and communications in the presence of loss and noise. The quantum repeater will reduce overall size, weight, power and cost (SWAPc) of fielded components of systems.

10188-18, Session 4

Sparse-based signal processing techniques for stepped frequency ultra-wideband radar

Lam H. Nguyen, U.S. Army Research Lab. (United States)

The U.S. Army Research Laboratory (ARL) has been investigating the capability of low-frequency, ultra-wideband (UWB) synthetic aperture imaging radar (SAR) systems to detect buried and obscured targets. These systems must operate in the low-frequency spectrum that spans from the UHF band to L band in order to achieve both resolution and penetration capability. Since 2005, we have employed our vehicle-mounted system, which is based on UWB impulse technology, to study the detection of buried targets in forward-looking mode. Although the impulse-based architecture has its own advantages, there are several drawbacks. First, its wideband frontend receiver is open to radio-frequency interference (RFI) noise. Large RF sources can easily drive the receiver into saturation. Second, since digitizing wideband signals requires a fast analog-to-digital (A/D) converter, we had to implement the interleaved sampling technique to achieve an equivalent high sampling rate using much slower A/D converters. The side effect of using the interleaved sampling technique is the spread of RFI spectral contents to the entire radar spectrum, which results in increasing the noise floor of the radar data. Third, it is very difficult for an impulse-based radar to transmit a radar signal with an arbitrary bandwidth and shape. This feature is crucial for the radar to be compliant with the local frequency authority. In addition, being able to transmit signals with an arbitrary spectral shape is an important step in developing the next generation of radars.

Therefore, we have designed a next-generation prototype radar based on a stepped-frequency architecture to address these issues. In this paper, we will analyze the step frequency data from the upcoming data collection. We will examine the two most important issues: 1) RFI noise in radar data and 2) the resulting artifacts due to missing information in the spectral domain. We will develop and apply sparsity-driven signal processing techniques to the step frequency SAR data to mitigate RF noise and recover information from missing spectral data, and evaluate any performance improvement.

10188-19, Session 4

Multi-mission and multi-function airborne radar sensing with low cost system: case study of PARADOX1

Ramesh Nepal, Yan R. Zhang, The Univ. of Oklahoma (United States); William Blake, Joel Andrews, Garmin International, Inc. (United States)

Polarimetric Airborne Radar Operating at X-band (PARADOX) is an airborne radar system concept currently being developed. The PARADOX is based on existing low-cost GWX and GSX radar system products from Garmin. The innovation of the concept is developing enhanced multi-functions and capabilities on current airborne radar platform through new software and processing algorithms. This study focuses on merging the Sense and Avoid (SAA) and severe weather observation functions into the same platform, and potential of dual-polarization. Low-cost mechanical scanning radar helps to achieve the goal of Space, Weight and Power (SWaP) for airborne radars, especially for unmanned aerial vehicles (UAVs). On the other hand, there are significant technical challenges for implementing this concept, including the aperture size-limited angular resolution, the real-time software for multi-mission, and the re-use of radar hardware to meet different standard mission requirements. To address these challenges, we performed a series of new tests focusing on innovative solutions based on (a) Multi-domain (angular, range and Doppler) super-resolution processing algorithms. For example, the tests of the side-by-side comparison of small aperture airborne radar data with the larger aperture, ground-based radar data, (b) Real-time target detection, tracking and weather observation software and processor, (c) Implementation of the processing algorithms in high-performance, embedded computing platforms. Our experiments successfully demonstrated the effectiveness of these solutions in real-time and actual field experiments. The experiments validate the feasibility of the PARADOX concept. The implementations of the new technologies and algorithms, the test results, and comparisons will be presented.

10188-20, Session 4

RFID antenna design for circular polarization in UHF band

Hamza Shahid, Muhammad T. A. Khan, Umais Tayyab, King Fahd Univ. of Petroleum & Minerals (Saudi Arabia); Usama Bin Irshad, Electrical Engineering Department, King Fahd University of Petroleum & Minerals (Saudi Arabia); Emad Alkhazraji, Electrical and Electronic Engineering Technology Department, Jubail Industrial College (Saudi

Arabia); Muhammad Sharjeel Javaid, King Fahd University of Petroleum and Minerals (Saudi Arabia)

A miniature half cross dipole antenna for defense and aerospace RFID applications in UHF band is presented. The dipole printed line arms are half crossed shape on top of dielectric substrate backed by reactive impedance surface (RIS). The antenna fed by a coaxial cable at the gap separating the dipole arms. Our design is intended to work at 2.42 GHz for RFID readers. The radiation pattern obtained has HPBW of 112°, RL of 22.24 dB and 90 MHz bandwidth. A new approach towards half cross line diploe antenna using RIS in UHF band is considered. Using half cross line and RIS, the size of the antenna is considerably reduced. The overall size of the antenna comes to be 124mm x 124mm x 1.56mm. The results show a good performance of antenna in UHF band for permittivity of 4.8 and also for permittivity of 6.1. The antenna is suitable for RFID applications like tracking of military tools and equipment.

10188-21, Session 4

VideoSAR collections to image underground chemical explosion surface phenomena

David A. Yocky, Terry M. Calloway, Daniel E. Wahl, Sandia National Labs. (United States)

Fully-polarimetric X-band (9.6 GHz center frequency) VideoSAR flew collections before, during, and after the fifth Source Physics Experiment (SPE) underground chemical explosion. This paper presents synthetic aperture RADAR (SAR) and VideoSAR products created and their utility for monitoring the surface effects caused by the explosion. To our knowledge, this has never been done before.

Since VideoSAR is a continuous phase history, the imagery and coherent products can be chosen from any aspect to the SPE shot pad. Also, since the SAR was collecting during the underground explosion event, it captures the surface expression of the fifth SPE event.

Products created are "movies" of coherence maps, digital elevation maps, and magnitude imagery. These movies show the two-dimensional, real-time surface movement. However, since there were other objects such as timing and firing hardware on the SPE test pad, these objects created unwanted, vibrating signatures during the event. Nevertheless, there is evidence that the dynamic changes are captured by the SAR during the event.

VideoSAR provides a unique, coherent measure of surface expression of an underground explosion in real-time.

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.

The authors would like to thank the National Nuclear Security Administration, Defense Nuclear Nonproliferation Research and Development, for sponsoring this work, and the Source Physics Experiment team, a multi-institutional and interdisciplinary group of scientists and engineers, for its technical contributions.

10188-22, Session 4

Noise and LPI radar as part of counter-drone mitigation system measures

Yan R. Zhang, The Univ. of Oklahoma (United States); Long Nguyen, Air Force Life Cycle Management Ctr., Wright-Patterson Air Force Base (United States); Ramesh Nepal, The Univ. of Oklahoma (United States); Tyler Moudy, Air Force Material Command (United States); Yih-Ru Huang, The Univ. of Oklahoma (United States)

With the rapid proliferation of small unmanned aerial systems (UAS) in the national airspace, small operational drones are being sometimes considered as a security threat for critical infrastructures, such as sports stadiums, military facilities, and airports. There have been many civilian counter-drone solutions and products reported, including radar and electromagnetic counter measures. For the current electromagnetic solutions, they are usually limited to particular type of detection and counter-measure scheme, which is usually effective for the specific type of drones. Also, control and communication link technologies used in even RC drones nowadays are more sophisticated, making them more difficult to detect, decode and counter. Facing these challenges, our team proposes a "software-defined" solution based on noise and LPI radar. For the detection, wideband-noise radar has the resolution performance to discriminate possible micro-Doppler features of the drone versus biological scatterers. It also has the benefit of more adaptive to different types of drones, and covertly detecting for security application. For counter-measures, wideband noise can be combined with "random sweeping" jamming scheme, to achieve the optimal balance between peak power allowed and the effective jamming probabilities. Some theoretical analysis of the proposed solution is provided in this study, a design case study is developed, and laboratory experiments, as well as outdoor tests using a typical RC transceiver and servo, are conducted to validate the basic concepts and theories. It is shown that a radar-counter measure solution based on software-defined noise and LPI radar concept can be effectively used in practical scenarios.

10188-23, Session 4

Determining the coherence matrix for single look polarimetric SAR data

Jorge V. Geaga, Consultant (United States)

The coherence matrix from the scattering matrix of a single look polarimetric SAR pixel will have an entropy of zero with the main eigenvalue being equal to the span and the other two eigenvalues being equal to zero. Each scattering matrix element from terrain scatter is a coherent sum from a large number of scatterers in a resolution cell. Entropy/alpha decomposition is only possible where the coherency matrix elements are determined from ensemble covariances. This is the case for multilook polarimetric SAR data where covariances from the exact same collection of scatterers are averaged using separate extraction filters in the SAR doppler direction. We report interesting observations from analysis of multilook SIR-C data at L and C bands from different oceans around the globe.

We present a strategy for segmenting single look polarimetric TerraSAR ocean data using an algorithm we have previously developed with the averaging of the resulting like pixels used to generate coherence matrices. We give a brief discussion of desert surfaces.

10188-24, Session 5

Does the central limit theorem always apply to phase noise? some implications for radar problems

John E. Gray, Naval Surface Warfare Ctr. Dahlgren Div. (United States); Stephen R. Addison, Univ. of Central Arkansas (United States)

The phase noise problem or Rayleigh Problem occurs in all aspects of radar (Gray & Addison). It is an effect that a radar engineer or physicist always has to take into account as part of a design or in attempt to characterize the physics of a problem such as reverberation. Normally, the mathematical difficulties of phase noise characterization are avoided by assuming the phase noise probability distribution function (PDF) is uniformly distributed, and the Central Limit Theorem (CLT) is invoked to argue that the superposition of relatively few random components obey the CLT and hence the superposition can be treated as a normal distribution. By formalizing the characterization of phase noise (Gray & Alouani) for an individual random

variable, the summation of identically distributed random variables is the product of multiple characteristic functions (CF). The product of the CF's for phase noise has a CF that can be analyzed to understand the limitations CLT when applied to phase noise. We mirror Kolmogorov's original proof as discussed in (Papoulis) to show the CLT can break down for receivers that gather limited amounts of data as well as the circumstances under which it can fail for certain phase noise distributions. We then discuss the consequences of this for matched filter design as well the implications for some physics problems.

J. E. Gray and S. R. Addison, "I see the Rayleigh Problem, ... It's everywhere", Radar Sensor Technology XIV, 5 - 7 April 2010, Orlando, FL, USA, SPIE Vol. 7769.

J. E Gray and A. T. Alouani, "Characterization of the PDFs of Coordinate Transformations in Tracking", IEEE Trans. on Aerospace and Electronic Systems, Vol. 50, No. 3, July 2014.A. Papoulis, The Fourier integral and its applications, (1960).

10188-25, Session 5

Reconfigurable signal processor designs for advanced digital array radar systems

Hernan Suarez, Yan R. Zhang, The Univ. of Oklahoma (United States); Barry Wood, Integrated Device Technology, Inc. (United States)

The new challenges originated from Digital Array Radar (DAR) demands a new generation of reconfigurable backend processor in the system. The new FPGA devices are able to support much higher speed, more bandwidth and processing capabilities for the need of digital Line Replaceable Unit (LRU). This study focuses on using the latest Altera and Xilinx devices in an adaptive beamforming processor. The field reprogrammable RF devices from Analog Devices are used as analog front end transceivers. Different from other existing Software-Defined Radio transceivers on the market, this processor is designed for distributed adaptive beamforming in a networked environment. The following aspects of the novel beamforming processor will be presented: (1) A new system-on-chip architecture based on Altera's devices and adaptive processing module will be introduced, (2) Successful implementation of generation 2 serial RapidIO (SRIO) data links on FPGA, which supports VITA-49 radio packet format for large distributed DAR processing. (3) Exploration of the open-source software in the processor implementation, especially the GNU radio and its variation. (4) Fast data transfer and management inside the FPGA chip, through a Direct Memory Access (DMA) design, (5) Demonstration of the feasibility and capabilities of the processor in a Micro-TCA based, SRIO switching backplane to support multi-channel beamforming in real-time. (6) Application of this processor in ongoing radar system development projects, including OU's dual-polarized digital array radar, the planned new cylindrical array radars and future airborne radars.

10188-26, Session 5

Linear chirp phase perturbing approach for finding binary phased codes

Bingcheng Li, Lockheed Martin Systems Integration-Owego (United States)

Binary phased codes have many applications in communication and radar systems and these applications demand low sidelobes for these codes. Barker codes are the ones that satisfy these requirements and they have lowest maximum sidelobes. However, these Barker codes have very limited code lengths (equal or less than 13) while many applications including low probability of intercept radar, and spread spectrum communication, demand much higher code lengths. Thus, techniques to find long binary phased codes with low sidelobes has been appeared in many literatures. These techniques include exhaust search, neural network, and evolutionary methods, and they all require very expensive computation. In this paper, by analyzing Barker code and linear chirp phases, we propose a new approach that is able to find long low sidelobe binary phased codes with reasonable computational cost.

First, we investigate the relationship between Barker codes and linear chirp. From this relationship, we propose a phase accumulation approach to construct continuous phases that represent Barker codes, and demonstrate that the constructed phases show quadratic characteristics which is very similar to linear Chirp phases. These results show that we may discretize linear chirp phases into binary level to create the initial binary codes for searching low sidelobe binary codes.

Using the relationship between Barker codes and linear chirp, we propose linear chirp phase perturbing approach to find low sidelobe binary phased codes. The new method includes three steps. In step 1, we use least square fitting to find a chirp phase function that best fit to all Barker codes. In step 2, the chirp phase function is perturbed with random noise and discretized into binary phased codes. In step 3, the autocorrelation of the binary phased codes generated in step 2 is computed, and the maximum sidelobes are picked up and compared with the existing best binary phased codes picked up before. If the new sidelobes are smaller than the existing ones, update it otherwise keep no change and go to step 1 to continue until the maximum iteration is reached.

We have conducted tests for new method and experimental results show that with equal or better performance, the new method is 100 times faster than the direct Monte Carlo method for finding long binary phased codes with similar sidelobe performance. We also did experiments to compare the new method with neural network and evolutionary methods, and test results show that the new method has equal or better performance than existing methods with simpler implementation. Finally, we apply the proposed approach and find very long low sidelobe binary phased codes with code length 100 to 200.

10188-27, Session 6

The operator approach to the non-uniform Doppler to radar: implications for signal processing

John E. Gray, Allen D. Parks, Jeremiah J. Hansen, Naval Surface Warfare Ctr. Dahlgren Div. (United States)

Since the inception of coherent waveforms, it has been realized that the effect of the motion of a non-point like object can induce structure in the return spectrum of the waveform (Gray & Addison, Gray et-al). There are many ways to think about this, but the one newer ones is to think of the induced law of motion induced onto the scattered waveform as being "generated" by an operator to produce the law of motion (Gray & Parks) One can use this observation to design a receiver's matched filter response specific to these type of operators that generate a law of motion. We use Lagrange's theorem for generating a Taylor series solution to a functional equation to illustrate how to do this. In addition, one can also do the same for three dimensional periodic motion using the rotation matrices as well. So, we illustrate this as well by developing the matched filter response for a rotating object in terms of the rotation matrix.

10188-28, Session 6

Advanced Doppler radar physiological sensing technique for drone detection

Ji Hwan Yoon, Hao Xu, Luis R. Garcia Carrillo, Univ. of Nevada, Reno (United States)

Doppler Radar Physiological Sensing (DRPS) has been successfully implemented in various civilian and military applications, including life sign detection, see-through wall monitors, biometrics, and medical appliances. DRPS systems are specifically designed to remotely monitor small movements (100 μm - few millimeters) of non-metallic tissues, such

as cardiopulmonary activity and respiration. They use advanced data processing to ignore other movement. Some Unmanned Aerial Vehicles (UAV) have a minimum amount of metallic components, which makes hard to detect with conventional radar systems. Once optimized, the unique capabilities of DRPS could possibly be used to detect these UAVs. A close corroboration with Olea Sensor Networks (Reno, NV) made it possible to conduct initial measurements using a life-presence sensor. These tests confirmed that DRPS technology is suitable to detect stationary or moving humans, as well as a largely non-metallic quarter-copter hovering in the air. This was done using a relatively low frequency (7.8 GHz center frequency), low power, and an antenna gain of 8 dBi. Based on these results, a medium-range human-detecting DRPS system, which can also detect UAVs, is currently under development for potential rescue and anti-drone applications. This novel UAV detection feature incorporates advanced signal processing including pattern recognition to detect multiple signatures of UAVs (such as movement generated by motors and propellers, as well as hovering patterns), while rejecting unnecessary targets, such as flying birds. In addition, to maximize the detection range and sensitivity, the operating frequency will be increased to 24 GHz, and a high peak pulse will be used.

10188-29, Session 6

Millimeter-wave micro-Doppler measurements of small UAVs

Duncan A. Robertson, Samiur Rahman, Univ. of St. Andrews (United Kingdom)

In the past few years, consumer drones have become readily available to the general public. Along with providing many opportunities, drones can also pose significant security threats. A user with malicious intent can use it for dropping/transferring explosives or contraband, illegal video recording etc. Equally importantly, even a novice user can create problems unintentionally which may disrupt a citizen's privacy/safety or create damage to an important facility.

Radar micro-Doppler signatures are an intrinsic characteristics of any small UAV (sUAV) due to its propeller rotation. Any countermeasure system for sUAVs flying over restricted areas would require classification of the detected moving target, hence micro-Doppler signatures can be very useful for sUAV identification. The purpose built radar systems developed so far usually operate in microwave frequency bands (i.e. S, C, X) and it appears that the micro-Doppler signatures of sUAVs have not been comprehensively studied for millimeter-wave frequencies.

In this paper, we will discuss the micro-Doppler features of sUAVS obtained from a millimeter-wave radar system. At first, simulation results will be shown to demonstrate the theoretical concept. It will be illustrated that as the propeller rotation rate of sUAVs is quite high (> 200 Hz), millimeter-wave radar systems are advantageous in terms of capturing the full micro-Doppler spread.

Along with the simulated micro-Doppler signatures, experimental results will also be shown. Measurements have been performed with both CW and FMCW radars (both operating at 94 GHz). The CW radar was used for obtaining micro-Doppler signatures of individual propellers. The field test data of the flying sUAV was collected by the FMCW radar and was processed to extract micro-Doppler signatures.

10188-30, Session 6

Micro-Doppler extraction of a small UAV in a non-line-of-sight urban scenario

Magnus Gustavsson, Åsa Andersson, Tommy Johansson, Rolf Jonsson, Nils Karlsson, Stefan Nilsson, FOI-Swedish Defence Research Agency (Sweden)

The appearance of small UAVs on the commercial market poses a real threat to both military operations and civilian safety. In open terrain a radar can detect and track even small UAVs at long distances. In a short range urban environment with limited line-of-sight, and strong static and non-static background returns, this capability is severely reduced. The radar cross section and the Doppler signature of these UAVs are normally small compared to the background. However, the rotors of the UAVs produce a characteristic micro-Doppler signature that can be exploited for detection and classification.

In this paper, we investigate in an experimental set-up, if it is possible in radar NLOS to detect a small UAV and to retrieve the micro-Doppler signature of the rotors. This is done by exploring up to four multipath bounces and by applying the short-time Fourier transform along with other signal processing techniques.

The measurements were made with a semi-monostatic single receiver-transmitter radar system operating at X-band in a stepped-frequency mode. The UAV was measured at four positions inside a 4 m wide corridor with metallic walls. For five of the positions the UAV was in radar NLOS. Two types of rotors were used; plastic rotors and metal coated plastic rotors.

Results show that we were able to detect the micro-Doppler of the rotors and to retrieve the rotor RPM in all six positions and for both rotor types. Measurements were also compared to FDTD-simulated results. Good agreement was found between measurements and simulation results.

10188-31, Session 6

Classification of micro-Doppler signatures of human aquatic activity through simulation and measurement using transferred learning

Youngwook Kim, California State Univ., Fresno (United States); Jinhee Park, Taesup Moon, DGIST (Korea, Republic of)

Remote detection of human aquatic activity can be applied not only to ocean surveillance but also to rescue operations. When a human is illuminated by electromagnetic waves, a Doppler signal is generated from his or her moving parts. A human's bodily movements make micro-Doppler signatures unique, and this actuality offers a chance to classify human motions. There have been studies on the analysis and recognition of human aquatic activity, but the topic has not been extensively studied. In the present research, we simulate the micro-Doppler signatures for a swimming person to investigate the signatures' characteristics. Human arms are modeled as point sactterers, and a simple arm motion is assumed. Using the micro-Doppler simulation, we can obtain spectrograms from a swimming person. Then, we extend our measurement to multiple participants. For the measurements, five aquatic activities from five participants are carried out. The five activities consist of freestyle, backstroke, and breaststroke, pulling a boat and rowing. As suggested by the simulation study, the spectrograms for the five activities show different micro-Doppler signatures, hence, we propose to classify them using deep convolutional neural networks (DCNN). In particular, we suggest the use of a transfer-learned DCNN, which is based on a DCNN pretrained by a large-scale RGB image dataset—that is, ImageNet. The classification accuracy is calculated using the five-fold cross-validation on our dataset. We report that the transfer-learned DCNN achieves the highest accuracy and a significant performance boost over the conventional handcrafted classification method.

10188-32, Session 7

Fly Eye radar: Detection through high scattered media

Pavlo A. Molchanov, Ashok Gorwara, Planar Monolithic Industries, Inc. (United States)

Longer radio frequency waves better penetrating through high scattered media than millimeter waves, but radar resolution limited by diffraction at longer wavelength . Same time frequency and amplitudes of diffracted waves (frequency domain measurement) provides spectrum signature of object. Phase shift of diffracted waves (phase front in time domain) consists information about shape of object and can be applied for reconstruction of object shape or even image by recording of multi-frequency digital hologram.

Fly Eye radar is multi-beam, monopulse, multi-frequency system. Multiple angularly shifted directional antennas are coupled with wide/multi band receivers and separately connected to processor by digital interface. Application of monopulse method with overlap closely spaced antenna patterns provides high accuracy measurement of amplitude, phase, and direction to signal source. Digitizing of received signals separately in each antenna relative to processor time provides phase/frequency independence.

Fly eye non-scanning multi-frequency radar system provides simultaneous continuous observation of multiple targets and wide possibilities for stepped frequency, simultaneous frequency, chaotic frequency sweeping waveform (CFS), polarization modulation for reliable object detection.

Proposed c-band fly eye radar demonstrated human detection through 40 cm concrete brick wall with human and wall material spectrum signatures and can be applied for through wall human detection, landmines, improvised explosive devices detection, underground or camouflaged object imaging.

10188-33, Session 7

A solid state 94 GHz FMCW Doppler radar demonstrator for cloud profiling.

Duncan A. Robertson, Robert I. Hunter, Univ. of St. Andrews (United Kingdom)

Millimeter wave radars are the preferred instrument to probe the structure of clouds and fog in the atmosphere due to their relatively high sensitivity to small hydrometeors (water droplets and ice particles). However, many cloud profiling radars (CPRs) use high power vacuum tube amplifiers (typically extended interaction klystron amplifiers) which are very expensive and this has limited the deployment of CPRs worldwide. Additionally, due to the need to have separate transmit and receive antennas of large diameter, the typical choice of Cassegrain antennas further adds to the system cost.

We will present the design and characterization of a ground-based, zenith-pointing, 94 GHz FMCW Doppler radar demonstrator for cloud profiling. The radar uses an all solid-state and relatively simple homodyne architecture with twin 0.5 m diameter Fresnel zone plate (FZP) antennas to reduce system costs.

The 4-level phase correcting FZP antennas not only offer a low cost alternative to Cassegrain antennas (at the expense of a longer f-number and hence greater system volume) but actually yield a sidelobe performance which exceeds that obtainable with a Cassegrain of equivalent size.

The low-phase noise, coherent radar employs a direct digital synthesis (DDS) chip for highly linear chirp generation. Signal processing is undertaken on a PC which performs real-time range-Doppler measurements with averaging, to yield target velocity spectra as a function of altitude. The design will be able to leverage ongoing future improvements in mm-wave low noise and power amplifier technology to maximize sensitivity against low reflectivity atmospheric targets. We anticipate that the high performance achievable with this lower cost architecture could lead to wider deployment of CPRs for operational atmospheric monitoring.

10188-34, Session 7

IoSiS: a radar system for imaging of satellites in space

Matthias Jirousek, Simon Anger, Stephan Dill, Eric Schreiber, Markus Peichl, Deutsches Zentrum für Luft- und Raumfahrt e.V. (Germany)

Space debris nowadays is one of the main threats for satellite systems especially in low earth orbit (LEO). More than 700,000 debris objects with potential to destroy or damage a satellite are estimated. The effects of an impact often are not identifiable directly from ground. High-resolution radar images are helpful in analyzing a possible damage. Therefor DLR is currently developing a radar system called IoSiS (Imaging of Satellites in Space), being based on an existing steering antenna structure and our multi-purpose high-performance radar system GigaRad for experimental investigations. GigaRad is a multi-channel system operating at X band and using a bandwidth of up to 4.4 GHz in the IoSiS configuration, providing fully separated transmit (TX) and receive (RX) channels, and separated antennas. For the observation of small satellites or space debris a high-power traveling-wave-tube amplifier (TWTA) is mounted close to the TX antenna feed. For the experimental phase IoSiS uses a 9 m TX and a 1 m RX antenna mounted on a common steerable positioner. High-resolution radar images are obtained by using Inverse Synthetic Aperture Radar (ISAR) techniques. The guided tracking of known objects during overpass allows here wide azimuth observation angles. Thus high azimuth resolution comparable to the range resolution can be achieved. This paper outlines technical main characteristics of the IoSiS radar system. Expected imaging examples obtained via simulation are shown in order to analyze the influence of major error sources. Since the system is currently under final construction, first experimental results may be available soon.

10188-35, Session 7

A prototype 160 GHz bistatic ISAR compact radar range: design and test results

Christopher J. Beaudoin, Andrew Gatesman, Guy DeMartinis, Thomas Goyette, Thomas Horgan, Univ. of Massachusetts Lowell (United States)

We present a prototype bistatic compact radar range operating at 160 GHz and capable of radar cross-section and electromagnetic scattering measurements. The bistatic ISAR system incorporates two 112-inch focal length, 27-inch-diameter diamond-turned mirrors fed by 160 GHz transmit and receive horns to establish the compact range. The prototype radar range with its modest sized quiet zone serves as a precursor to a fully developed compact radar range incorporating a larger quiet zone capable of collecting X-band bistatic RCS data and 3D imagery using 1/16th scale objects.

The 10 mW millimeter-wave transmitter provides 24 GHz of swept bandwidth in the single linear (Horizontal/Vertical) polarization while the millimeter-wave receiver, that is sensitive to linear Horizontal and Vertical polarization, possesses a 7 dB noise figure. We present the design of the compact radar range, report on test results collected to validate the system's performance against CEM/Xpatch codes, and introduce scale model bistatic ISAR and 3D interferometric imagery generated from the system.

10188-36, Session 7

A novel remote RF sensor for search and rescue and through-wall 3D imaging

Hossein Ghaffari Nik, George Mason Univ. (United States) and Rhein Tech Labs., Inc. (United States); Desmond A. Fraser, Rhein Tech Labs., Inc. (United States); Aref Fouladi, Advanced Geolocation Solutions, LLC (United States); Nathalia Peixoto, George Mason Univ. (United States)

RF reflections can be leveraged to detect movement behind walls and through rubble. A potential application of such technology is the detection of buried or concealed humans and their vital signs in search and rescue missions. Generally, these techniques and equipment rely on multiple transmitter-receiver pairs that are displaced from each other to enable

the detection of multiple targets in three dimensions (3D). For instance, WiTrack 2.0 from the Massachusetts Institute of Technology uses an array of 10 antennas with 5 transmitters and 5 receivers to track up to 5 individuals with accuracy of 15 cm. This need for multiple transmitter-receiver pairs and physical antenna displacement results in large, complex and expensive equipment. It would be ideal, especially for mobile robots, to achieve multiple target localization in 3D using only a single transmitter-receiver pair. In this paper we investigate the effects of different antenna polarities in human body RF reflections and RF propagation through different obstacles. We also propose a novel rotary single transmitter-receiver pair radar system that uses multiple polarities with spatial antenna displacement due to rotation in order to achieve multiple target detection and localization in 3D. We report field test results of our system in 3D localization and vital sign detection for moving and stationary multiple human targets behind walls and simulated rubble. The results indicate that by adding multiple polarities and spatial displacement of single transmitter-receiver pair similar accuracy and detection capabilities are achievable with a portable system without complex and expensive circuitry.

10188-37, Session 8

Handheld microwave bomb-detecting imaging system

Pavlo A. Molchanov, Ashok Gorwara, Planar Monolithic Industries, Inc. (United States)

Existing x-ray technology is limited to short range applications only, and expose users to harmful radiation. Proposed system is based on the application of a long wavelength low power monopulse RF/Microwave imaging system with enhanced camouflage and foliage penetration. Low microwave frequencies allow for decreased transmitter power over a broader range of exploration through the use of radar technology, providing increased detection probability, classification and precision imaging.

UWB Software Defined Receiver coupled with the object and reference antennas can record real time digital hologram which consists of amplitude and phase information of the diffracted RF/Microwave signals. Information about shape of object is contained within the electromagnetic phase front and can be restored from recorded digital hologram. Spectrum signature will provide information about material of object.

Proposed novel imaging technique will provide all weather high-resolution imaging and recognition capability for RF/Microwave signals with good penetration through highly scattered media: fog, snow, dust, smoke, even foliage, walls and ground. Image resolution in proposed imaging system is not limited by diffraction and will be determined by processor and sampling frequency. Proposed imaging system can simultaneously cover wide field of view, detect multiple targets and can be multi-frequency, multi-function. Directional antennas in imaging system can be close positioned and installed on small aircraft or distributed around protected border or object. Non-scanning monopulse system allows dramatically decrease in transmitting power and at the same time provides increased imaging range by integrating 2-3 orders more signals than regular scanning imaging systems.

10188-38, Session 8

A K-band multi-channel FPGA-based micro radar for wide-area indoor human motion monitoring

Baokun Liu, Minjie Jian, Zhenzhong Lu, Ancortek, Inc. (United States)

We have developed a K-band multi-receiving-channel FMCW micro-radar operating at 24.125 GHz for real-time wide-area monitoring of indoor human movements. The low-power and light-weight micro radar system consists of a multi-receiving-channel RF module and a FPGA-based processor module. A high-performance chip with integrated front-end circuit by Infineon is used in the RF-module. A patched antenna array with one transmitting and multiple receiving channels is attached to the RF-module. A high-performance processor module with multi-channel ADCs is carefully designed for implementing the software-defined concept. A graphical user interface provides a simple way for users to select radar operating parameters, display maps of the range, velocity, and angle-of-arrival in real-time, and store the collected radar raw data.

In this paper, the state of the art of the low-power and light-weight micro radar system is discussed. We introduce the architecture of the multi-channel radar system and the algorithms of the digital signal processing. The design concepts, advantages, and special consideration for indoor human motion monitoring are described. The signal processing and digital beamforming procedures for mapping of range, Doppler and angle-of-arrival information are analyzed. A number of interesting measurement results are also discussed in detail.

The micro radar system has been fully tested to monitor and track the location of individuals in high multipath indoor scenarios. Real-time measurement results of multiple people in a scene are presented.

10188-39, Session 8

System upgrades and performance evaluation of the spectrally agile, frequency incrementing reconfigurable (SAFIRE) radar system

Brian Phelan, Kenneth I. Ranney, Marc A. Ressler, Kelly D. Sherbondy, Getachew A. Kirose, John T. Clark, Arthur Harrison, U.S. Army Research Lab. (United States); Daniel T. Golanas, Alion Science and Technology Corp. (United States); Philip J. Saponaro Jr., Wayne Treible, Univ. of Delaware (United States); Ram M. Narayanan, The Pennsylvania State Univ. (United States)

The U.S. Army Research Laboratory has developed a Spectrally Agile Frequency-Incrementing Reconfigurable (SAFIRE), vehicle-mounted radar capable of imaging concealed/buried targets using forward- and side-looking orientations. The SAFIRE system incrementally steps from 300 MHz{2 GHz, the step size can be adjusted in multiples of 1 MHz. It is also capable of excising adaptable frequency bands, which makes it ideal for operation in congested and/or contested RF environments. Furthermore, the SAFIRE receiver has a super-heterodyne architecture which was designed so that intermodulation products caused by interfering signals could be easily filtered from the desired received signal. In this paper, results from the SAFIRE's initial field tests are presented. A performance analysis is given based on the settings of the reconfigurable parameters of the radar system. The SAFIRE radar system was developed as an experimental testbed to determine the practicality of using UWB radar to detect buried and concealed explosive hazards at considerable standoff distances.

10188-40, Session 9

Coherence in radar processing *(Keynote Presentation)*

Douglas L. Bickel, Sandia National Labs. (United States)

Coherence of radar data is a fundamental property that allows all manner of data exploitation and information extraction. Its understanding is crucial to maximizing the utility of radar data. This presentation will discuss the property of coherence as it relates to a variety of radar modes and exploitation techniques, as well as what factors influence it, and its quality.

10188-41, Session 10

A 24-GHz portable FMCW radar with continuous beam steering phased array *(Invited Paper)*

Zhengyu Peng, Changzhi Li, Texas Tech Univ. (United States)

A portable 24-GHz frequency-modulated continuous-wave (FMCW) radar with continuous beam steering phased array is presented. This board-level integrated radar system consists of a phased array antenna, a radar transceiver and a baseband. The phased array used by the receiver is a 4-element linear array. The beam of the phased array can be continuously steered with a range of ±30° on the H-plane through an array of vector controllers. The vector controller is based on the concept of vector sum with binary-phase-shift attenuators. Each vector controller is capable of independently controlling the phase and the amplitude of each element of the linear array. The radar transceiver is based on the six-port technique. A free-running voltage controlled oscillator (VCO) is controlled by an analog "sawtooth" voltage generator to produce frequency-modulated chirp signal. This chirp signal is used as the transmitter signal, as well as the local oscillator (LO) signal to drive the six-port circuit. The transmitter antenna is a single patch antenna. In the baseband, the beat signal of the FMCW radar is detected by the six-port circuit and then processed by a laptop in real time. Experiments have been performed to reveal the capabilities of the proposed radar system for applications including indoor inverse synthetic aperture radar (ISAR) imaging, vital sign detection, and short-range navigation, etc.

10188-42, Session 10

Radar research at University of Oklahoma *(Invited Paper)*

Yan R. Zhang, Mark E. Weber, The Univ. of Oklahoma (United States)

This presentation will focus on radar research programs at the University of Oklahoma, the radar research in OU has more than 50 years history of collaboration with NOAA, and has been through tremendous growth since early 2000. Before 2010, the focus was weather radar and weather surveillance, and since the Defense, Security and Intelligence (DSI) initiative in 2011, there have many new efforts on the defense and military radar applications. This presentation will focus on the following information: (1) The history, facilities and instrumentations of Advanced Radar Research Center, (2) Focus area of polarimetric phased array systems, (3) Focus area of airborne and spaceborne radars, (4) Intelligent radar information processing, (5) Innovative antenna and components.

10188-43, Session 10

Radar research at The Pennsylvania State University *(Invited Paper)*

Ram M. Narayanan, Pennsylvania State Univ. (United States)

No Abstract Available

10188-44, Session 10

Radar research at the University of Kansas *(Invited Paper)*

Shannon D. Blunt, Christopher Allen, Emily Arnold, Richard Hale, Rongqing Hui, Shahriar Keshmiri, Carlton Leuschen, Jilu Li, John D. Paden, Fernando Rodriguez-Morales, Alessandro Salandrino, James M. Stiles, The Univ. of Kansas (United States)

No Abstract Available

10188-45, Session 11

Cognitive software defined radar: waveform design for clutter and interference suppression

Benjamin H. Kirk, The Pennsylvania State Univ. (United States); Jonathan W. Owen, The Univ. of Kansas (United States); Ram M. Narayanan, The Pennsylvania State Univ. (United States); Shannon D. Blunt, The Univ. of Kansas (United States); Anthony F. Martone, Kelly D. Sherbondy, U.S. Army Research Lab. (United States)

Clutter and radio frequency interference (RFI) are prevalent issues in the field of radar and are specifically of interest in the field of cognitive radar. Methods for applying and testing the utility of cognitive radar for clutter and RFI mitigation are explored. Using the adaptable transmit capability, environmental database, and general "awareness" of a cognitive radar system, a matched waveform can be used to improve the signal-to-clutter ratio (SCR) if the target response and an estimate of the environmental clutter response are known a priori. RFI may also be mitigated by sensing the spectrum and adapting the transmit center frequency and bandwidth using methods (i.e. the spectrum sensing, multi-optimization (SS-MO) algorithm) that optimize bandwidth and signal-to-interference plus noise ratio (SINR). The improvement is shown by a reduction in the interference floor.

Using the cognitive radar's "awareness" to changing environments, the transmit waveform may be adapted using real time data and clutter models applicable to the operation environment. The cognitive radar may choose optimal models based on location and system feedback. However, complications come to rise when these concepts are put into application. Commercial off the shelf (COT) devices are desirable for their cost effectiveness, general ease of use, as well as technical and community support, but these devices provide design challenges in order to be effective. The USRP X310 software defined radio (SDR) is a relatively cheap and portable device that has all the functionality needed for a basic cognitive radar (i.e. on-board memory (database), adaptable transmitter, adaptable receiver, and parallelized processor). This convenient device provides several obstacles however. Issues of phase coherency between channels, bandwidth limitations, dynamic range, and speed of computation and data communication are all addressed.

10188-46, Session 11

Comparison of RF spectrum prediction methods for dynamic spectrum access

Jacob A. Kovarskiy, The Pennsylvania State Univ. (United States); Anthony F. Martone, Kyle A. Gallagher, Kelly D. Sherbondy, U.S. Army Research Lab. (United States); Ram M. Narayanan, The Pennsylvania State Univ. (United States)

A cognitive radar system is under development using custom high resolution spectrum measurement instruments as well as spectrum sensing algorithmic approaches to find the widest band of spectrum opportunity. Given the spectral diversity of known RFI emitter signals both temporally and in frequency, a controllable synthetic spectrum generator based on real-world RFI would be most advantageous for development of a cognitive radar system. Thus a random synthetic spectrum generator provides ground truth for spectrum sensing algorithms and assists the characterization of different RFI emitters. The goal of cognitive radar is to emit the widest band signal in open spectrum to minimize RFI but maximize range resolution. To find open spectrum, various RFI emitters must be identified and characterized. We have developed a pseudorandom spectrum generator which outputs a random distribution of common waveforms based on user defined spectrum occupancy and total average power. The user also defines bandwidth of interest, center frequency, and various waveform control parameters. The software displays the frequency, magnitude, and various characteristics of each individual emitter. The generator can save, replay, and display information for the produced spectra; allowing for a large database with known RFI emitters. Selected input parameters for simulation correspond to real world ambient RF measurements. Our synthetic spectrum generator creates a large database of spectra modeling real world RFI. This database provides a large set of possible training data for machine learning algorithms (e.g. neural networks) to characterize sources of RFI and perform channel prediction. This spectrum database improves the validation and optimization of spectrum sharing algorithms for cognitive radar.

10188-47, Session 11

Linearizing an intermodulation radar transmitter by filtering switched tones

Gregory J. Mazzaro, The Citadel-The Military College of South Carolina (United States); Andrew J. Sherbondy, Kenneth I. Ranney, Kelly D. Sherbondy, Anthony F. Martone, U.S. Army Research Lab. (United States)

A challenge encountered when designing a nonlinear radar is to achieve linearity in the transmitter high enough to detect targets whose reflections are typically very weak. Unfortunately, the transmit power required to generate a detectable response from a nonlinear target is relatively high, and generating high power for transmission is achieved at the cost of linearity. If self-generated spurious frequencies are not attenuated or otherwise eliminated before they arrive at the transmit antenna, they will radiate into the environment and reflect from purely linear targets and/or clutter. Reflections of spurious frequencies from linear targets and clutter manifest as false alarms.

A technique to mitigate distortion, yet to be implemented in an intermodulation radar, is Linearization by Time-Multiplexed Spectrum (LITMUS). The LITMUS technique reduces distortion introduced by a nonlinear element such as an RF amplifier by time-multiplexing an otherwise phase/frequency-modulated signal before the nonlinear element, passing the time-multiplexed version of the signal through the nonlinear element, and reversing the time-multiplexing operation by attaching a carefully-selected filter to the output of the nonlinear element. Linearity is improved at the cost of a slight increase in complexity in the RF chain and a spreading of the transmit signal's bandwidth immediately before it encounters the nonlinear element. In this paper, an experimental detection system for an intermodulation radar achieves a signal-to-noise ratio up to 20 dB for a total transmit power of approximately 80 mW and nonlinear targets placed at a standoff distance of 2 meters.

10188-48, Session 11

Recent non-linear radar research at the Army Research Laboratory

Kyle A. Gallagher, Kelly D. Sherbondy, Chris Fazi, U.S. Army Research Lab. (United States)

No Abstract Available

10188-49, Session PSWed

An architecture for pre-warping general parametric frequency-modulated radar waveforms

Armin W. Doerry, Sandia National Labs. (United States)

We present techniques for making fine adjustments to dynamically warp general Frequency Modulated (FM) waveforms. These warping adjustments will facilitate real-time motion compensation of waveforms in radar systems, especially when those waveforms are generated by a digital parametric waveform generator. Relevant waveforms include the Linear-FM (LFM) chirp, Non-Linear FM (NLFM) chirp, and other general FM waveforms.

10188-50, Session PSWed

Using coherence as a quality measure for complex radar image compression

Armin W. Doerry, Douglas L. Bickel, Sandia National Labs. (United States)

We desire a metric to evaluate the "goodness" of various image compression schemes in recreating an original Synthetic Aperture Radar image. Herein we propose a "coherence" measure that results in a single quality number for such an evaluation.

10188-51, Session PSWed

Discriminating spurious signals in radar data using multiple channels

Armin W. Doerry, Douglas L. Bickel, Sandia National Labs. (United States)

Spurious energy in received radar data is a consequence of nonideal component and circuit behavior. This might be due to I/Q imbalance, nonlinear component behavior, additive interference (e.g. cross-talk, etc.), or other sources. The manifestation of the spurious energy in a range-Doppler map or image can be influenced by appropriate pulse-to-pulse phase modulation. Comparing multiple images having been processed with the same data but different signal paths and modulations allows identifying undesired spurs and then cropping or apodizing them.

10188-52, Session PSWed

Use of unmanned SAR and EO/IR sensor suites for monitoring wildfires

Randy Saddler, General Atomics (United States); Ralf Dunkel, General Atomics Aeronautical Systems, Inc. (United States); Armin W. Doerry, Sandia National Labs. (United States)

Synthetic Aperture Radar (SAR) is a proven, effective tool to monitor and map changing topography in rapidly expanding wild fire disaster situations. The broad area coverage provided by SAR can be used to detail areas of fire damage while high resolution imagery can be used to determine fire movement and possibly provide warning to areas in the fire's path. General Atomics Aeronautical Systems, Inc. (GA-ASI) recently collected data with an airborne Lynx SAR, operating in the Ku Band, in conjunction with a FLIR Systems Star Safire 380-HD electrical optical – infrared (EO/IR) camera system on Southern California's Blue Cut Fire. The Blue Cut Fire began in the Cajon Pass East of Los Angles and burned a total of 36,000 Acres . GA-ASI was able to overfly the fire, map the area and detail current location as well as additional areas the fire was spreading. Image Analysts were able to review the collected data and provide valuable information regarding location and possible fire direction. Analysts also conducted fire damage assessments to determine which structures were lost or damaged in the Fire. The real time analysis of SAR and EO/IR data collections has the potential to significantly increase effectiveness of firefighting crews attempting to contain a dynamic wildfire.

10188-53, Session PSWed

Classification of radar jammer FM signals using a neural network approach

Ariadna E. Mendoza, Alberto Soto, Benjamin C. Flores, The Univ. of Texas at El Paso (United States)

An artificial Neural Network (NN) approach is proposed as a means of classifying wideband jamming radar signals. For instance, classification of signals allows for more effective use of countermeasures. A robust NN will be used to correctly differentiate Frequency-Modulated (FM) and chaotic FM signals from bandlimited Additive White Gaussian Noise (AWGN). Experiments show that frequency-domain moments of the FM signal itself are better descriptors than time-domain moments. Consequently, in this study we seek to determine the performance of the NN when using either the temporal and frequency domain data as input. First, MATLAB is used to simulate N=1024 samples of an FM radar signal. The normalized spectrum of the signal is randomized between 0.05 and 0.30. The signal is subsequently filtered using a 40 dB Chebyshev bandpass filter. Samples of either the autocorrelation or the spectrum are then fed to the NN which has ten hidden layers. The samples are randomly divided into 3 groups, 70% for training, 15% for validating and 15% for testing. When training the NN with M=4096 power spectrum samples, a Signal to Noise Ratio (SNR) of 5 dB allows the network to approach a 0.5% average Probability of Error (PE). Training with the autocorrelation yields comparable results. For a 5 dB SNR the average PE is 0.3%. For both experiments the NN reaches zero percent PE at 10 dB SNR. Additional tests will be discussed where the number of temporal and frequency samples are used to determine optimal performance.

10188-54, Session PSWed

Optimization of neural network architecture for radar jammer FM signal classification

Alberto Soto, Ariadna E. Mendoza, The Univ. of Texas at El Paso (United States)

Several Neural Network (NN) architectures are examined in order to design a cognitive radar system capable of optimally distinguishing linear Frequency-Modulated (FM) signals from bandlimited Additive White Gaussian Noise (AWGN). After analyzing the moments of a linear FM, data suggests that the frequency-domain power spectral densities characterize a signal more efficiently than its time-domain counterparts. Therefore, data are preprocessed by calculating the magnitude square of the Discrete Fourier Transform of the digitally sampled AWGN and linear FM signals to populate a matrix containing M number of spectra and N number of samples. This matrix is used as input for the NN modeled in MATLAB whose default architecture is composed of ten neurons, a two-layered feed forward network, and a sigmoid transfer function found at the hidden layer of the network. The power spectra contained in the matrix are divided as follows: 70 percent for training, 15 percent for validation, and 15 percent for testing. Also, a default Scaled Conjugate Gradient (trainscg) algorithm is used for training. Results show the probability of detection (PD) for a linear FM approaches 100 percent for a Signal to Noise Ratio (SNR) greater than 5dB. However, at SNR below 5dB, the PD declines below 95 percent. Modifying the default architecture and number of hidden neurons ought to improve performance of the NN at SNR below 5dB. The aim of this study is to identify an optimal NN architecture capable of yielding high PD at SNRs.

10188-55, Session PSWed

Using TerraSAR-X satellite data to detect road age and degradation

Marius Necsoiu, Southwest Research Institute (United States); Nicolas Longepe, Collecte Localisation Satellites (France); Jorge O. Parra, Gary R. Walter, Southwest Research Institute (United States)

Analysis of satellite-acquired synthetic aperture radar (SAR) data provides a way to rapidly survey road conditions over large areas. This capability could be useful for identifying road segments that potentially require repair or at least onsite inspection of their condition due to changes in vehicular traffic associated with change in land use. We conducted a feasibility study focused on urban roads near the Southwest Research Institute® (SwRI®) campus in San Antonio, Texas. The roads near SwRI were affected by heavy truck traffic, they were easily inspected, and the age and construction of the pavement was known. TerraSAR-X (TSX) SpotLight satellite data were used to correlate radar backscattering response to pavement age and condition. Our preliminary results indicate that TSX radar imagery can be useful for detecting changes in pavement type, damage to pavement, such as cracking and scaling, and, occasionally, severe rutting. In addition multi-temporal interferometric analysis showed patches of settlement along two roads south of the SwRI campus. Further development of an automated approach to detect degradation of roads could allow transportation departments to prioritize inspection and repair efforts. The techniques could also be used to detect surreptitious heavy truck traffic in areas where direct inspection is not possible.

10188-56, Session PSWed

"SAFIRE-radar" processing for forward- and side-looking collection modes

Kenneth I. Ranney, Brian Phelan, Getachew A. Kirose, John T. Clark, Kelly D. Sherbondy, Arthur Harrison, Marc A. Ressler, U.S. Army Research Lab. (United States)

No Abstract Available

10188-57, Session PSWed

A quantum inspired model of radar range and range-rate measurements with applications to weak value measurements in radar

George Escalante, Chapman Univ. (United States)

Weak Value Measurements (WVMs) with pre- and post-selected quantum mechanical ensembles were proposed by Aharonov, Albert, and Vaidman in 1988 and have found numerous applications in both theoretical and

applied physics. In the field of precision metrology, WVM techniques have been demonstrated and proven valuable as a means to shift, amplify, and detect signals and to make precise measurements of small effects in both quantum and classical systems, including: particle spin, the Spin-Hall effect of light, optical beam deflections, frequency shifts, field gradients, and many others. WVM amplification techniques are also possible in radar and could be a valuable tool for precision measurements. However, relatively limited research has been done in this area. This talk presents a quantum-inspired model of radar range and range-rate measurements of arbitrary strength, including standard and pre- and post-selected measurements. The model is used to extend WVM amplification theory to radar, with the receive filter performing the post-selection role. It is shown that the description of range and range-rate measurements based on the quantum-mechanical measurement model and formalism produces the same results as the conventional approach used in radar based on signal processing and filtering of the reflected signal at the radar receiver. Numerical simulation results using simple point scatterrer configurations are presented, applying the quantum-inspired model of radar range and range-rate measurements that occur in the weak measurement regime. Potential applications and benefits of the quantum inspired approach to radar measurements are presented, including improved range and Doppler measurement resolution.

10188-58, Session PSWed

Design and analysis of a multi-passband complex filter for the multiband cognitive radar system

Hua-Chin Lee, Der-Hong Ting, Ya-Lan Tsao, National Chung-Shan Institute of Science and Technology (Taiwan)

Multiband cognitive radar systems, operating in a variety of frequency bands and combining the different channels into a joint system, can provide significant flexibility and capability to detect and track hostile targets. This paper proposes a multi-passband complex filter (MPCF) architecture and the related circuit design for a multiband cognitive radar system. By operating under the 5.8GHz UNII band, the sensing part detects the current usage of frequency bands from 5.15GHz to 5.825GHz and provides the information of unused channels. The multiband cognitive radar system uses the whole unused channels and eliminates the used channels by using an on-chip MPCF in order to be coexistent with the Wi-Fi standard. The MPCF filters out the unwanted channels and leave the wanted channels. It dynamically changes the bandwidth of frequency from 20MHz to 80MHz using the 0.18μm CMOS technology. The MPCF is composed of the combination of 5th-order Chebyshev low-pass filters and high-pass filters, and the overall inband ripple of the MPCF is 1.2dB. The consuming current is 21.7mA at 1.8V power supply and the 20MHz bandwidth noise is 55.5nV. The total harmonic distortion (THD) is 45dB at 25MHz and the adjacent channel rejection is 24dB. This results of the MPCF guarantees the performance requirements of the multiband cognitive radar system.

10188-59, Session PSWed

Radar detection of buried targets in coastal environments

Chad M. Brode, Ram M. Narayanan, Pennsylvania State Univ. (United States)

Coastal soils offer a number of challenges in electromagnetic remote sensing applications. They tend to contain large amounts of high salinity water resulting in high values for the real and imaginary parts of their permittivity. Due to this fact, it is desirable to model these properties and determine how they will affect the detection and location of targets buried in coastal soil environments. We examined the propagation of a plane wave with three different incidence angles on a cubic PEC target contained within a dielectric ground with the same properties as the soil using the FEKO electromagnetic modeling software. This response was then compared to that of a baseline target with no dielectric surrounding it and a dielectric similar to dry sand. The results show that the signal is both highly reflected at the surface of the soil, and it is also significantly attenuated as it propagates through the wet sand dielectric. The results of our modeling and simulation studies over a wide range of conditions (e.g. frequency, soil salinity, burial depth, etc.) will be presented and trade-offs examined in order to develop a cognitive radar system for enhancing target detection and clutter suppression.

10188-60, Session PSWed

Low-elevation tracking technique for x-band unmanned aerial vehicle automatic take-off and landing system

Shu-Yu Lin, Ming-Hsiang Cho, Ming-Yung Lin, Wen-Yin Hu, National Chung-Shan Institute of Science and Technology (Taiwan); Jwo-Shiun Sun, National Taipei Univ. of Technology (Taiwan)

In this study, an X-band automatic take-off and landing system (ATOLS) was developed to provide day/night, all weather, automatic takeoff and landing for unmanned aerial vehicles (UAV). The ATOLS contains a ground-based tracking radar subsystem and an airborne transponder subsystem. This X-band tracking radar can provide precise position information for UAV-control operations (beacon mode) as well as fire-control systems (skin mode). It provides 360 degrees of azimuth coverage and therefore can be employed for navigation applications. Its maximum tracking range is about 17 km and accuracy of altitude measurement is about 1 ft with a 50-ft decision height above ground level. To substantiate the proposed ATOLS system, a differential global positioning system (DGPS) was also developed.

When a UAV at a low-elevation angle is detected and tracked by an X-band tracking radar, multipath propagation often leads to the degradation of tracking accuracy or even cause the radar to break track. As a result, it becomes a potential risk to flight safety of the ATOLS guidance and control of UAV. To overcome this technique difficulty, this paper proposes a solution based on optimization of radar parameters to mitigate the interference from multipath signal. The feasibility of proposed method has been experimentally proven through the flight trials of UAV. Compared to the conventional low-elevation tracking techniques, the proposed one employs improved radar signal processing, and does not consume additional hardware and resources.

10188-61, Session PSWed

Bearing angle estimation on synthetic radar (SAR) image

Xingyu Xiang, Zhonghai Wang, Zijian Mo, Genshe Chen, Intelligent Fusion Technology, Inc. (United States)

The bearing angle could be estimated based on the high resolution image obtained by Multiple-Input Multiple-Output (MIMO) synthetic aperture radar (SAR). By extending the previous work of SAR images simulator for 3D target model, two estimation methods are proposed for calculating the bearing angle according to the provided SAR images. Without loss of generality, the SAR images are derived through the raytracing aided simulator of a TDMA MIMO SAR system with 13 transmitting antennas and 8 receiving antennas. Assuming the true bearing angles range from 10° to 10°, the estimation results along with the error analysis are presented after the discussion about the estimation methods. The root mean square error (RMSE) value varies with different threshold settings for erasing the undesired pixels, and an RMSE less than 1.6° could be achieved in most circumstances. The estimation error could be further decreased after bias correction.

Conference 10189: Passive and Active Millimeter-Wave Imaging XX

SPIE. DCS DEFENSE+ SECURITY

Thursday 13–13 April 2017

Part of Proceedings of SPIE Vol. 10189 Passive and Active Millimeter-Wave Imaging XX

10189-1, Session 1

Millimeter wave imaging: a historical review *(Invited Paper)*

Roger Appleby, Roger Appleby MMW Consulting Ltd. (United Kingdom)

The first edition of this continuous series of SPIE conferences on millimeter wave imaging took place in 1997. In the subsequent twenty years the field has steadily evolved, reflecting changes in the motivating applications, enabling technology and key participating organizations and individuals. In this twentieth anniversary year, the field is as vibrant as ever and the conference provides an annual focal point and leading international forum at which the community can meet and share its work.

To celebrate this milestone we will provide a historical review of the evolution and key achievements in millimeter wave imaging, both passive and active, which have taken place over the past two decades. We will examine how advances in device technology have enabled continuous improvement in imager performance, reduction in system cost and ultimately commercial maturity. Many different imaging architectures and modes have been pursued which have driven developments in both hardware and signal processing.

Much of the early work was concerned with collecting and understanding phenomenological data in order to better understand this relatively new view of the world and this aspect continues to be important as new applications emerge. Today millimeter wave imaging is relevant in many diverse applications such as security, remote sensing, non-destructive testing and synthetic vision. The future appears very healthy for our topic and community or practitioners and we look forward to many more exciting developments and research results in the next twenty years.

10189-2, Session 1

Expanding the spectrum: 20 years of advances in MMW imagery *(Invited Paper)*

Christopher A. Martin, John A. Lovberg, Valdimir G. Kolinko, Trex Enterprises Corp. (United States)

The advantages of imaging in the MMW portion of the spectrum have been recognized for many years, but the ability to create high quality MMW imagery had generally been restricted to that possible with single-pixel imagers. Advances in electronic component materials and manufacturing in the past twenty years have given us higher performance and less expensive components, leading to both greatly improved imagers and broader range of applications, as well as an expansion of imagers from MMW into the THz regime. This paper explores the resulting imagers and applications.

10189-3, Session 1

Developments in the use and capability of millimetre wave technologies for stand-off detection of threat items over the last decade

Elena Ollett, Anthony S. Clark, Chris Selway, Gillian Knevitt, Robert Kidd, Aron Krausz, Home Office Ctr. for Applied Science and Technology (United Kingdom)

The Home Office Centre for Applied Science and Technology (CAST) has a longstanding history in the evaluation of passive and active millimetre wave (mmW) systems for stand-off detection. The requirements for stand-off detection have evolved greatly over the last decade due to changes in threat, as has the capability of technologies. CAST has worked with these changes to evaluate systems alongside other government departments, developing expertise in the standard of technology from low to high technology readiness level (TRL) as well as understanding the limitations in detection.

In this paper I discuss the work that has been undertaken by CAST since 2007, exploring the developments in methodology that have become necessary for trials to capture the requirements successfully. This involves utilising aspects of test protocols to ensure consistency across testing between CAST and other organisations, allowing for a fair comparison of data. The trials undertaken vary from evaluating the system capability in a static setting to the capability in a crowded environment such as a train station. Understanding the performance capability of passive and active (mmW) systems in crowded places is particularly important given the current threat status of the UK.

10189-4, Session 1

Developing an ANSI standard for image quality tools for the testing of active millimeter wave imaging systems

Jeffrey Barber, James C. Weatherall, Kevin Yam, Joseph Greca, Battelle Memorial Institute (United States); Peter R. Smith, AASKI Technology, Inc. (United States); Barry T. Smith, Transportation Security Lab. (United States)

In 2016, the millimeter wave (MMW) imaging community initiated the formation of a standard for millimeter wave image quality metrics. This new standard, American National Standards Institute (ANSI) N42.59, will apply to active MMW systems for security screening of humans. The Electromagnetic Signatures of Explosives Laboratory (EMXLAB) at the Transportation Security Laboratory is supporting the ANSI standards process via the creation of initial prototypes for round-robin testing with MMW imaging system manufacturers and experts.

To date, initial test objects for measuring spatial resolution and depth resolution have been created. Several spatial resolution targets consisting of one-dimensional 3-bar patterns and a Siemens star covering the range 30 mm (10 GHz) to 0.5 mm (600 GHz). Patterns were fabricated via photochemical etching of 16.5 x 16.5 x 0.2 in. stainless steel substrates, allowing for orthogonal measurements without the need for alternate fixturing. Depth resolution targets consist of 0.5 in. steel balls embedded in 12 x 12 x 0.5 in. polystyrene sheets. The front sheet contains a steel ball at the center for image registration, while subsequent sheets contain balls placed at a constant radius, forming a clockwise spiral in depth.

Results obtained for these prototypes will be used to inform the community and lead to consensus objective standards amongst stakeholders. Images collected with laboratory systems will be presented along with results of preliminary image analysis. Future considerations for object design, data collection and image processing via automated software will be discussed.

10189-5, Session 2

Identifying explosives using broadband MMV imaging

James C. Weatherall, Kevin Yam, Jeffrey Barber, Battelle Memorial Institute (United States); Barry T. Smith, Transportation Security Lab. (United States); Peter R. Smith, AASKI Technology, Inc. (United States); Joseph Greca, Battelle Memorial Institute (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 their location on a generic outline of a person using imaging data collected over a range of frequency. We propose using the spectral information from the imaging data to identify the composition of an anomalous object, in particular if it is an explosive material [1]. The discriminative value of the technique has been illustrated in the laboratory for military sheet explosive using millimeter-wave reflection data [2] at frequencies 18 ? 40 GHz, and commercial explosives using 2 - 18 GHz [3]. Recent work explores how the method can be used on imaging data collected with an experimental high-definition imaging system that operates at 10 – 40 GHz.

The identification of explosives is accomplished by extracting the dielectric constant from free-space, multi-frequency reflection data. The reflection coefficient is a function of frequency because of propagation effects associated with the material's complex dielectric constant. In partially transparent materials, constructive interference from multiple reflections and the energy loss in the ray paths traversing the sample affect the reflected spectrum. In commercial explosives, which are likely to be conductive and more opaque, the variation in reflection coefficient is apparent in a lower band of frequency, and is due to skin-depth effects. The dielectric constant is obtained by numerically fitting the reflection coefficient as a function of frequency to a theoretical model based on geometric optics. In principal, the implementation of this technique in standoff imaging systems would allow threat assessment to be accomplished within the scope of millimeter-wave screening.

[1] B. T. Smith, J. C. Weatherall, and J. Barber, "Method for identifying materials using dielectric properties through active millimeter wave illumination," U.S. Patent 8,946,641, Feb. 3, 2015.

[2] J. C. Weatherall, J. Barber, and B. T. Smith, "Identifying explosives by dielectric properties obtained through wide-band millimeter-wave illumination," in SPIE Defense+ Security. International Society for Optics and Photonics, May 2015, pp. 94 620F–94 620F.

[3] J. C. Weatherall, J. Barber and B. T. Smith, "Spectral signatures for identifying explosives With wideband millimeter-wave illumination," in IEEE Transactions on Microwave Theory and Techniques, vol. 64, no. 3, pp. 999-1005, March 2016.

10189-7, Session 2

Improved characterization of scenes with a combination of MMW radar and radiometer information

Stephan Dill, Markus Peichl, Eric Schreiber, Deutsches Zentrum für Luft- und Raumfahrt e.V. (Germany)

For security related applications MMW radar and radiometer systems in remote sensing or stand-off configurations are well established techniques. The range of development stages extends from experimental to commercial systems on the civil and military market. Typical examples are systems for personnel screening at airports for concealed object detection under clothing, enhanced vision or landing aid for helicopter and vehicle based systems for suspicious object or IED detection along roads. Due to the physical principle of active (radar) and passive (radiometer) MMW measurement techniques the appearance of single objects and thus the complete scenario is rather different for radar and radiometer images.

A radar system consists of a transmitter and a receiver path. It performs an active illumination of a scenario and records the reflected signals. It delivers a range measurement in combination with information about the objects reflectivity properties. A radiometer system has only a receiver path in order to measure the natural thermal radiation power of objects. The measured signal provides information on the emission and reflection properties of objects whereas the cosmic background radiation and the complete environment act as illumination source for a scenario.

The illumination and imaging principles of the both techniques and the related scattering behavior of objects will deliver different and often complementary information of a scenario. A reasonable combination of both measurement techniques could lead to enhanced object information. However, some technical requirements should be taken into account. The imaging geometry should be nearly identical, the geometrical resolution and the wavelength should be similar and at best the imaging process should be carried out simultaneously.

Therefore theoretical and experimental investigations on a suitable combination of MMW radar and radiometer information have been conducted.

The antenna system of an existing mechanical linescanner was improved in order to provide a similar imaging geometry for radar and radiometer system. The investigations concentrate on rather basic scenarios with canonical targets like flat plates, spheres, corner reflectors and cylinders. Experimental results of different image products are shown and discussed.

10189-8, Session 2

Measurements of the dielectric properties of explosives and inert materials at millimeter wave frequencies (V-band and above) using free space reflection methods

Peter R. Smith, AASKI Technology, Inc. (United States); James C. Weatherall, Jeffrey Barber, Joseph Greca, Battelle Memorial Institute (United States); Barry T. Smith, Transportation Security Lab. (United States)

Dielectric properties of energetic materials and inert materials are of interest to the security scanning of humans. The Electromagnetic Signatures of Explosives Laboratory (EMXLAB) at the Transportation Security Laboratory supports the test and evaluation of millimeter wave imaging systems through the development of simulants for explosives. By accurately characterizing explosives and inert materials, it is possible to develop inert simulants for the safe testing of imaging portals. Accurate dielectric properties are also necessary in order to identify materials as threat or benign.

Commercial MMW imaging systems are being developed above 50 GHz (V-band) in order to obtain higher spatial resolution. This is driving the need for dielectric measurements at higher frequencies. Measurements at these frequencies are challenging, however. Loaded waveguide methods become more difficult at millimeter-wave frequencies as dimensions get smaller. Absorption in materials also increases with increasing frequency, preventing transmission measurements from being performed on many materials. We describe a system using free space propagation at E band (60 – 90 GHz), extending previous work done in the 18 – 40 GHz range, that reduces these challenges. Data is collected using reflection-only (S11) measurements via a network analyzer and a banded millimeter wave transceiver. Dielectric properties are extracted using numerical fitting of the S11 data to a theoretical model based on geometric optics. Transparent and opaque materials are handled by a similar model. System calibration, sample fixturing, modeling and results will be presented.

10189-10, Session 3

Background limited passive sub-mm/mm wave imaging at video rates with kinetic inductance detectors

Sam Rowe, Cardiff Univ. (United Kingdom); Ken Wood, QMC Instruments Ltd. (United Kingdom)

Kinetic inductance detectors (KIDs) are coming into prominence in the field of sub-millimetre and millimetre-wave imaging by virtue of their high sensitivity, broadband spectral coverage; the ease of their fabrication and the simplicity of the associated electronic readout of large format arrays.

The Astronomy Instrumentation Group at Cardiff University, in collaboration with QMC Instruments Ltd., is developing a general purpose camera based on focal plane arrays of lumped element KIDs (LEKIDs) for video rate, background limited passive imaging. We aim to have a fully functioning and versatile camera that is ready to enter the commercial marketplace within the next two years.

Here we present our progress to date on the design and construction of the cryogen-free cooling platform and cold imaging optics system; the development and fabrication of detector array architectures suitable for a range of optical bands, including options for simultaneous multi-band observations; the development and assembly of a multiplexing readout system based on ROACH-2 electronics; the development and testing of intuitive and simple-to-operate control software; and concepts for modular optical coupling units for application specific imaging capabilities.

10189-11, Session 3

Design and performance of a THz block camera with a 130nm CMOS focal plane array

Erin F. Fleet, Hugo Romero, U.S. Naval Research Lab. (United States); Joseph Schlupf, Alaire Technologies, Inc. (United States); Andrew J. Boudreau, Trident Systems, Inc. (United States); Kenneth K. O., Daeyeon Kim, The Univ. of Texas at Dallas (United States)

Recent advances in 130 nm CMOS based Schottky barrier diode THz power detectors enable relatively simple, high-performance focal plane arrays. We present a low size, weight and power block camera which uses polymer refractive optics and a 6x6 focal plane array to image the return from an active source operating at 218 GHz. The operating frequency is chosen for multiple reasons: to coincide with atmospheric transmission windows, to image through degraded visual environments, and to leverage recently developed high power sources available at the Naval Research Laboratory. The sensor achieves better than 30 pW/√Hz NEP at video frame rates while lock-in detecting a modulated source. The three and a half pound camera houses a COTs aspheric polymer optic, detector array, signal amplification and lock-in detection, and outputs data over an Ethernet connection. We will present the camera design, performance metrics, and sample imagery.

10189-12, Session 3

Security screening via computational imaging using frequency-diverse metasurface apertures

David R. Smith, Duke Univ. (United States); Matthew S. Reynolds, Univ. of Washington (United States); Jonah N. Gollub, Daniel L. Marks, Mohammadreza F. Imani, Okan Yurduseven, Duke Univ. (United States); Daniel Arnitz, Andreas Pedross-Engel, Univ. of Washington (United States); Timothy Sleasman, Parker Trofatter, Duke Univ. (United States); Alec Rose, Evolv Technology (United States); Michael Boyarsky, Hayrettin Odabasi, Guy Lipworth, Duke Univ. (United States)

Security screening at microwave frequencies has conventionally relied on mechanical raster scanning and electrical beamforming. These methods have shown excellent performance, but are costly and cumbersome to implement. In this work, we present computational imaging using frequency-diverse apertures as an alternative method for security screening with much lower cost and simpler hardware. Frequency-diverse apertures are defined by their ability to generate spatially-distinct radiation patterns as a function of the driving frequency. These complex waveforms can be used to illuminate a scene and encode its spatial content into simple backscatter frequency measurements. The resulting signals are post-processed through computational techniques to obtain high-quality images of the scene. In this manner, frequency-diverse apertures can obtain excellent image quality within a fraction of the acquisition time associated with conventional techniques. In addition, frequency-diverse apertures are planar, do not rely on moving parts, and can be fabricated using standard printed circuit board technology. Given these advantages, they are a promising and potentially revolutionary platform for security screening and threat detection at microwave and millimeter wave frequencies.

Over the last few years, our group has proposed and experimentally demonstrated a variety of frequency diverse imaging systems. In this presentation, we review outcomes of our efforts, and describe various methods to achieve desired frequency diversity. In particular, we illustrate metasurface apertures which take advantage of frequency-diverse modes supported within an electrically-large cavity to form distinct radiation patterns. The principles of operation are discussed and a complete imaging system, consisting of multiple frequency-diverse apertures as transmitters and receivers, intended to image human-sized objects is also presented. Further, the hardware platform, customized RF circuitry, and the critical role of RF calibration are discussed. Experimental reconstructions of mannequins with threat objects are shown using the proposed system. Lastly, the future outlook for such devices and their exciting potentials for fast and reliable 3D imaging throughout the electromagnetic spectrum are discussed.

10189-13, Session 3

High resolution, wide field of view, real time 340GHz 3D imaging radar for security screening

Duncan A. Robertson, David G. Macfarlane, Robert I. Hunter, Scott L. Cassidy, Univ. of St. Andrews (United Kingdom); Nuria Llombart, Erio Gandini, Technische Univ. Delft (Netherlands); Tomas Bryllert, Wasa Millimeter Wave AB (Sweden); Mattias Ferndahl, Gotmic AB (Sweden); Hannu Lindström, Jussi Tenhunen, Hannu Vasama, VTT Technical Research Ctr. of Finland Ltd. (Finland); Jouni Huopana, Timo Selkälä, Antti-Jussi Vuotikka, Global Boiler Works Oy (Finland)

Submillimeter wave 3D radar imaging is suitable for the detection of concealed objects in security applications such as next generation walk-by screening. The principal challenges in this are achieving high volumetric resolution over a relatively wide field of view, with high dynamic range, and at a sufficiently high frame rate to cope with dynamic scenes.

The EU FP7 project CONSORTIS (Concealed Object Stand-Off Real-Time Imaging for Security) is addressing this need and is developing a demonstrator system for next generation airport security screening which will combine passive and active submillimeter wave imaging sensors.

Here we report on the development of the 340 GHz 3D imaging radar which achieves high volumetric resolution over a wide field of view with high dynamic range and a high frame rate. A sparse array of 16 radar transceivers is coupled with high speed mechanical beam scanning to achieve a field of view of ~ 1 x 1 x 1 m3 and a 10 Hz frame rate.

The radar uses an FMCW homodyne architecture with frequency multiplying transceivers which exploit self-mixing multiplier technology, dispensing with the need for explicit duplexing components. The transceivers are driven by a wideband (~10%) 16 channel chirp generator which exhibits excellent channel balance and amplitude flatness. State-of-the-art wide field of view Dragonian mirror optics, in combination with the beam scanning optomechanics, yields high spatial resolution, low scan loss and low aberration over the field of view at relatively short range. High speed data acquisition and real time signal processing complete the concept demonstrator.

10189-14, Session 4

A 110-170GHz transceiver front-end in 130nm SiGe BiCMOS technology for FMCW applications

Herbert Zirath, Yu Yan, Tomas Bryllert, Sten E. Gunnarsson, Chalmers Univ. of Technology (Sweden)

A 110-170 GHz transceiver is designed and fabricated in a 130 nm SiGe BiCMOS technology. The transceiver operates as an amplifier for transmitting and simultaneously as a fundamental mixer for receiving. In a measured frequency range of 120-160 GHz, a typical output power of 0 dBm is obtained with an input power of +3 dBm. As a fundamental mixer, a conversion gain of -9 dB is obtained at 130 GHz LO, and a noise figure of 19 dB is achieved. The transceiver is successfully demonstrated as a FMCW radar front-end for distance measurement. With a chirp rate of 1.6x1012 Hz/s and a bandwidth of 14.4 GHz, a range resolution of 2.8 cm is demonstrated, and transmission test is shown on different objects.

10189-15, Session 4

Quad-channel beam switching WR3-band transmitter MMIC

Daniel Mueller, Karlsruher Institut für Technologie (Germany); Gülesin Eren, Univ. Stuttgart (Germany); Sandrine Wagner, Axel Tessmann, Arnulf Leuther, Fraunhofer-Institut für Angewandte Festkörperphysik (Germany); Thomas Zwick, Karlsruher Institut für Technologie (Germany); Ingmar Kallfass, Univ. Stuttgart (Germany)

Besides their compact dimensions, millimeter-wave radar systems offer several advantages such as the combination of high resolution and the penetration of adverse atmosphere like smoke, dust or rain. Commonly these systems are restricted to one scanning dimension. To overcome these limitation one approach is to combine a 1D beam steering system with a frequency agile antenna. Therefore, one dimension is swept via classical beam steering while the second dimension is controlled by the output frequency of the transmitter. This paper presents a monolithic millimeterwave integrated circuit (MMIC) which offers beam steering capabilities by employing an active switch which addresses an on-chip integrated Butler matrix.

To simplify packaging, the input is kept at relatively low frequencies, using a frequency tripler which multiplies the 76.6 - 83.3 GHz input signal to the intended 230 – 250 GHz output frequency range. Afterwards the signal is amplified by a two-stage buffer-amplifier to generate sufficient LO drive for the subsequent mixer. The mixer is intended for future enhancements in terms of radar signal coding or communication applications. Following the mixer stage the signal is amplified by a second two stage buffer amplifier and fed to the actual beam steering network. To keep losses as low as possible, this network is realized using an active single pole quadruple throw (SP4T) switch. The four output ports of the SP4T are connected to the integrated Butler matrix which creates the actual wavefront for the frequency agile off-chip antenna.

The MMIC was fabricated in a 35 nm GaAs mHEMT process and all measurements were performed on-wafer. The chip dimensions are 4.0x1.5 mm2. The measured LO output power for the uppermost port and all four switching states is between -15 and -17 dBm. To equally split the input power to the output ports the Butler matrix have to be terminated with 50 Ohm loads at each port. The measurement setup only terminates one port, leading to the variation in output power. The measured lower side band shows a conversion loss of roughly 20 dB up to IF bandwidths of 10 GHz.

10189-16, Session 4

Optical-fiber-connected 300GHz FM-CW radar system

Atsushi Kanno, Norihiko Sekine, Akifumi Kasamatsu, Naokatsu Yamamoto, National Institute of Information and Communications Technology (Japan); Tetsuya Kawanishi, Waseda Univ. (Japan) and National Institute of Information and Communications Technology (Japan)

High-resolution imaging technique using high-frequency radio waves is a promising solution for enhancing security and safety; actually, in an airport runway, a foreign object debris detection system has been developed and tried to detect the object using millimeter-wave radio waves. Such high-frequency radios have a significant issue on limitation of the transmission distances due to its short wavelengths and high atmospheric attenuation coefficients: trade-off relationship to the image resolution and detectable size of the object. Moreover, for increase of range/image resolution, bi-static and/or multi-static radar configuration is promising solution. In the scenario, signal feeding network is indispensable for realization of signal coherency.

In the study, optical signal generation for terahertz-wave FM-CW radar system is demonstrated, and the signal distribution over an optical fiber network based on passive optical network configuration is evaluated. The saw-type FM-CW signal at a center frequency of 300 GHz with a bandwidth of 4.8 GHz and a duration of 5 us was generated by the optical frequency multiplier with a multiplication factor of 30. The optical signal was transmitted over the fiber network to one 300-GHz transmitter and two 300-GHz receivers with different fiber lengths. In the proof-of-concept evaluation of a bi-static radar system, difference of the fiber lengths is clearly observed as a difference of the intermediate frequency by a FM-CW radar method under a back-to-back (transmitter and receivers were connected directly by the power splitters) configuration.

10189-17, Session 4

Reconfigurable metasurface aperture for security screening and microwave imaging

Timothy Sleasman, Mohammadreza F. Imani, Michael Boyarsky, Laura Pulido-Mancera, Duke Univ. (United States); Matthew Reynolds, Univ. of Washington (United States); David R. Smith, Duke Univ. (United States)

Microwave imaging systems have progressively grown larger and more powerful in recent decades, yet hardware architectures have not scene drastic changes. With the advent of metasurfaces and their recent application in security screening and satellite communication, a wealth of opportunities exist for developing and honing the metasurface aperture technology. Recent thrusts have introduced dynamic reconfigurability directly into the aperture layer, providing powerful control from a physical layer with astounding simplicity. The waveforms generated from such dynamic metasurfaces make these devices suitable for application in synthetic aperture radar (SAR) and, more generally, computational imaging.

In this presentation, we introduce a dynamic metasurface aperture capable of performing microwave imaging in the K-band (17.5-26.5 GHz). The aperture possesses a planar form factor, is inexpensively fabricated via printed circuit technology, and is readily adapted to a variety of applications. These impressive traits are enabled by the tunability of dynamic metasurfaces, which provides the dexterity necessary to generate field patterns ranging from a sequence of steered beams to a series of uncorrelated radiation patterns. Imaging is experimentally demonstrated with a voltage-tunable metasurface aperture and it is shown that cross range resolution is not sacrificed as the operational bandwidth is reduced—even down to a single frequency point. We also demonstrate its utility in real-time measurements and perform volumetric imaging in a SAR context. The extraordinary capabilities of a fabricated prototype are detailed and the future prospects of general dynamic metasurface apertures are discussed.

10189-18, Session 4

Alternative synthetic aperture radar (SAR) modalities using a 1D dynamic metasurface antenna

Michael Boyarsky, Timothy Sleasman, Laura Pulido-Mancera, Mohammadreza F. Imani, Duke Univ. (United States); Matthew S. Reynolds, Univ. of Washington (United States); David R. Smith, Duke Univ. (United States)

Synthetic aperture radar (SAR) systems conventionally rely on mechanically-actuated reflector dishes or phased arrays for generating steerable directive beams. While these systems have yielded extremely high-resolution images from far distances, the hardware suffers from considerable weight, high cost, substantial power consumption, and cumbersome moving parts-disadvantages particularly relevant to spaceborne systems.

Dynamic metasurface antennas have emerged as a capable platform for microwave imaging applications. Metasurface antennas consist of an electrically-large waveguide loaded with subwavelength radiators, which each selectively leak energy from a guided wave into free space to form various radiation patterns. By tuning each radiator, we can modulate the aperture's overall radiation pattern to generate steered, directive beams without moving parts or phase shifters. Furthermore, leveraging established manufacturing methods has made these apertures extremely lightweight, low-cost, and planar.

In addition to their hardware benefits, dynamic metasurfaces can leverage their high switching speeds to conduct alternative SAR modalities for improved performance. We first discuss how dynamic metasurfaces can perform existing SAR modalities with quality results. We will then describe additional modalities which may achieve improved performance as compared to spotlight and stripmap. These modalities, enhanced resolution stripmap and diverse pattern stripmap, offer the ability to circumvent the trade-off between resolution and region-of-interest size. Simulated imaging results verify the advantages of these modalities and we discuss practical considerations such as noise effects. Ultimately, the hardware gains and additional performance modalities made possible by dynamic metasurface antennas have poised them to propel the SAR field forward and open the door to exciting opportunities.

10189-19, Session 4

Coded aperture subreflector array for high resolution radar imaging

Jonathan J. Lynch, Florian Herrault, Keerti Kona, Mike Wetzel, David L. Hammon, Robert G. Nagele, Harris P. Moyer, Tom Tsen, David Brown, Dean Regan, Joel Wong, Helen Fung, Miro Micovic, HRL Labs., LLC (United States)

HRL Laboratories, LLC has been developing a new approach for high resolution radar imaging on stationary platforms. Funded by DARPA STO on the Advanced Scanning Technology for Imaging Radars (ASTIR) program, high angular resolution is achieved by operating at 235 GHz and using a scalable tile array architecture that has the potential to realize thousands of elements at an affordable cost. HRL utilizes aperture coding techniques to minimize the size and complexity of the RF electronics needed for beamforming, and wafer level fabrication and integration allow tiles containing 1024 elements to be manufactured with reasonable costs.

This conference paper will describe the details of the development of HRL's Coded Aperture Subreflector Array (CASA), including the design of a 1024 element array of antennas with integrated single-bit phase shifters that utilize GaN HEMTs to modulate signals upon reflection. The use of an active reflect-array allows the high resolution radar to be implemented using a single 235 GHz radar transceiver, and we will describe how modulated signals from the CASA array may be used to digitally form pencil beams with multiplicative transmit and receive patterns.

Conference 10190: Ground/Air Multisensor Interoperability, Integration, and Networking for Persistent ISR VIII

Monday - Thursday 10–13 April 2017

Part of Proceedings of SPIE Vol. 10190 Ground/Air Multisensor Interoperability, Integration, and Networking for Persistent ISR VIII

10190-1, Session 1

Integrated vision: UK's approach to coalition ISTAR interoperability *(Keynote Presentation)*

Paul A. Thomas, Defence Science and Technology Lab. (United Kingdom)

No Abstract Available

10190-2, Session 1

ISA for the internet of tactical things

Christine L. Moulton, Jared J. Hepp, U.S. Army CERDEC NVESD (United States)

No Abstract Available

10190-3, Session 1

Interoperability at the tactical edge: Lessons learned from Enterprise Challenge 2016

Susan Toth, U.S. Army Research Lab. (United States); William R. Hughes Sr., Radiance Technologies (United States) and U.S. Army Research Lab. (United States)

No Abstract Available

10190-4, Session 1

Performing data analytics on information obtained from various sensors on a OSUS compliant system

Kevin Klawon, Nilesh Powar, Darian Landoll, Univ. of Dayton Research Institute (United States)

The Open Standard for Unattended Sensors (OSUS) was developed by DIA and ARL to provide a plug-n-play platform for sensor interoperability. Our objective is to use the standardized data produced by OSUS in performing data analytics on information obtained from various sensors. Two kinds of information from the sensor are extracted: aerial images, and sensor parameters like GPS coordinates, resolution etc. For each image from a sensor, specific regions of interest are estimated using convolutional neural network-based networks such as selective segmentation using R-CNN, deep mask or sharp mask. These local regions can be further evaluated by pre-trained and fine-tuned CNN models to denote various geographical elements and landmarks such as residential housing, interstate and highways, stadiums, military installations. A rich set of attributes can then be generated for specific time stamps for each sensor imagery. These attributes along with sensor specific information can be combined with a natural language model and lexicon to create a semantic description from a short stream of sensory imagery. So, within the OSUS framework, this semantic information can be integrated with events along with the corresponding sensor data, transform them into a standardized format across all sensor models, and be transferred to a remote server using the OSUS remote interface protocol. In this manuscript, we will perform feasibility study of this concept by integrating three different sensor models within the OSUS framework and perform further analytics of the extracted attributes in a cloud-computing based remote server.

10190-5, Session 1

Dynamic and adaptive policy models for coalition operations

Geeth R. de Mel, IBM United Kingdom Ltd. (United Kingdom); Elisa Bertino, Purdue Univ. (United States); Seraphin Calo, Supriyo Chakraborty, IBM Thomas J. Watson Research Ctr. (United States); Emil Lupu, Imperial College London (United Kingdom)

It is envisioned that the success of future military operations depends on the better integration—organizationally and operationally—among allies, coalition members, interagency partners, intergovernmental and nongovernmental organizations, and so forth. However, this leads to a challenging and complex environment where the heterogeneity and dynamism in the operating environment intertwines with the evolving situational factors that affect the decision-making life cycle of the war fighter.

Therefore, the users in such environments need secure, accessible, and resilient information infrastructures where policy-based mechanisms adopt the behaviours of the systems to meet end user goals. By specifying and enforcing a policy based model and framework for operations and security which accommodates heterogeneous coalitions, high levels of agility can be enabled to allow rapid assembly and restructuring of system and information resources. However, current prevalent policy models (rule based event-condition-action model and variants) are not sufficient to deal with the highly dynamic and plausibly non-deterministic nature of these environments. Therefore, to address the above challenges, in this paper, we present our research vision into developing a new generative policy model paradigm with analytics support to operationalize a dynamic policy-based autonomous management framework for coalition context.

10190-6, Session 1

Aligning vocabulary for interoperability of ISR assets using authoritative sources

Steve Hookway, Terry Patten, Joe Gorman, Charles River Analytics, Inc. (United States)

The growing arsenal of network-centric sensor platforms shows great potential to enhance situational awareness capabilities. Non-traditional sensors collect a diverse range of data that can provide a more accurate and comprehensive common operational picture when combined with conventional intelligence, surveillance, and reconnaissance (ISR) products. One of the integration challenges is mediating differences in terminology that different data providers use to describe the data they have extracted. A data consumer should be able to reference information using the vocabulary that they are familiar with and rely on the framework to handle the mediation; for example, it should be up to the framework to identify that two different terms are really synonyms for the same concept. In this paper we present an approach for automatically performing this alignment using authoritative sources such as Wikipedia (a stand-in for the Intellipedia wiki), and provide experimental results that demonstrates this approach is able to align a large number of concepts between different terminologies.

10190-7, Session 1

Instinctive analytics for coalition operations

Geeth R. de Mel, IBM United Kingdom Ltd. (United Kingdom); Thomas La Porta, The Pennsylvania State Univ. (United States); Tien Pham, U.S. Army Research Lab. (United States); Gavin Pearson, Defence Science and Technology Lab. (United Kingdom)

The success of future military coalition operations—be they combat or humanitarian—will increasingly depend on a system's ability to share data and processing services (e.g. aggregation, summarization, fusion), and automatically compose services in support of complex tasks at the network edge. We call such an infrastructure instinctive—i.e., an infrastructure that reacts instinctively to address the analytics task at hand. However, developing such an infrastructure is made complex for the coalition environment due to its dynamism both in terms of user requirements and service availability.

In order to address the above challenge, in this paper, we highlight our research vision and sketch some initial solutions into the problem domain. Specifically, we propose means to (1) automatically infer formal task requirements from mission specifications; (2) discover data, services, and their features automatically to satisfy the identified requirements; (3) create and augment shared domain models automatically; (4) efficiently offload services to the network edge and across coalition boundaries adhering to their computational properties and costs; and (5) optimally allocate and adjust services while respecting the constraints of operating environment and service fit. We envision that the research will result in a framework which enables self-description, discover, and assemble capabilities to both data and services in support of coalition mission goals.

10190-8, Session 2

Towards secure communications in commercial off-the-shelf Internet of Things device applications in the military domain

Manas Pradhan, Fahrettin Gökgöz, Nico Bau, Daniel Ota, Fraunhofer FKIE (Germany)

Battlefield environments are evolving and presenting new challenges for the military all around the world. This is pushing the necessity for evolution of military sensor technologies at an unprecedented rate. The military domain is considering the use of Commercial off-the-Shelf (COTS) sensors due their inherent advantages. While military contractors and manufacturers are gearing up to use COTS Internet of Things (IoT) devices, security and trust considerations make it difficult for such devices to be deployed in the battlefield.

In this paper, we present an approach towards establishing security and trust in communications between the IoT and existing devices in the military domain. The IoT devices mounted on Unmanned Ground Vehicles (UGVs) and Unmanned Aerial Vehicles(UAVs) gather sensing and surveillance data. In order for the data to be distributed with other military entities, trust mechanisms are needed to establish and ensure the identities of the participating devices. After the appropriate devices have been identified, the data gathered and processed is securely distributed between the UGVs/UAVs, the convoy vehicles and the higher echelons using the existing military communication framework extended by the MIOT architecture.

The trust and security of data distribution between the UGVs/UAVs and convoy vehicles is provided by the NATO Generic Vehicle Architecture (NGVA) complemented by the Data Distribution Service (DDS) Security Specification. The publishing of consolidated and processed data from the ground to the higher echelons like command centres is carried out using the Multilateral Interoperability Programme (MIP) specification. The MIP provides security using the Web Service Security Standards (WSS) implementation and uses the confidentiality labelling mechanism for identifying the trusted parties for data exchange.

10190-9, Session 2

Coalitions of Things: Supporting ISR tasks via Internet of Things approaches

Alun D. Preece, Ian J. Taylor, Cardiff Univ. (United Kingdom); Dave Braines, Anna Thomas, Nicholas O'Leary, IBM United Kingdom Ltd. (United Kingdom); Thomas La Porta, The Pennsylvania State Univ. (United States); Jonathan Z. Bakdash, Erin Zaroukian, U.S. Army Research Lab. (United States)

In the wake of rapid maturing of Internet of Things (IoT) approaches and technologies in the commercial sector, the IoT is increasingly seen as a key 'disruptive' technology in military environments. Future operational environments are expected to be characterised by a lower proportion of human participants and a higher proportion of autonomous and semiautonomous devices. This view is reflected in both US "third offset" and UK "information age" thinking and is likely to have a profound effect on how multinational coalition operations are conducted in future. Much of the initial consideration of IoT adoption in the military domain has rightly focussed on security concerns, reflecting similar cautions in the early era of electronic commerce. As IoT approaches mature, this initial technical focus is likely to shift to considerations of interactivity and policy. In this paper, rather than considering the broader range of IoT applications in the military context, we focus on roles for IoT concepts and devices in future intelligence, surveillance and reconnaissance (ISR) tasks, drawing on experience in sensor-mission resourcing and human-computer collaboration for ISR. We highlight the importance of low training overheads in the adoption of IoT approaches, and the need to balance proactivity and interactivity (push vs pull modes). As with sensing systems over the last decade, we emphasise that, to be valuable in ISR tasks, IoT devices will need a degree of mission-awareness in addition to an ability to self-manage their limited resources (power, memory, bandwidth, computation, etc). In coalition operations, the management and potential sharing of IoT devices and systems among partners (e.g. in cross-coalition tactical-edge ISR teams) becomes a key issue. Finally, we briefly outline a platform that we have developed in order to experiment with human-IoT teaming on ISR tasks, in both physical and virtual settings.

10190-10, Session 2

Using OSUS and node red to integrate IoT devices based on events

Kevin Klawon, Joshua Gold, Pat Ryan, Univ. of Dayton Research Institute (United States)

The concept and capabilities of the Internet of Things (IoT) is quickly enabling commercial and residential communities to task sensors and application-level devices, as well as providing infrastructure to process, exploit, and disseminate (PED) the data that is collected. There are a multitude of platforms as well, from the cloud to open-source frameworks that allow consumers to visualize and fuse their own data. These application platforms leverage configurable user interfaces, workflow designers, triggers, and query languages to fuse data and exploit using mobile and web clients.

The ISR analysts of today should have that same capability with the assets they are monitoring. In the same vein as the IoT world, the assets should be configurable based on their mission and their interaction with each other should be customizable based on potential inputs/outputs. However, other factors must also be considered, such as security, disadvantaged communication links, and constrained resources.

The Open Standard for Unattended Sensors (OSUS) was developed by the DIA and ARL to provide an open platform for sensor interoperability. Its plug-in environment allows for the integration of customized communication and sensor assets based on well-documented and open standard. Node-RED is web-based application that allows users to wire

together IoT devices based on events. This topic explores the possibility of combining government interoperable sensors with open-source applications that provide powerful capability for mission programming with an intuitive user interface that does not require it to be tightly coupled with the application platform.

10190-11, Session 2

Tractable policy management framework for IoT

Geeth R. de Mel, IBM United Kingdom Ltd. (United Kingdom); Emre Goynugur, Murat Sensoy, Ozyegin Univ. (Turkey); Seraphin Calo, IBM Thomas J. Watson Research Ctr. (United States)

Due to the advancements in the technology, hype of connected devices (henceforth referred to as IoT) in support of automating the functionality of many domains—be it military or smart environments—have become a reality. However, with the proliferation of such connected and interconnected devices, efficiently managing networks manually becomes an impractical, if not an impossible task. This is because devices have their own obligations and prohibitions in context, and humans are not equipped to maintain a bird's-eye view of the state space. Traditionally, policies are used to address such issues, but in the IoT arena, one requires a policy framework in which the language can provide sufficient amount of expressiveness along with efficient reasoning procedures to automate the management. In this work, we present our initial work into creating a scalable knowledge-based policy framework for IoT and discusses its applicability through task delegation scenario.

10190-12, Session 3

Deep learning on temporal-spectral data for anomaly detection

King Ma, Henry Leung, Univ. of Calgary (Canada); Ehsan Jalilian, Daniel Huang, Hifi Engineering Inc. (Canada)

Detecting anomalies is important for continuous monitoring of sensor systems. One significant challenge is to use sensor data and autonomously detect changes that cause different conditions to occur. Using deep learning methods, we are able to monitor and detect changes as a result of some disturbance in the system. We utilize deep neural networks for sequence analysis of time series. We use a multi-step method for anomaly detection. We train the network to learn spectral and temporal features from the acoustic time series. We test our method using fiber-optic acoustic data from a pipeline.

10190-13, Session 3

A generative model for predicting terrorist incidents

Dinesh Verma, IBM Thomas J. Watson Research Ctr. (United States); Gavin Pearson, Defence Science and Technology Lab. (United Kingdom); Diane Felmlee, The Pennsylvania State Univ. (United States); Archit Verma, Princeton Univ. (United States); Roger M. Whittaker, Cardiff Univ. (United Kingdom)

A major concern in coalition peace-support operations in any theater is the incidence of civilian terrorist activity. In this paper, we propose a generative model for the occurrence of the terrorist incidents, and illustrate that an increase in diversity, as measured by the number of different groups that an individual is likely to belong to, should be inversely correlated with the likelihood of a terrorist incidents in the society. A generative model has the benefit that it can predict the likelihood of events in new contexts, as opposed to statistical models which are used to predict the future incidents based on the history of the incidents in an existing context. Generative models can be very useful in planning for persistent ISR since they allow an estimation of regions in the theater of operation where terrorist incidents may arise. This can be used to better allocate the assignment and deployment of ISR assets which are highly like to be in short supply.

In this paper, we present a taxonomy of terrorist incidents, provide a mathematical analysis calculating the likelihood of occurrence of terrorist incidents given simple models for distribution of groups and population in a region, as well as conduct computer simulations for more complex types of distribution of groups in the area. The mathematical analysis is formulated on modeling four factors - aggression probability, aggression opportunity, aggression reward and aggression penalty. We use the modeling to prove two assertions regarding the occurrence of terrorist incidents.

10190-14, Session 3

Discovering anomalous events from urban informatics data

Vigneshwaran Subbaraju, Kasthuri Jayarajah, Archan Misra, Tam La Thanh, Singapore Management Univ. (Singapore)

Singapore's "smart city" agenda is driving the government to provide public access to a broader variety of urban informatics sources, such as the geotagged records of available taxis and bus arrival time estimates at different bus stops. Such informatics data serves as probes of evolving conditions at different spatiotemporal scales. This paper will explore how such multi-dimensional informatics data can be used to establish the normal operating conditions at different city locations, and then apply appropriate outlier-based analysis techniques to identify anomalous events at these selected locations. We will introduce the overall architecture of socio-physical analytics, where such infrastructural data sources can be combined with social media analytics to not only detect such anomalous events, but also explain them. We shall demonstrate a key difference between the discriminative capabilities of such informatics vs. social media data: while social media streams provide discriminative signals during the occurrence of such an event, urban informatics data can often reveal patterns that have higher persistence, including before and after the event. Our approach requires extraction of novel multi-dimensional features and adoption of multi-scale outlier detection techniques. In particular, as an exemplar of our proposed sociophysical analytics framework, we shall demonstrate how combining data from (i) geotagged taxi demand, (ii) bus arrival times, (iii) traffic cameras and (iv) parking garage occupancy can help identify unusual events, across different spatiotemporal boundaries.

10190-15, Session 3

Deep learning for anomaly detection in maritime vessels using AIS-cued camera imagery

Abir Mukherjee, Yi Zang, George A. Lampropoulos, Ting Liu, A.U.G. Signals Ltd. (Canada)

Ground-based Automatic Identification System (AIS) is widely used to identify vessels in open waters. In maritime surveillance it is necessary to validate the self-reported AIS identity against other intelligence to prevent a possible threat. Erroneous AIS reports can be generated by a vessel with malicious intent, to hide its identity, geo-coordinates or destination. In such a scenario, visual imagery can be used to corroborate the validity of the AIS information provided.

The presented work is an extension of previous work carried out at A.U.G. Signals Ltd. The problem is approached herein for vessel identification/verification using Deep Learning Neural Networks in a persistent surveillance scenario. The images utilized for testing and validation of the work in

this paper are of vessels in a harbour.The images were captured by a camera that was autonomously cued using the AIS position report of an approaching vessel. Using these images, Deep Learning Neural Networks were set up to: detect vessels from still imagery (visible wavelength); detect and recognize the MMSI and vessel name printed on the hull; recognize the ship-type based on the shape and size of the hull.

Different neural network designs were implemented for vessel detection and compared based on learning performance (speed and demanded training sets) and estimation accuracy. Other neural network setups were explored for the recognition of MMSI and ship-type. Unique features from these designs were taken to create an optimized solution. This paper presents a comparison of the deep learning approaches implemented and their relative capabilities in vessel verification.

10190-16, Session 3

Framework for behavioral analytics in anomaly identification

Maroun Touma, IBM Thomas J. Watson Research Ctr. (United States); Elisa Bertino, Purdue Univ. (United States); Brian K. Rivera, U.S. Army Research Lab. (United States); Seraphin Calo, Dinesh Verma, IBM Thomas J. Watson Research Ctr. (United States)

Abstract(draft): Behavioral Analytics (BA) relies on digital breadcrumbs to build user profiles and create clusters of users who exhibit a large degree of similarity. The prevailing assumption is that users will assimilate the group behavior of the cluster they belong to. Our understanding of BA and its application in different domains continues to evolve and is a direct result of the growing interest in Machine Learning (ML) research. When trying to detect security threats, we use BA techniques to identify anomalies which we define as deviations from the group's behavior. Research to date have shown that BA based techniques tend to have high false positive rates as they often trigger security alerts based on deviation from the cluster learned behavior despite the behavior being within the norm of what the system defines as an acceptable behavior. Further, domain specific security policies tend to be narrow and inadequately represent what a user can do. Hence, they a) limit the amount of useful data during the learning phase and b) lead to users violating policy during the execution phase. In this paper, we propose a framework for future research on the role of policies and behavior security in a coalition setting, with emphasis on anomaly detections and individual's deviation from group activities.

10190-17, Session 4

The machine and situational understanding *(Invited Paper)*

Michael A. Kolodny, U.S. Army Research Lab. (United States)

No Abstract Available

10190-18, Session 4

The need for separate operational and engineering user interfaces for command and control of airborne synthetic aperture radar systems

Laura M. Klein, Laura A. McNamara, Sandia National Labs. (United States)

In this paper, we address the needed components to create usable engineering and operational User Interfaces (UIs) for airborne Synthetic Aperture Radar (SAR) systems. As airborne SAR technology gains wider acceptance in the remote sensing and Intelligence, Surveillance, and Reconnaissance (ISR) communities, the need for effective and appropriate UIs to command and control these sensors has also increased. However, despite the growing demand for SAR in operational environments, the technology still faces an adoption roadblock, in large part due to the lack of effective UIs. It is common to find operational interfaces that have barely grown beyond the disparate tools engineers and technologists developed to demonstrate an initial concept or system. While sensor usability and utility are common requirements to engineers and operators, their objectives for interacting with the sensor are different. As such, the amount and type of information presented ought to be tailored to the specific application.

10190-19, Session 5

Smart coalition systems: a deep machine learning approach

Graham Bent, Flavio Bergamaschi, IBM United Kingdom Ltd. (United Kingdom)

Future coalition operations at the tactical edge will rely more and more on having the right information at the right time. Too much information leads to clutter, too little leads to inefficiency. Asset's and people's mobility combined with the right amount of information sharing will be the key to success. Future coalition information networks will have to have to adaptively respond to the changes in the infrastructure and changes in on how different coalition groups combine for different tasks. This paper highlights some of the research questions we intend to address: 1) Can we apply Deep Machine Learning to the problem of adaptively compose services and adaptively reconfigure the infrastructure in support of coalition operations? 2) How the microservices paradigm can be applied to coalition information networks; 3) How compact are the microservices that still provide meaningful functionality; 4) With the right microservices granularity, how to take advantage of asset's and people's mobility, including opportunistic services and systems aggregation.

10190-20, Session 5

In context query reformulation for failing SPARQL queries

Amar Viswanathan, Rensselaer Polytechnic Institute (United States); James R. Michaelis, Taylor Cassidy, U.S. Army Research Lab. (United States); Geeth R. de Mel, IBM United Kingdom Ltd. (United Kingdom); James Hendler, Rensselaer Polytechnic Institute (United States)

Knowledge bases for decision support systems are growing increasingly complex, through continued advances in data ingest and management approaches. However, humans do not possess the cognitive capabilities to retain a bird's-eye-view of such knowledge bases, and may end up issuing unsatisfiable queries to such systems.

This work focuses on the implementation of a query reformulation approach for graph-based knowledge bases, specifically designed to support the Resource Description Framework (RDF). The reformulation approach presented is instance-and schema- aware. Thus, in contrast to relaxation techniques found in the state-of-the-art (e.g., generalizing queries by substituting variables for instances), the presented approach produces in context reformulation. The work has recently been transitioned to the US Army Research Laboratory (ARL),and aims to facilitate not only formal task-based user studies that extrinsically evaluate knowledge network construction algorithms, but will also allow researchers to elicit feedback from a diverse set of perspectives.

10190-21, Session 5

Cloning and sharing: Interaction designs for reducing work and maintaining state across 24X7 operations teams

John Ganter, Paul Reeves, Sandia National Labs. (United States)

No Abstract Available

10190-22, Session 5

"Does this interface make my sensor look bad?" Basic principles for designing usable, useful interfaces for sensor technology operators

Laura A. McNamara, Laura M. Klein, Sandia National Labs. (United States)

Even as remote sensing technology has advanced in leaps and bounds over the past decade, the remote sensing community lacks interfaces and interaction models that facilitate effective human operation of our sensor platforms. Interfaces that make great sense to electrical engineers and flight test crews can be anxiety-inducing to operational users who lack professional experience in the design and testing of sophisticated remote sensing platforms. This paper reflects on several years' worth of design and evaluation projects to identify and describe major issues that frustrate sensor operators and to explain their impact on the efficiency and effectiveness of sensor tasking, collections, exploitation and production in high-consequence workflows. Drawing on basic principles from cognitive and perceptual psychology and interaction design, we provide simple, easily learned guidance for minimizing common barriers to system learnability, memorability, and user engagement.

10190-23, Session 6

B-SAVED: A modular multi-sensor node for event detections, tracking, and recognition in persistent ISR applications

Nicolas Hueber, Pierre Raymond, Christophe Hennequin, Philippe Voisin, Alexander Pichler, Maxime Perrot, Louise Sarrabezolles, Institut Franco-Allemand de Recherches de Saint-Louis (France)

No Abstract Available

10190-24, Session 6

Persistent maritime traffic monitoring for the Canadian Arctic

Martin Ulmke, Fraunhofer FKIE (Germany)

No Abstract Available

10190-25, Session 6

Detection and localization of multiple wideband intermittent acoustic sources

Kung Yao, Ralph E. Hudson, Univ. of California, Los Angeles (United States)

We have been interested in the analytical and experimental study of real-life bird song sources for several years. Bird sources are characterized by either a single or multiple bird vocalizations independent of each other or in response to others. The sources may be physically-stationary or exhibit movements and the signals are wide-band in frequency and often intermittent with pauses and possibly restarting with repeating previously used songs or with new songs. Thus, the detection, classification, and 2D or 3D localization of these birds pose challenging signal and array problems. Due to the fact that some birds can mimic other birds, time-domain waveform characterization may not be sufficient for determining the number of birds. Similarly, due to the intermittent nature of the vocalizations, data collected over a long period cannot be used naively. Thus, it is necessary to use short-time Fourier transform (STFT) to fully exploit the intricate natures of the time and frequency properties of these sources and displayed on a spectrogram. Various dominant spectral data over the relevant frames are used to form sample covariance matrices. Eigenvectors associated with the decompositions of these matrices for these spectral indices can be used to provide 2D/3D DOA estimations of the sources over different frames for intermittent sources. Proper cluttering of these data can be used to perform enhanced detection, classification, and localization of multiple bird sources. Various collected bird data will be used to demonstrate these claims.

10190-26, Session 6

Novel machine learning methods to enhance the detection and classification of objects in multi-spectral multi-resolution synthetic aperture radar images

Flavio Bergamaschi, IBM United Kingdom Ltd. (United Kingdom); Valentina Bono, IBM United Kingdom Ltd (United Kingdom); David Conway-Jones, IBM United Kingdom Ltd. (United Kingdom); Richard Tomsett, IBM United Kingdom Ltd (United Kingdom); Electra Panagoulia, Andrea Minchella, Satellite Applications Catapult (United Kingdom)

Maritime security and surveillance are key to ensuring that maritime activities, such as logistics and fishing, are compliant with relevant existing legislation. Monitoring the movement and localization of vessels on the seas is a great challenge not only because it is very difficult to monitor when vessels are far from land, but also because the various tracking system, such as the Automatic Identification System (AIS), can be hacked and made to distribute false information or even switched off completely. Overall, illegal activities in the maritime sector and illegal activities that are supported through them have cost the global economy several billion dollars each year. As a result, it is important for law enforcement agencies to have access to data that do not have geographic or weather restrictions, are of a high enough resolution to allow the detection of ships of various sizes, and, importantly, are easily accessible and available very soon after an acquisition is made. Synthetic Aperture Radar (SAR) imagery is ideal for this purpose, as it can be acquired at any time of day and it is not affected by cloud cover, unlike optical imagery, and it is available in a range of resolutions. For this reason, SAR imagery using satellites has, in recent years, become an indispensable tool in applications that require the detection and tracking of marine vessels.

This paper presents a novel machine learning methods to enhance the detection and classification of objects in multi-spectral and multi-resolution

Synthetic Aperture Radar (SAR) images taken from the European Space Agency's (ESA) Sentinel 1 satellites. The work presented in this paper focus on the detection and classification of vessels on the surface of the sea. Traditional target detection in SAR image analysis mostly rely on Constant False Alarm Rate (CFAR) detection which doesn't alway provide the necessary accuracy and are cumbersome to tune for the variety of locations on Earth. We present a novel technique in which we extract feature sets from the SAR data before it is heavily processed into an image and take advantage of the cross-polarization information combined with multi-resolution data sets combined with novel machine learning method to greatly increase the capability to detect and classify vessels on the surface of the sea.

10190-27, Session 6

Track classification with unattended wireless sensor network

Robin Doumerc, Benjamin Pannetier, Julien Moras, Jean Dezert, Loic Canevet, ONERA (France)

In this paper, we present our study on track classification by taking into account environmental information and target estimated states. The tracker uses several motion model adapted to different target dynamics (pedestrian, ground vehicle and SUAV) and works in centralized architecture. The main idea is to explore both: classification given by heterogeneous sensors and classification obtained with our fusion module. The fusion module, presented in his paper, provides a class on each track according to track location, velocity and associated uncertainty. To model the likelihood on each class, a fuzzy approach is used considering constraints on target capability to move in the environment. Then both evidential approaches and DSM fusion approach are use to perform a time integration of this classifier output. The fusion rules are tested and compared on real data obtained with our wireless sensor network.

10190-28, Session 7

Integration of UGV's and UAV's in an unmounted platoon to create a soldier-multi-robot team

Bernd Brueggermann, Fraunhofer FKIE (Germany)

No Abstract Available

10190-29, Session 7

Dynamic network based learning systems for sensor information fusion

Dinesh Verma, IBM Thomas J. Watson Research Ctr. (United States); Simon J. Julier, Univ. College London (United Kingdom)

Modern battle-spaces get information from different types of sensing systems that must be processed in many different ways. To provide the modularity and reconfigurability desired , these systems are often wrapped into a set of services which can form dynamic connections. For example, consider the case in which a drone seeks to determine if it is under attack . This inference is very complicated and requires the fusion of multiple types of inference from different types of information using multiple types of analysis engine:

In the current state-of-the-art, this architecture services would be composed manually and in a programmatic manner . However, this can be both difficult to implement (because all eventualities must be considered) and inefficient (because the rules might not specify the right solution for the given context). Rather, we seek methods for service composition which would choose the services and their topology automatically based on context.

In this paper, we consider a simplified first step. In this step, we suppose that the topology is given, and a choice exists about the different types and kinds of algorithms which can exist at each step. We proposed to investigate algorithms by which the system can determine what's most appropriate. This includes the use of contextual information and techniques such as multi-arm bandits for investing the exploration and exploitation tradeoff. Future papers can relax the assumption on topology.

10190-30, Session 7

Invocation oriented architecture for agile code and agile data

Dinesh Verma, IBM Thomas J. Watson Research Ctr. (United States); Kevin Chan, U.S. Army Research Lab. (United States); Kin K. Leung, Imperial College London (United Kingdom)

In order to perform distributed analytics effectively, we need to explore new approaches and architectures that are suitable for different types of processing in sensor information fusion environments. Current focus on sensor information fusion has focused heavily on streaming type of architecture, where sensor data is sent to a processing center using a streaming model such as Apache Edgent, or it is sent to a cloud based environment where services are implemented using a Service Oriented Architecture (SOA) or micro-services. Both of these models have limitations that make them unsuitable for working in a tactical coalition environment.

In order to address the unique requirements of the tactical coalition environment, we are proposing a new architecture -- one based on the concept of invocations. An invocation is a combination of a software code and a piece of data. This model provides a better model for coalition sensor information fusion that streaming or SOA.

It can be implemented using a few fixed basic services at each node in a distributed system, and those fixed basic services can be made highly resilient and self-managing. Based on ICN principles, the retrieval process for code and data seamlessly enforce policy checks across coalition partner boundaries.

An invocation oriented architecture delivers significant benefits for senor information fusion in coalition environments. In this paper, we will discuss limitations of current approaches, present the architecture for an invocation oriented architecture, illustrate how it works with an example scenario, and provide reasons for its suitability in a coalition environment.

10190-32, Session 7

Heterogeneous information sharing of sensor information in contested environments

Jason Wampler, INCA Engineering (United States) and U.S. Army Research Lab. (United States); Chien Hsieh, ICF International (United States) and U.S. Army Research Lab. (United States); Andrew Toth, Ryan Sheatsley, U.S. Army Research Lab. (United States)

The inherent nature of unattended sensors makes these devices most vulnerable to detection, exploitation and denial in contested environments. Physical access is often cited as the easiest way to compromise any device or network. A new mechanism for mitigating these types of attacks developed under the ASD (R&E) project Smoke Screen in Cyberspace was demonstrated in a live over-the-air experiment. Smoke Screen encrypts, slices up and disburses redundant fragments of files throughout the network. Recovery is only possible after recovering all fragments and attacking/denying one or more nodes does not limit the availability of other

fragment copies in the network. This experiment proved the feasibility of redundant file fragmentation and is the foundation for developing sophisticated methods to blacklist compromised nodes, move data fragments from risks of compromise and forward stored data fragments closer to the anticipated retrieval point. This paper outlines initial results in scalability of node members, fragment size, file size and performance in a Wireless Network after Next (WNaN) radio network.

10190-33, Session 8

A block chain based architecture for asset management in coalition operations

Dinesh Verma, Nirmit Desai, IBM Thomas J. Watson Research Ctr. (United States); Alun D. Preece, Ian J. Taylor, Cardiff Univ. (United Kingdom)

During coalition operations, where dynamic communities of interests (CoIs) need to be formed rapidly to deal with the events unfolding on the ground, efficient sharing of ISR assets among coalition partners can make a significant impact on the effectiveness of coalition operations. The increasing number and diversity of asset types exacerbates the problem of dynamically assigning assets to coalition missions. Moreover, national policies and security considerations may hinder complete linkage among various coalition members. In order to enable rapid dynamic sharing of assets, while maintaining compliance with national policies, new architectures that enable asset information to be shared between participating coalition members are needed.

In wired environmentsm the technology of block-chain is emerging which has many attractive features. Block-chain has its origins in digital currency systems like bitcoin, and enables parties that do not trust each other to validate transactions by maintaining distributed consensus among several parties. This can be very useful in coalition environments, but block-chain technologies need to be re-architected in a manner that is more suitable for coalition environments.

In this paper, we discuss the details of the block chain architecture modifications that are required to obtain a suitable environment, and discuss how the system can be used to manage assets and assign assets to mission in dynamic CoI environments.

10190-34, Session 8

Evaluating the integration of operations tasks while optimizing ISR activities

Moises Sudit, Univ. at Buffalo (United States); Katie McConky, Rochester Institute of Technology (United States); Hector J. Ortiz-Peña, Chad Poe, CUBRC, Inc. (United States)

Current decision making processes separate the Intelligence tasks from the Operations tasks. This creates a system that is reactive rather than proactive, leaving potential gains in the timeliness and quality of responding to a situation of interest. In this paper we will present a new optimization paradigm that combines the tasking of Intelligence, Surveillance, and Reconnaissance (ISR) assets with the tasks and needs of Operational assets. Some of the collection assets will be dedicated for one function or another, while a third category that could perform both will also be considered. We will use a scenario to demonstrate the value of the merger by presenting the impact on a number of Intelligence and Operations measures of performance and effectiveness (MOPS/MOEs). Using this framework, mission readiness and execution assessment for a simulated Humanitarian Assistance/Disaster Relief (HADR) mission is monitored for tasks on intelligence gathering, distribution of supplies, and repair of vital lanes of transportation, during the relief effort. The innovative approach uses a combination of discrete optimization methods to obtain heuristic solutions effectively to an NP-Hard problem. Furthermore, the method is flexible to adapt to dynamic objective functions which will allow for changes in the environment or goals of a mission.

10190-35, Session 8

Mission informed needed information - discoverable, available sensing sources (MINI-DASS): the operators and process flows the magic rabbits must negotiate

Michael A. Kolodny, U.S. Army Research Lab. (United States)

No Abstract Available

10190-36, Session 8

Using the Missions and Means Framework to model and simulate the impact of ISR on situational understanding

John Nelson, Morris Nelson & Associates, LLC (United States)

No Abstract Available

10190-37, Session 8

Query generation and recommendation via mission plan interpretation

James R. Michaelis, U.S. Army Research Lab. (United States)

No Abstract Available

10190-38, Session 8

Extending warfighting methods: linking explicit mission requirements to materiel assessment

Britt Bray, Morris Nelson & Associates, LLC (United States)

No Abstract Available

10190-39, Session 9

Modeling of signal propagation and sensor performance for infrasound and blast noise

D. Keith Wilson, Danney Glaser, Lauren E. Waldrop, Carl R. Hart, Michael J. White, Edward T. Nykaza, U.S. Army Engineer Research and Development Ctr. (United States)

This paper describes a comprehensive modeling approach for infrasonic (sub-audible acoustic) signals, which starts with an accurate representation of the source spectrum and directivity, propagates the signals through the environment, and senses and processes the signals at the receiver. The calculations are implemented within EASEE (Environmental Awareness for Sensor and Emitter Employment), which is a general software framework for modeling the impacts of terrain and weather on target signatures

and the performance of a diverse range of battlefield sensing systems, including acoustic, seismic, RF, visible, and infrared. At each stage in the modeling process, the signals are described by realistic statistical distributions. Sensor performance is quantified using statistical metrics such as probability of detection and target location error. To extend EASEE for infrasonic calculations, new feature sets were created including standard octaves and one-third octaves. A library of gunfire noise spectra and directivity functions was added from ERDC's SARNAM software. Infrasonic propagation modeling is supported by extension of several existing propagation algorithms, including a basic ground impedance model, and the Green's function parabolic equation (GFPE), which provides accurate numerical solutions for wave propagation in a refractive atmosphere. The BNOISE propagation algorithm, which is based on tables generated by a fast-field program (FFP), was also added. Finally, an extensive library of transfer functions for microphones operating in the infrasonic range were added, which interface to EASEE's sensor performance algorithms. Example calculations illustrate terrain and atmospheric impacts on infrasonic signal propagation and the directivity characteristics of blast noise.

10190-40, Session 9

Point cloud compression and transmission in tactical networks

Andrew C. Madison, Richard D. Massaro, Clayton D. Wayant, John E. Anderson, Clint B. Smith, U.S. Army Corps of Engineers (United States)

We report progress toward the development of a compression schema suitable for use in the Army's Integrated Sensor Architecture (ISA) tactical network, which is currently under development in the Communications-Electronics Research, Development and Engineering Center´s (CERDEC) Night Vision and Electronic Sensors Directorate (NVESD). The ISA facilitates the dissemination of information across all Warfighter echelons through the establishment of data standards and networking methods that coordinate the readout and control of a multitude of sensors in a common operating environment. When integrated with a robust geospatial mapping functionality, the ISA can be leveraged to deliver force tracking, remote surveillance, and heightened situational awareness to Soldiers at the tactical level. Our work establishes a point cloud compression algorithm based on the photogrammetric deconstruction and reconstruction of pre-collected 3D data and explores transmission of compressed point clouds between active components on an ISA network. In particular, we use the open source visualization toolkit to deconstruct 3D scenes based on ground mobile light detection and ranging (LIDAR) into a series of images with associated metadata that can be easily transmitted on a tactical network. Stereo photogrammetric reconstruction is then conducted on the received image stream to reveal the transmitted point cloud. The reported method boasts nominal compression ratios typically greater than 102 with minimal perceptible loss or error in geo-registration. Our work advances the scope of persistent intelligence, surveillance, and reconnaissance through the development of 3D visualization techniques relevant to the tactical operations environment.

10190-41, Session 9

An overview of the U.S. Army Research Laboratory's sensor information testbed for collaborative research environment (SITCORE)

Dennis Ward, Kelly W. Bennett, Tien Pham, Michael A. Kolodny, U.S. Army Research Lab. (United States)

No Abstract Available

10190-42, Session 10

Distributed subterranean exploration and mapping with teams of UAVs

John G. Rogers III, U.S. Army Research Lab. (United States); Ryan Sherrill, Air Force Research Lab. (United States); Arthur Schang, Engility Corp. (United States); Shava L. Meadows, Air Force Research Lab. (United States); Brendan Byrne, David Q. Baran, U.S. Army Research Lab. (United States); J. Willard Curtis III, Air Force Research Lab. (United States)

Teams of small autonomous UAVs can be used to map and explore unknown environments which are inaccessible to teams of human operators in humanitarian assistance and disaster relief efforts (HA/DR). In addition to HA/DR applications, teams of small autonomous UAVs can enhance Warfighter capabilities and provide operational stand-off for military operations such as cordon and search, counter-WMD, and other intelligence, surveillance, and reconnaissance (ISR) operations. Human operators are required to teleoperate the current generation of mobile robots for these applications; however, teleoperation becomes impractical in contested environments or with limited communications beyond line-of-sight.

In the multi-UAV scenario, resources are spread between a team of smaller and cheaper assets as opposed to being concentrated on one large and expensive asset. A distributed team of heterogeneous "peer" UAVs is able to continue its mission even if many of the assets are disabled or destroyed. A single UAV can only explore or monitor at one location at a time; however, a multi-robot team can potentially cover an area more quickly.

These advantages of an autonomous multi-UAV team come at the cost of increased complexity in communication, coordination, and deployment. This paper will present a hardware platform and software architecture to enable distributed teams of heterogeneous UAVs to navigate, explore, and coordinate their activities to accomplish a search task in a previously unknown environment. These capabilities are relevant to many ISR and HA/DR applications. Experimental results will be presented from a set of trials in a test facility.

10190-43, Session 10

Robust drone detection for day/night counter-UAV with static VIS and SWIR cameras

Thomas Müller, Fraunhofer-Institut für Optronik, Systemtechnik und Bildauswertung (Germany)

Recent progress in the development of unmanned aerial vehicles (UAVs) has led to more and more situations in which drones like quadrocopter or octocopter pose a potential serious thread or could be used as a powerful tool for illegal activities. Therefore, Counter-UAV systems are required in a lot of applications to detect approaching drones as early as possible. In this paper, an efficient and robust algorithm is presented for UAV detection using static VIS or SWIR cameras. Whereas VIS cameras with a high resolution enable to detect UAVs in the daytime in further distances, surveillance at night can be performed with a SWIR camera. First, a background estimation and structural adaptive change detection process detects movements and other changes in the observed scene. Afterwards, the local density of changes is computed used for background density learning and to build up the foreground model which are compared in order to finally get the UAV alarm result. The density model is used to filter out noise effects on the one hand. On the other hand, moving scene parts like moving leaves in the wind or driving cars on a street can easily be learned in order to mask such areas out and suppress false alarms there. This scene learning is done automatically simply by processing without UAVs in order to capture the normal situation. The given results document the performance of the presented approach in VIS and SWIR in different situations.

10190-45, Session 10

Tree detection in urban region from aerial imagery and DSM based on local maxima points

Ozgur Korkmaz, Yasemin Yardimci Cetin, Middle East Technical Univ. (Turkey); Erdal Yilmaz, Zibumi (Turkey)

In this study, we propose an automatic approach for tree detection and classification in registered 3-band aerial images and associated digital surface models (DSM). The tree detection results can be used in 3D city modelling and urban planning. This problem is magnified when trees are in close proximity to each other or other objects such as rooftops in the scenes. This study presents a method for locating individual trees and estimation of crown size based on local maxima from DSM accompanied by color and texture information. Firstly, small trees which are under a certain height are eliminated. Local maxima of the DSM extraction is followed by 3-band mean-shift segmentation of the aerial image. Only the segments including the local maxima of the DSM are utilized. The segment classification as tree and non-tree is made using support vector machines based on color, texture and height features. Individual trees in tree groups are extracted by employing templates with various radii. Resolving closely placed trees will be achieved by better modeling of tree crowns. We will apply gabor filter and properties of gray level co-occurrence matrix as a texture features in order to improve classification results. In addition to this, post processing on the classification results will be needed to improve accuracy of tree detection and estimation of crown size. The tree detection problem is designated as a binary classification problem and the overall results will be proposed with receiver operating characteristic curves.

10190-46, Session 10

Improvements on hyperspectral vegetation detection with neural networks

Okan B. Ozdemir, Yasemin Yardimci Cetin, Middle East Technical Univ. (Turkey)

Hyperspectral images have been used in many areas including city planning, mining and military decision support systems. Hyperspectral image analysis techniques have a great potential for vegetation detection with their capability to identify the spectral differences across the electromagnetic spectrum. With their ability to provide information about the chemical compositions of materials, these techniques have great potential for hyperspectral vegetation detection. The performances of the well-known classification techniques are not adequate with limited training data. In order to improve the classification accuracy spectral similarity can be used. This study introduces a vegetation detection method employing Artificial Neural Network (ANN) over hyperspectral imaging. The algorithm employed backpropagation MLP algorithm for training neural networks with limited training data. The algorithm first obtains the certainty measure from ANN, following the completion of this process, for all pixels' angular distance is calculated with SAM to obtain spectral similarity. The certainty measure from ANN and spectral angle from SAM combined to obtain better outcome. Results from ANN, SAM and Support Vector Machine (SVM) algorithms are compared and evaluated with the result of the algorithm. The results demonstrate that joint use of ANN and SAM significantly improves classification accuracy.

10190-47, Session 11

Multiple methods of yaw control for multi-rotor aircraft

Harris Edge, U.S. Army Research Lab. (United States)

This research is part of an overall effort within the U.S. Army Research Laboratory to develop technologies to allow UAS to fly safely and perform work in the near Earth environment. Flying with precision, applying intelligent behaviors, and performing work in the near Earth environment produces a number of challenges which may benefit from increased options for controlling aircraft position, attitude, and yaw. Lightweight multi-rotor aircraft typically use conservation of angular momentum to control yaw. This works quite well when the rotating motor and propeller mass are a sizable percentage of the weight of the aircraft and payload. However, as payload increases and size of multi-rotors increase the ratio of the rotating motor and propeller mass to total platform mass may decrease to the point where the change of rotating mass momentum between the thrust generating motors and rotors may become decreasingly effective and increasingly inefficient. When payload mass increases, there may also be increasing volumes for packages that increase drag and moments from airflow due to aircraft speed or wind. This may also contribute to issues with traditional multi-rotor yaw control. In addition, while using a multi-rotor propulsion system to perform work such as airborne manipulation or close inspection of buildings, additional methods of yaw control may be beneficial by allowing some independency between yaw, and attitude and position control. Flow field effects on multi-rotor aircraft near a wall have been directly measured and indicate that close interaction with a wall will require propulsion control compensation. There are well known methods for employing additional methods of yaw control, the most common being thrust vectoring. Thrust vectoring can be employed by placing an airfoil or blockage in the rotor wake or changing the attitude of the thrust generating rotor with respect to the aircraft. Both of these methods will be discussed in the paper with example implementations. While effective, thrust vectoring does incur penalties such as weight and complexity. However, there may be some efficiency benefits if implemented properly for aircraft with demanding near Earth mission tasks.

10190-48, Session 11

Piezo-based, high dynamic range, wide bandwidth steering system for optical applications

Nir Karasikov, Nanomotion Inc. (United States)

Piezoelectric motors and actuators are characterized by direct drive, fast response, high positioning resolution and high mechanical power density. These properties are beneficial for optical devices such as gimbals, optical image stabilizers and mirror angular positioners. The range of applications includes sensor pointing systems, image stabilization, laser steering and more. This paper reports on the construction, properties and operation of three types of piezo based building blocks for optical steering applications: a small gimbal and a two-axis OIS (Optical Image Stabilization) mechanism, both based on piezoelectric motors, and a flexure-assisted piezoelectric actuator for mirror angular positioning. The gimbal weighs less than 170 grams, has a wide angular span (solid angle of > 2ϖ) and allows for a 80 micro-radian stabilization with a stabilization frequency up to 25 Hz. The OIS is an X-Y, closed loop, platform having a lateral positioning resolution better than 1 um, a stabilization frequency up to 25 Hz and a travel of +/-2 mm. It is used for laser steering or positioning of the image sensor, based on signals from a MEMS Gyro sensor. The actuator mirror positioner is based on three piezoelectric actuation axes for tip tilt (each providing a 50 um motion range), has a positioning resolution of 10 nm and is capable of a 1000 Hz response. A combination of the gimbal with the mirror positioner or the OIS stage is explored by simulations, indicating a < 10 micro-radian stabilization capability under substantial perturbation. Simulations and experimental results are presented for a combined device facilitating both wide steering angle range and bandwidth.

10190-49, Session 12

The image-interpretation-workstation of the future: lessons learned

Sebastian Maier, Florian van de Camp, Boris Wagner, Elisabeth Peinsipp-Byma, Jürgen Beyerer, Fraunhofer-Institut für Optronik, Systemtechnik und Bildauswertung (Germany)

In recent years, professionally used workstations got increasingly complex and multi-monitor systems are more and more common. Novel interaction techniques like gesture recognition were developed but used mostly for entertainment and gaming purposes. These human computer interfaces are not yet widely used in professional environments where they could greatly improve the user experience. To approach this problem, we combined existing tools in our image-interpretation-workstation of the future, a multi-monitor workplace comprised of four screens. Each screen is dedicated to a special task in the image interpreting process: a geo-information system to geo-reference the images and provide a spatial reference for the user, an interactive recognition support tool, an annotation tool and a reporting tool. To further support the complex task of image interpreting, self-developed interaction systems for head-pose estimation and hand tracking where used in addition to more common technologies like touchscreens, face identification and speech recognition. A set of experiments where conducted to evaluate the usability of the different interaction systems. Two typical extensive tasks of image interpreting where devised and approved by military personal. They were then tested with a current setup of an image interpreting workstation using only keyboard and mouse against our image-interpretation-workstation of the future. To get a more detailed look at the usefulness of the interaction techniques in a multi-monitor-setup, the hand tracking, head pose estimation and the face recognition where further evaluated using tests inspired by everyday tasks. The results of the evaluation and the discussion will be presented in this paper.

10190-50, Session 12

Particle flow filter-based airborne-SLAM

Erol Duymaz, Ersan A. Oguz, Turkish Air Force Academy (Turkey); Hakan Temeltas, Istanbul Technical Univ. (Turkey)

SLAM has been a popular research topic in the field of robotics for many years. Moreover, its applications on land vehicles are still going on intensively. SLAM is relatively easy to implement in robotics compared to air vehicles. Since robots and land vehicles move at lower speeds in a 2D area, necessary mathematical model is developed in two dimensions only. In contrast, UAVs which move much faster than robots or land vehicles need more complex mathematical models in a 3D environment. This further complicates the application of SLAM technique on UAVs, which is known as Airborne SLAM (A-SLAM). Moreover, kinematic model of a UAV results in a set of nonlinear equations which brings additional complexity. As the result Simultaneous Localization and Mapping (SLAM) is a good choice for UAV navigation when both UAV's position and region map are not known. Expectedly due to nonlinearity of kinematic equations of a UAV Extended Kalman Filter (EKF) and Unscented Kalman Filter (UKF) are employed whereas in this study, not just EKF and UKF based A-SLAM concepts are reviewed but also particle flow filter based A-SLAM discussed in details by presenting the formulations and MATLAB Simulink model with simulation results. The UAV kinematic model and state-observation models for these filter based A-SLAM methods are developed to analyze the filters' consistencies. Results supports the superiority of particle flow filter in recursive state estimation in A-SLAM problem in spite of its some drawbacks.

Conference 10191: Laser Radar Technology and Applications XXII

Tuesday - Wednesday 11–12 April 2017

Part of Proceedings of SPIE Vol. 10191 Laser Radar Technology and Applications XXII

10191-2, Session 1

Demonstration of coherent Doppler lidar for navigation in GPS-denied environments

Farzin Amzajerdian, Glenn D. Hines, NASA Langley Research Ctr. (United States); Diego F. Pierrottet, Coherent Applications, Inc. (United States); Bruce W. Barnes, Larry B. Petway, John M. Carson III, NASA Langley Research Ctr. (United States)

A coherent Doppler lidar has been developed to address NASA's need for a high-performance, compact, and cost-effective velocity and altitude sensor onboard its landing vehicles. Future robotic and manned missions to solar system bodies require precise ground-relative velocity vector and altitude data to execute complex descent maneuvers and safe, soft landing at a pre-designated site. This lidar sensor, referred to as Navigation Doppler Lidar (NDL), can meet the required performance of the landing missions while complying with the vehicle's size, mass, and power constraints. Operating from up to four kilometers altitude, the NDL can provide velocity and range precision with about 2 cm/sec and 2 meters, respectively, dominated by the vehicle motion. The NDL can also benefit terrestrial aerial vehicles that cannot rely on the GPS for position and velocity data. The NDL offers a viable option for enabling aircraft operation in areas where the GPS signal can be blocked or jammed by intentional or unintentional interference. The NDL transmits three laser beams at different pointing angles toward the ground and measures range and velocity along each beam using a frequency modulated continuous wave (FMCW) technique. The three line-of-sight measurements are then combined in order to determine the three components of the vehicle velocity vector and its altitude relative to the ground. This paper describes the performance and capabilities of the NDL demonstrated through extensive ground tests, helicopter flight tests, and onboard an autonomous rocket-powered test vehicle operating in closed-loop with a guidance, navigation, and control (GN&C) system.

10191-3, Session 1

Transient light imaging laser radar with advanced sensing capabilities: reconstruction of arbitrary light in flight path and sensing around a corner

Martin Laurenzis, Jonathan Klein, Frank Christnacher, Institut Franco-Allemand de Recherches de Saint-Louis (France)

Laser radars are widely used for laser detection and ranging in a wide field of application scenarios. In the recent past, new sensing capabilities in the context of transient light imaging have been demonstrated enabling imaging of light pulses during flight and the estimation of position and shape of targets outside the direct field of view. High sensitive imaging sensors are available give the chance to detect laser pulse in flight which are sparsely scattered in air. Theory and experimental investigation of arbitrary light propagation paths show the possibility to reconstruct the light path trajectory. This result could enable the remote localization of laser sources which will become an important reconnaissance task in future scenarios. Further, transient light imaging can reveal information about objects outside the direct field of view or hidden behind obscurants by computational imaging. In this talk, we present different approaches to realize transient light imaging (e.g. time correlated single photon counting) and their application for relativistic imaging, real-time non-line of sight tracking and reconstruction of hidden scenes.

10191-4, Session 1

Methane measurements from space: technical challenges and solutions

Haris Riris, Kenji Numata, Stewart T. Wu, NASA Goddard Space Flight Ctr. (United States)

Atmospheric methane (CH4) is the second most important anthropogenic greenhouse gas with approximately 25 to 100 times the radiative forcing of carbon dioxide (CO2) per molecule. CH4 also contributes to pollution in the lower atmosphere through chemical reactions leading to ozone production. Yet, lack of understanding of the processes that control CH4 sources and sinks and its potential release from stored carbon reservoirs contributes significant uncertainty to our knowledge of the interaction between carbon cycle and climate change that challenges our ability to make confident projections of future climate.

At Goddard Space Flight Center (GSFC) we have been developing the technology needed to remotely measure CH4 from orbit, using lasers. Our concept for a CH4 lidar is a nadir viewing instrument that uses the strong laser echoes from the Earth's surface to measure CH4. The instrument has a tunable, narrow-frequency light source and photon-sensitive detector to make continuous measurements from orbit, in sunlight and darkness, at all latitudes and can be relatively immune to errors introduced by scattering from clouds and aerosols. Our measurement technique uses Integrated Path Differential Absorption (IPDA), which measures the absorption of laser pulses by a trace gas when tuned to a wavelength coincident with an absorption line.

We have demonstrated ground and airborne CH4 measurements with a different transmitters and a sensitive receiver. In this paper we will review our results to date and discuss the technology options to scale the laser power to space.

10191-5, Session 2

A fresh view of laser purpose in observation sensor suite: toward affordable enhanced DRI performance through versatile laser illumination technology and latest advanced sensors

Regis Grasser, CILAS (France)

Observation sensor suites always ask for longer DRI range, more versatile systems and lower SWaP-C. Lasers have been often suggested as an answer to these ever increasing needs. Range-gated active imaging technology, associating pulsed laser illumination and fast integration sensor, presents great demonstrated potential for threat detection, bad conditions identification enhancement, through window or obscurant observation or 3D reconstruction. However, the spread of this valuable technology to demanding applications remains limited because of the complexity and cost of current technical solutions.

Cilas, subsidiary of Airbus Safran Launcher, has been working in the field of active systems for the past 15 years. Many combat proven systems have been deployed in operation. We demonstrate lasers and active systems are valuable assets and sometime the only answer for threat detection and identification. We bring these capacities on the field through optimized, low SWaP-C solutions. Innovative versatile illumination platform dedicated to range-gated active imaging has been developed. Based on proprietary design, high peak power laser illumination suitable for NIR and/or SWIR range-gated active imaging is possible through a single cost effective and small footprint solution. We consolidated system level features to mitigate laser side effects such as ocular hazard. Sensor development from Europeans companies is also leveraged. Latest CMOS sensor enables range-

gated active acquisitions while offering outstanding performance in passive mode. Combining these new technologies enables seamlessness integration of laser and range-gated active features on sensor suite, significantly improving performances for detection and identification in urban and rural environment while keeping deployment burden low.

10191-6, Session 2

Improved TDEM formation using fused ladar/digital imagery from a low-cost small UAV

Bikalpa Khatiwada, Scott E. Budge, Utah State Univ. (United States)

Formation of a Textured Digital Elevation Model (TDEM) has been useful in many applications in the fields of agriculture, disaster response, terrain analysis and more. Use of a low-cost small UAV system with a texel camera (fused lidar/digital imagery) can significantly reduce the cost compared to conventional aircraft-based methods. This paper reports continued work on this problem reported in a previous paper by Bybee and Budge, and reports improvements in computational efficiency and performance.

A UAV fitted with a texel camera is flown at a fixed height above the terrain and swaths of texel image data of the terrain below is taken continuously. Each texel swath has one or more lines of lidar data surrounded by a narrow strip of EO data. Texel swaths are taken such that there is some overlap from one swath to its adjacent swath. The GPS/IMU fitted on the camera also give coarse knowledge of attitude and position. Using this coarse knowledge and the information from the texel image, the error in the camera position and attitude is reduced which helps in producing an accurate TDEM.

This paper reports improvements in the original work by using a more efficient method for finding corresponding points, requiring less computation. In addition, the improvement provided by multiple lines of lidar data per swath is reported. The final results are shown and analyzed for numerical accuracy.

10191-7, Session 2

Doppler lidar power, aperture diameter, and FFT size trade-off study

David B. Chester, Scott E. Budge, Utah State Univ. (United States)

Doppler lidar systems can play a critical role in obtaining accurate position, attitude, and velocity data, which is necessary during the descent phase of a planetary landing mission. In response to NASA's proposal of an advanced Doppler lidar system with multiple beams to perform this role during a landing vehicle's descent, a robust parametric simulation of Doppler lidar was added to the LadarSIM system simulation software. This simulation software includes modulated pulse generation and coherent detection methods, beam footprint simulation, beam scanning, and interaction with terrain.

In the design or selection of a Doppler lidar instrument for a spacecraft, it is important to evaluate the balance between performance requirements and cost, weight, and power consumption. Leveraging the capability of LadarSIM, a thorough trade-off study was performed to evaluate the interaction between the laser transmission power, aperture diameter, and FFT size in a Doppler lidar system. For this study, systems comprising combinations of aperture diameters of 25, 38.1, and 50 mm, FFT sizes of 2^16, 2^17, and 2^18, and transmission powers from 0.5 W to 5 W in 0.5 W increments were simulated. Each simulated system was evaluated using a number of scenarios which simulated various descent paths and scanning patterns. This paper reports the results of this trade off study with commentary on the effects of varying each of the aforementioned parameters.

10191-8, Session 2

Design of a cost-effective laser spot tracker

Göktuğ G. Artan, TÜBITAK SAGE (Turkey); Hüseyin Sari, Ankara Univ. (Turkey)

The basis of guided systems consists of detection, decision making and controlled actuation. The sensitivity of the detection affects the whole system performance. Taking into account the price per unit, the most convenient detection in the sense of precision can be achieved with a laser spot tracker. This study deals with a military grade, high performance and cost-effective laser spot tracker for a guided system. The aim is to develop a system with a field of view of ±15° that will detect proportionally at a distance of 3 kilometers from the target and give the line-of-sight angle of the target as an output, in which the target is designated with a 1064 nm wavelength Nd:YAG laser from 3 kilometers and where the field of view and detection range parameters are set as the design criteria of the study. The study basically consists of the system design, modeling and analyzing on a computer environment, producing and the conducting performance tests of the whole system. The system consists of 3 optical components; a protective window to isolate the system from environmental conditions, a band-pass filter to reduce noise and an aspheric lens for semi-focusing. ZEMAX is used for the base optical system design and modeling as well as thermal analysis and tolerance analysis. After the design is proved the system is assembled and tested using a pulsed laser diode collimator. Finally the system performance is analyzed and compared to the system requirements.

10191-9, Session 3

MACHETE: Advanced FOPEN ladar system

M. Jalal Khan, MIT Lincoln Lab. (United States)

No Abstract Available

10191-10, Session 3

2D and 3D flash laser imaging for long-range surveillance in maritime border security: Detection and identification for counter UAS applications

Laurent Hespel, Nicolas Rivière, Paul-Edouard Dupouy, Antoine Coyac, Philippe Barillot, Aurélien Plyer, Michel Fracès, ONERA (France); Éric Nascimben, Cédric Perez, EXAVISION (France); Denis Gorce, Intervention Sur et Sous la Mer (France)

To respond to the issues of maritime border surveillance or long range UAV detection and identification, we develop two laser imagers (a 2D and a 3D system) with long range capacities to improve significantly the performances in terms of scope of monitoring and persistence functions (H24, degraded visibility ...). These systems are based on a new generation of focal plane arrays with avalanche photodiode and are combined with high-performance image processing ("real-time") devoted to superresolution or tracking. In this paper, we first present the results of several surveillance or Counter-UAS demonstrations respectively conducted on a coastal site and two sensitive areas. Comparisons between passive and active sensors are shown. The measurements obtained on various maritime targets or small UAVs (fixed or rotary wings) are finally compared with end to end modelling in order to assess the systems performances in various atmospheric environments.

10191-11, Session 3

Feature reconstruction from labeled 3D point clouds

Lori A. Magruder, Holly W. Leigh, Amy L. Neuenschwander, Applied Research Labs., The Univ. of Texas at Austin (United States)

Three dimensional point clouds are powerful data sets that have a variety of applications in the area of geospatial intelligence and analysis. Recent efforts have focused on the use of point clouds to virtually reconstruct features such that they can be rendered within gaming engines. Light detection and ranging (Lidar) technology offers the capability to rapidly capture high-resolution, 3-dimensional point cloud data with centimeter-level accuracy. The use of stereo photogrammetry to generate point clouds from high-resolution imagery has grown in recent years, resulting in "electro-optical," or EO, point clouds. Point clouds collected using different sensor modalities will have varied spatial characteristics and accuracies, often requiring different algorithms to classify, or label, the individual points as belonging to a particular surface type; however, similar reconstruction algorithms can be used once the point cloud has been classified. Common surface types identified by classification algorithms include ground, vegetation, buildings, vehicles, bridges/overpasses, and water bodies. Data-driven methods for reconstructing building and vegetation features from a classified point cloud and a coincident Digital Terrain Model (DTM) are presented here. Methodologies for representing buildings in Level of Detail 1 (LOD1) and Level of Detail 2 (LOD2) have been developed using image processing techniques and result in shapefiles and building mesh file types that can be ingested by commonly used gaming engines. Vegetation is extracted to LOD2 using a watershed algorithm and additional tree attributes are estimated from commonly used allometric relationships.

10191-12, Session 3

Photon counting micro-ladar for small UAVs

Alexandru N. Vasile, MIT Lincoln Lab. (United States)

No Abstract Available

10191-13, Session 3

Bathymetric depth sounder with novel echo signal analysis based on exponential decomposition

Andreas Ullrich, Martin Pfennigbauer, RIEGL Laser Measurement Systems GmbH (Austria); Roland Schwarz, RIEGL Laser Measurement Systems GmbH (Austria) and RIEGL Research Forschungsgesellschaft mbH (Austria)

We present a laser range finder specifically designed for bathymetric surveying tasks. The compact and lightweight instrument is capable of measuring through the water surface, ideally suited for generating profiles of waterbodies when operated from a UAV. The topobathymetric LiDAR sensor comprises a tilt compensation, an IMU/GNSS unit with antenna, a control unit, and supports triggering of external digital cameras. The laser range finder sends out laser pulses at a rate of 4 kHz. The echo signal for each laser pulse is digitized and recorded for the entire range gate of 50 m. This means that predetection averaging of the waveforms can be performed in post processing, increasing the depth performance. The averaging rate can be chosen after the flight on basis of measurement conditions. The waveforms are processed by a full waveform processing algorithm based on exponential decomposition which uses segments of an exponential function as base functions to model the backscatter cross-section of the target objects. Water surface, water column, and ground targets are modeled using a set of base functions of which an optimization selects the most suitable combination to fit the echo signal. This leads to high accuracy of the points and to automatic target classification.

10191-14, Session 4

Measuring laser reflection cross-sections of small unmanned aerial vehicles for laser detection, ranging and tracking

Martin Laurenzis, Emmanuel Bacher, Frank Christnacher, Institut Franco-Allemand de Recherches de Saint-Louis (France)

An increasing number of incidents are reported where small unmanned aerial vehicles (UAV) are involved flying at low altitude. This type of UAV is becoming more and more a serious threat in civilian and military scenarios leading to serious danger to safety or privacy issues. In this context, the detection and tracking of small UAV flying at low altitude in urban environment or near background structures is a challenge for state of the art detection technologies.

A systematic evaluation of different sensor technologies needs a fundamental knowledge about the nature of the target. In this paper, we focus on detection, tracking and identification by laser sensing technologies that are Laser Gated Viewing and scanning LiDAR. The application of laser detection and ranging systems is discussed in theory and first experimental results are presented. Further, fundamental physical properties of different UAVs are investigated with a special focus on laser reflection characteristics. Laser reflection cross-sections LSCS are determined and their impact on the system performance in means of detection, recognition and identification (DRI) ranges is discussed.

10191-15, Session 4

Signatures of dynamical processes in Raman lidar profiles of the atmosphere

C. Russell Philbrick, Hans D. Hallen, North Carolina State Univ. (United States)

Raman lidar measurements of the profiles of several different tracers of spatial and temporal variations provide excellent signatures for studies of dynamical processes in the atmosphere. An examination of Raman lidar data collected during the past 40-years clearly show signatures of atmospheric planetary waves, gravity waves, low-level jets, frontal zone passages, turbulence from surface wind shear, turbulence from shear at the interface of the boundary layer and the free troposphere, and several other features occurring in the atmosphere. The sources of these dynamical features are primarily due to pressure waves and wind shears; which are associated with large and small scale weather systems, orographic forcing, and reduced atmospheric stability from extremes in temperature and moisture gradients, as well as convection from heating of the atmosphere by surfaces. Examples of several of these processes are shown with analysis of the associated atmospheric stability properties. The turbulence eddies generated in the wind shear region near the top of the boundary are often present and those eddies are found to persist long enough to mix downward into the atmospheric boundary layer. These data suggest that use of these techniques will enable significant steps in understanding the coupling between simultaneously occurring processes, as well as tracking of the sources and the dissipation of turbulence eddies. The results from this research provide a better understanding for describing optical propagation through the atmosphere.

10191-17, Session 4

Scene classification and object identification in complex lidar imagery

William Basener, Rochester Institute of Technology (United States); Abigail Basener, Piedmont Valley Community College (United States)

We develop practical methods for classification and object recognition at a high level of specification in complex LIDAR data. Our object classes include buildings of various types, building rooftop structures, forest trees, landscape trees, landscape bushes, cars, light posts of varying sizes, fences, paved surfaces, and grass. The level of specification and complexity is achievable by computing multi-scale features and choosing non-parametric methods that are appropriate for the task. Our primary classification method is a Random Forest, but we also investigate K-Nearest Neighbors and Support Vector Machines. We evaluate the algorithms for accuracy, required training sample size, and runtime.

10191-18, Session 4

Signature stability in laser Doppler vibrometry

Thomas Iverson, Univ. of Dayton (United States); Edward A. Watson, Univ. of Dayton Research Institute (United States)

Speckle can complicate signal acquisition in coherent laser systems such as Laser Doppler Vibrometry (LDV). Variations in the speckle pattern at the receiver due to fluctuations in system operating conditions, such as beam pointing, can lead to impulsive events in the signature. The beam size at the object has a direct influence on the size of the speckle at the receiving aperture. Increasing the beam spot size reduces the average speckle size, but also decreases the strength of the signal coupled with the local oscillator in the LDV. In this paper we experimentally investigate the effects of speckle size and decreasing signal strength on the stability of an LDV signature. We use a kurtosis metric previously reported in the literature to assess the stability and quality of the signature.

10191-24, Session 4

Mitigating atmospheric effects in synthetic aperture ladar (SAL) imagery

Randy S. Depoy Jr., Air Force Research Lab. (United States); Arnab Shaw, Wright State Univ. (United States)

No Abstract Available

10191-25, Session 4

Visualization and analysis of lidar wavefront data

Richard C. Olsen, Jeremy P. Metcalf, Naval Postgraduate School (United States); Robert VanNice, The Boeing Co. (United States)

A visualization technique for waveform data from airborne laser scanners has been developed that utilizes spectral waterfall techniques. The technique is extended to allow for display approaches analogous to multi-dimensional spectral data. These approaches allow for the representation and analysis at time scales associated with individual waveforms to full airborne flight-lines. Scan angle effects are distinguished from topographic effects and variations along flight-lines.

10191-26, Session 4

Spectral lidar analysis for terrain classification

Charles McIver, Jeremy P. Metcalf, Richard C. Olsen, Naval Postgraduate School (United States)

Data from the Optech Titan airborne laser scanner were collected over Monterey, CA, in three wavelengths: 532 nm, 1055 nm, and 1550 nm, in June 2016 by the National Center for Airborne Lidar Mapping (NCALM). Analysis techniques have been developed using spectral technology largely derived from the analysis of spectral imagery. Data are analyzed as individual points, vs techniques that emphasize spatial binning. The primary tool which allows for this exploitation is the N-dimensional visualizer contained in the ENVI software package. The results allow for significant improvement in classification accuracy compared to results obtained from techniques derived from standard Lidar analysis tools.

10191-19, Session 5

An auto-locked laser system for precision metrology and lidar applications

Hermina C. Beica, Adam Carew, Andrejs Vorozcovs, Patrick J. Dowling, Alexander Pouliot, Boris Barron, A. Kumarakrishnan, York Univ. (Canada)

We present a unique external cavity diode laser system that can be auto-locked with reference to atomic and molecular spectra. The vacuum-sealed laser head design uses an interchangeable base-plate comprised of a laser diode and optical elements that can be selected for desired wavelength ranges. The feedback light to the laser diode is provided by a narrow-band interference filter, which can be tuned from outside the laser cavity to fine-adjust the output wavelength. To stabilize the laser frequency, the digital laser controller relies either on a pattern-matching algorithm stored in memory, or on first or third derivative feedback. We have used the laser systems to perform spectroscopic studies in rubidium at 780 nm, and in iodine at 633 nm. The system shows a linewidth of ~1 MHz, a lock stability of ~500 kHz, and we present Allan deviation measurements of these parameters. The 633-nm lasers have been used to perform a precise measurement of the gravitational acceleration g using a state-of-the-art industrial gravimeter (Scintrex FG5X) with an absolute accuracy of 1 ppb. The value of g measured with our lasers agrees with a baseline measurement obtained from an iodine-stabilized He-Ne laser, and shows lower scatter. Furthermore, we show that the laser system can be the basis for a new class of lidar transmitters in which a temperature-stabilized fiber-Bragg grating is used to generate frequency references for on-line points of the transmitter. We show that the fiber-Bragg grating spectra can be calibrated with reference to atomic transitions.

10191-20, Session 5

A multi-wavelength IR Laser for space applications

Steven X. Li, Anthony W. Yu, Xiaoli Sun, Molly E. Fahey, Numata Kenji, Michael A. Krainak, NASA Goddard Space Flight Ctr. (United States)

We present a laser technology development with space flight heritage to generate laser wavelengths in the near- to mid-infrared (NIR to MIR) for space lidar applications. Integrating an optical parametric crystal to the LOLA (Lunar Orbiter Laser Altimeter) laser transmitter design affords selective laser wavelengths that are not easily obtainable from traditional diode pumped solid-state lasers. By replacing the output coupler of the LOLA laser with a properly designed parametric crystal, we successfully demonstrated a monolithic intra-cavity optical parametric oscillator

(iOPO) laser based on all high technology readiness (TRL) subsystems and components. Several desired wavelengths at 2.1 um, 2.6um, 2.7 um and 3.4um have been generated. The primary objective of this iOPO laser development is for detection and measurement of water ice on the Moon, comets and other airless bodies. A lidar similar to LOLA but at 2.6 to 3.5 um wavelength can unambiguously detect water ice on the Moon and track its transport from day to night. This laser can also find applications in trace-gas remote sensing, as many molecules possess their unique vibrational transitions in this wavelength region, as well as in time-of-flight mass spectrometer where desorption of samples using MIR laser wavelengths have been successfully demonstrated.

10191-21, Session 5

Non-mechanical beam control for entry, descent and landing laser radar

Jay E. Stockley, Kelly Kluttz, Lance Hosting, Steve Serati, Boulder Nonlinear Systems (United States); Cullen P. Bradley, Paul F. McManamon, Exciting Technology, LLC (United States); Farzin Amzajerdian, NASA Langley Research Ctr. (United States)

Laser radar for entry, descent, and landing (EDL) applications as well as the space docking problem could benefit from a low size, weight, and power (SWaP) beam control system. Moreover, an inertia free approach employing non-mechanical beam control is also attractive for laser radar that is intended to be employed aboard space platforms. We are investigating a non-mechanical beam steering (NMBS) sub-system based on liquid crystal polarization grating (LCPG) technology with emphasis placed on improved throughput and significant weight reduction by combining components and drastically reducing substrate thicknesses. In addition to the advantages of non-mechanical, gimbal free beam control, and greatly improved SWaP, our approach also enables wide area scanning using a scalable architecture. An extraterrestrial application entails additional environmental constraints, consequently an environmental test plan tailored to an EDL mission will also be discussed. In addition, we will present advances in continuous fine steering technology which would complement the coarse steering LCPG technology. A low-SWaP, non-mechanical beam control system could be used in many laser radar remote sensing applications including meteorological studies and agricultural or environmental surveys in addition to the entry, descent, and landing application.

10191-22, Session 5

Closed-loop control of gimbal-less MEMS mirrors for increased bandwidth in LiDAR applications

Veljko Milanovic, Abhishek Kasturi, James Yang, Frank Hu, Mirrorcle Technologies, Inc. (United States)

In 2016, we presented a low SWaP wirelessly controlled MEMS mirror-based LiDAR system which utilized an OEM laser rangefinder for distance measurement. The MEMS mirror was run in open loop based on its exceptional repeatability performance. However, to extend the bandwidth and incorporate necessary eye-safety features, we recently focused on providing mirror position feedback and running the system in closed loop control.

Multiple optical position sensors, mounted on both the front- and the back-side of the MEMS mirror, have been developed and will be presented. In all cases, they include a light source (LED or laser) and a 2D photosensor. The most compact version is mounted on the backside of the MEMS mirror ceramic package and can "view" the mirror's backside through openings in the mirror's PCB and ceramic carrier. This version increases the overall size of the MEMS mirror submodule from ~12mm x 12mm x 4mm to ~15mm x 15mm x 7mm. The sensors also include optical and electronic filtering to prevent interference from the ranging laser illumination.

With relatively simple FPGA-based PID control running at the rate of 100 kHz, device bandwidth could be increased to nearly 3-4 times that of the open loop bandwidth due to its capability to suppress the natural resonance. A 2.4mm diameter integrated MEMS mirror with a resonant frequency of 800 Hz was limited to 350Hz bandwidth in open loop driving but was increased to ~1.3kHz bandwidth with the closed loop controller. A 4.2mm diameter mirror bandwidth was increased from ~150Hz to ~500Hz.

10191-23, Session 5

Large area of MCP electronic rinse system design

YaFeng Qiu Sr., ChengXin Song, Nanjing Univ. of Science and Technology (China)

An electronic surface-emitting source was redesigned in this system. The way it works is that the ultraviolet light source emits a uniform ultraviolet light on the gold cathode with voltage of several hundred volts, thus numerous uniform electrons are emitted from the surface of gold cathode. At the same time,0V ~ 700V adjustable high voltage is adopted between the gold cathode and the standard MCP(diameter of 105mm) to generate an accelerating electric field. After electrons are accelerated by the electric field, the high energy is obtained, and the standard MCP is bombarded. The number of electrons can be exponentially increased and controlled by the voltage applied between the input and output surface of the standard MCP.200v voltage is applied between the output surface of standard MCP and input surface of the MCP to be rinsed to lead the uniform electron beam to bombard the MCP to be rinsed, then the gas molecules and related impurities are cleared out in this process. In the original electron rinse system, which is suitable for the MCP with the diameter of 30mm,uniform emitted electrons are obtained by heating the planar spiral tantalum filament in the thermal electronic surface-emitting source in vacuum System. The largest effective emitting diameter of uniform electrons produced by such a thermal electronic surface-emitting source is 50mm, and it cannot meet the size requirement of the electron rinse of large area MCP. Meanwhile, prolonged use of this thermal electronic surface-emitting source causes the filament oxidation and deformation problems. And complexity of the tantalum filament production process and the design of the accelerating field makes difficult to guarantee the reliability of the uniformity of emission electrons. This successful design of the electronic surface-emitting source in the system not only overcomes the limitation of the thermal electronic surface-emitting source based on tantalum filament in use, but also the analysis of the results of the electronic uniformity testing experiment indicates the electronic uniformity of the electronic surface-emitting source has reached 98%,which is 5% higher comparing to the thermal electronic surface-emitting source based on tantalum filament in use.

Conference 10192: Laser Technology for Defense and Security XIII

Tuesday 11–11 April 2017

Part of Proceedings of SPIE Vol. 10192 Laser Technology for Defense and Security XIII

10192-1, Session 1

Good beam quality and high peak powers from coiled Er-doped SHARC fiber amplifiers having core areas up to 22x400 um^2

Friedrich S. Strohkendl, David A. Rockwell, Andrew T. Koll, Sean W. Moore, Vladimir V. Shkunov, Raytheon Space and Airborne Systems (United States); Fabio Di Teodoro, Raytheon Co. (United States); John R. Marciante, Univ. of Rochester (United States)

High-peak-power, eye-safe nsec-pulsed fiber sources are well suited to remote sensing, owing to good atmospheric transmission, spectral compatibility with mature photo-detectors, reliance on telecom component/ materials, and usability in environments where glint can reach bystanders.

To scale peak power with low nonlinear effects, fibers of larger cores are required, in which it is generally difficult to obtain simultaneously good beam quality and to be compatible with tight coiling. We are developing semi-guiding high-aspect-ratio-core (SHARC) fibers for these applications. The rectangular cores achieve very large core areas that raise the nonlinear thresholds and also increase the energy-storage capacity. Coiling ensures good beam quality in the narrow dimension, while good beam quality in the wide dimension is achieved by means of gain filtering, whereby the Er concentration is localized along the core axis, providing the fundamental mode with greatest spatial overlap and the highest gain.

We describe experiments in which nsec 1553nm pulses were launched into Er:SHARC fibers having core areas up to 22x400 um^2. The 5-m fibers were coiled with a diameter of ~ 15 cm and core-pumped by a 1480nm Raman fiber laser. In-band core-pumping provides low-quantum-defect heating and high pump absorption per unit length, which permit the use of short, lower-nonlinearity, fibers while keeping waste heat removal manageable. In past work, SHARC fibers having a core are of 2000 um^2 had generated peak powers of up to 350 kW with good beam quality. We will present data showing the higher peak powers and good beam quality achieved with the larger-core fibers.

10192-2, Session 1

A new class of resonator for slab waveguide lasers

Andrew Ongstad, Air Force Research Lab. (United States); Joseph Chavez, Leidos, Inc. (United States); Gregory C. Dente, GCD Associates (United States)

Since the early 1960's it was recognized that optical resonators could house a myriad of resonant oscillatory modes including transverse and longitudinal modes. A large number of gain geometries of many shapes/sizes were developed over the ensuing years and provided a rich database for the detailed analysis of resonator modal phenomena. Studies have included detailed analysis of longitudinal and transverse modes for both stable and unstable resonators. The standard design is to force the resonator to run on the lowest loss transverse mode that typically coincides with the lowest order transverse mode of the resonator. An additional important design goal is mode discrimination. With good mode discrimination, the laser cavity may operate on a single transverse mode that will saturate the entire gain medium, provide uniform power extraction, and focus into the far-field with good beam quality. However, the path to high power lasers typically requires broadening the gain medium and this leads to substantial mode competition resulting in poor beam quality.

We describe modeling, fabricating and testing a new class of laser resonator, which reduces mode competition and enforces single lateral mode operation even for large resonator geometries. The resonator incorporates a feedback collimator optic, which provides feedback that is mode-matched onto a higher order lateral mode of a slab waveguide laser. In addition, the resonator in out-coupling, converts the stabilized higher-order mode into a laterally collimated output beam. These two functions of selective modal feedback and collimation provide an optically unique high brightness and collimated laser source.

10192-3, Session 1

Power scaling of the double-clad Er-nanoparticle-doped fiber laser

Jun Zhang, Youming Chen, Radha K. Pattnaik, U.S. Army Research Lab. (United States); Colin C. Baker, E. Joseph Friebele, Daniel L. Rhonehouse, Jasbinder S. Sanghera, U.S. Naval Research Lab. (United States); Mark Dubinskii, U.S. Army Research Lab. (United States)

It is well known that power scaling of Er-doped fiber lasers is hindered by relatively low absorption and emission cross sections of Er ion in silica based fiber, as well as deleterious Er upconversion and clustering effects. A nanoparticle (NP) doping technique of fabrication erbium-doped fibers (EDFs) significantly helps to mitigate both Er upconversion and clustering effects, while also slightly increasing laser cross sections. Optical-to-optical slope efficiencies of over 74% have been measured earlier in single-mode NP-doped EDFs. Reported here are the results of major laser power scaling achieved with recently fabricated double-clad NP-doped EDFs.

10192-4, Session 1

The self Q-switched Tm/Ho doped co-axial fiber laser

G. Alex Newburgh, U.S. Army Research Lab. (United States); Krysta Boccuzzi, John R. Marciante, Univ. of Rochester (United States); Mark Dubinskii, U.S. Army Research Lab. (United States)

We present the laser performance of a 800-nm diode-pumped Tm/Ho doped co-axial fiber laser built from a Tm doped clad, Ho doped core glass exhibiting MHz frequency self Q-switched operation. Experimental results along with the numerical results of the time-dependent behavior of this new form of fiber laser will be detailed. Also presented are design considerations of this novel fiber and the modal analysis in the proper design

10192-5, Session 1

Efficient operation of a clad-pumped double-clad Yb:YAG-core/YAG-cladding fiber laser *(Invited Paper)*

Jun Zhang, Youming Chen, U.S. Army Research Lab. (United States); Shizhuo Yin, The Pennsylvania State Univ. (United States); Claire Luo, General Opto Solutions, LLC (United States); Mark Dubinskii, U.S. Army Research Lab. (United States)

Double-clad fibers with the 'crystalline core/crystalline clad' (CCCC = C4) architecture have a power scaling laser potential estimated to be 10-100 times that of conventional double-clad (DC) glass fiber lasers. Here we present the investigation results of a diode-cladding-pumped DC fiber laser based on a round C4 structure: 'Yb3+-doped YAG core/undoped YAG cladding'. This is the first reported lasing from a round, true double-clad, bendable, and fully crystalline, fiber structure fabricated without using diffusion bonding. The emitted core-guided (NA ≈ 0.025) multimode laser output has been obtained with the optical-to-optical efficiency of 45%.

10192-6, Session 1

Polarized milliJoule fiber laser system with high-beam quality and pulse shaping ability

Rui Zhang, China Academy of Engineering Physics (China)

Generally, laser amplification systems can be divided into high peak power and high average power laser system. However there is a wide field of applications in between that require both high peak power and high repetition rate along with low power consumption. The coherent amplification network (CAN) aims at developing a laser system based on the coherent combination of multiple laser beams, which are produced through a network of high beam quality optical fiber amplifiers. The scalability of the CAN laser facilitates the development of many novel applications, such as fiber-based acceleration, orbital debris removal and inertial confinement fusion. According to the requirements of CAN and the front end of high power laser facility, a millijoule polarized fiber laser system was studied here. This fiber laser system outputs 1.06-mJ energy at 10 ns with diffraction limited mode quality and 1-kHz pulse repitation rate. Using polarization maintaining Ytterbium-fiber laser system as the seed, 40-?m core polarizing photonic crystal fiber (PCF) and 85-?m rod-type PCF as the power amplifiers, 2.5-mJ energy at 10-ns pulsewidth was obtained with better than 500:1 peak-to-foot pulse shaping ability. The energy fluctuation of the system is 1.3% rms with 1-mJ output in one hour. When using phase-modulated pulse as the seed, the frequency modulation to amplitude modulation conversion ratio of the system is better than 5%. This fiber laser system has the advantages of diffraction limited mode quality, high beam shaping ability, good stability, small volume and free of maintenance, which can be used in many applications.

10192-7, Session 2

Rare Earth-doped calcium lanthanum sulfide mid-IR laser gain material

L. Brandon Shaw, Michael Hunt, Woohong Kim, Shyam Bayya, U.S. Naval Research Lab. (United States); Christopher G. Brown, Univ. Research Foundation (United States); Steven R. Bowman, Jasbinder S. Sanghera, U.S. Naval Research Lab. (United States)

Development of solid state lasers based upon the mid-IR transitions of rare earth doped ions is currently limited by availability of suitable laser host materials for the rare earth ions. While direct mid-IR laser emission in halide materials such as LaCl3 and KPb2Cl5 has been demonstrated, the halide host materials suffer from durability issues due to high hygroscopicity (LaCl3) or low rare earth dopant concentration due to lack of a suitable site for rare earth doping (KPbCl5). As a solution, we report on our investigations of rare earth doped calcium lanthanum sulfide (CaLa2S4) as a potential mid-IR solid state laser material. CaLa2S4 is an environmentally durable cubic crystalline material with broad transmission out to 14 μm. Rare earth ions can be easily doped into the lanthanide site of the crystalline matrix and the host exhibits a low phonon energy of 285 cm-1, which is promising for low multiphonon quenching of the mid-IR rare earth transitions. We have fabricated transparent samples of Pr3+ doped CaLa2S4 by a ceramic process, whereby highly purified and sulfurized percursors were hot pressed and sintered to fabricate the Pr3+: CaLa2S4 samples. The mid-IR transitions of Pr3+: CaLa2S4 were characterized and broad mid-IR emission was observed.. Strong absorption and emission cross-sections and long msec-lifetimes were measured, showing potential for high gain and good energy storage. We will report on spectroscopy, and laser potential of this new mid-IR laser material.

10192-8, Session 2

Efficient pr3+ laser material excitation by three-for-one cross-relaxation

Larry D. Merkle, Mark Dubinskii, U.S. Army Research Lab. (United States)

Laser materials for the mid-infrared wavelength range are more promising if they can be excited by well-developed, efficient laser diodes. In the case of the Pr3+ laser ion, this is possible by using laser diodes at wavelengths around 1.5 microns developed for telecommunications. This ion has three excited manifolds with lower manifolds at the right energies to give fluorescence between 3.5 and 5.5 microns. In the investigation of Pr:RbPb2Cl5 as a low-phonon-energy laser material, we have observed strikingly strong fluorescence in this wavelength range following 1.53-micron excitation. Careful analysis of the spectra and the decay kinetics indicates that this is due to two cross-relaxation processes that, together, efficiently convert one initial excitation to the Pr3+ 3F¬3 manifold into three ions excited to the 3H5 manifold. Just as the well-known "two-for-one" cross-relaxation in Tm3+ enables efficient excitation of that ion's two-micron laser upper level, this newly-discovered "three-for-one" cross-relaxation process in Pr3+ may greatly enhance its utility as a mid-infrared laser ion. Detailed evidence for this process will be presented.

10192-9, Session 2

Doping transition metal ions into laser host crystals by hot isostatic pressing (HIP)

Jacob O. Barnes, UES, Inc. (United States); Ronald W. Stites, Gary Cook, Air Force Research Lab. (United States); Sean McDaniel, Air Force Research Lab./RYDH (United States); Douglas M. Krein, General Dynamics Information Technology (United States); Shekhar Guha, John Goldsmith, Air Force Research Lab. (United States)

This paper describes using a hot isostatic pressing (HIP) to improve II-VI crystal characteristics and diffuse metal ions into laser host crystals. Thin layers of metal are sputtered onto the surface of zinc selenide and zinc sulfide crystals prior to being HIP treated. The pre and post treatment optical properties for these materials are measured using various methods and at a variety of dopant concentrations.

10192-10, Session 2

Optical characterizations on surface-polished polycrystalline YAG fibers

Hyunjun Kim, Air Force Research Lab. (United States) and UES, Inc. (United States); Nicholas G. Usechak, Randall S. Hay, Air Force Research Lab. (United States); Sean McDaniel, Leidos, Inc. (United States) and Air Force Research Lab. (United States); Gary Cook, Augustine M. Urbas, Air Force Research Lab. (United States); Kathleen N. Shugart, Ali H. Kadhim, Dean P. Brown, Air Force Research Lab. (United States) and UES, Inc. (United States); Benjamin Griffin, Air Force Research Lab. (United States); HeeDong Lee, Randall G. Corns, Air

Force Research Lab. (United States) and UES, Inc. (United States)

Transparent polycrystalline ceramics are attracting a lot of attention as laser gain media because of their superior thermal and optical properties over current glass-based gain media. Fibers also have other advantages such as compactness, vibration-resistance, and reduced cooling requirements. Transparent polycrystalline ceramic fibers take advantage of the thermal and optical properties of ceramics and of fibers. We have been developing polycrystalline yttrium aluminum garnet (YAG) fibers for optical applications, but the scattering coefficients were not low enough. Recently it was found that surface roughness caused by grain boundary grooving in polycrystalline YAG fiber dominates optical scattering even though there were other scattering sources in the fiber. Therefore, a lot of effort went to fabrication of fibers with smooth surfaces. We developed a mechanical polishing method for polycrystalline YAG fibers. The surface roughness of the fiber was reduced, while maintaining a circular cross section. Roughness of the surface-polished fiber was measured using a FIB (Focused Ion Bean) system, SEM, and image analysis. The relationship between surface roughness and scattering coefficient of polycrystalline YAG fibers will be discussed, and optical characteristics of the surface polished fibers will be presented.

10192-11, Session 2

Development of cladded single crystal YAG fiber lasers

L. Brandon Shaw, U.S. Naval Research Lab. (United States); Charles G. Askins, Sotera Defense Solutions, Inc. (United States); Woohong Kim, Shyam Bayya, U.S. Naval Research Lab. (United States); John R. Peele, Sotera Defense Solutions, Inc. (United States); Daniel L. Rhonehouse, Univ. Research Foundation, U.S. Naval Research Lab. (United States); Rajesh Thapa, Sotera Defense Solutions, Inc. (United States); Daniel Gibson, Jason D. Myers, Rafael R. Gattass, Jasbinder S. Sanghera, U.S. Naval Research Lab. (United States)

Power scaling of narrow linewidth silica fiber lasers is currently limited by stimulated Brillouin scattering (SBS) and thermal effects such as mode instability (MI). One strategy to mitigate SBS and MI is to move to fiber materials with lower SBS cross-sections and higher thermal conductivities. Single crystal laser hosts such as Yttrium Aluminum Garnet (YAG) have thermal conductivities ~ 10 x higher and SBS cross-sections ~100x lower than silica glass. In addition, single crystal YAG offers the potential for higher rare earth dopant concentration to enable shorter fiber lengths which leads to lower nonlinearities. Use of rare earth doped YAG core fibers also mitigates issues associated with photodarkening, inherent to current rare earth doped silica fibers and the silica multiphonon edge absorption and OH- quenching observed in Ho doped silica fiber lasers operating at a wavelength of 2.1 μm. Based on these superior properties, calculations indicate that power scaling can be 10x higer than is possible with silica glass based fiber lasers. In this paper, we report on progress in development of fiber laser based on cladded single crystal core fiber with architectures analogous to those seen in large mode area silica fiber. Both Yb:YAG and Ho:YAG small diameter fibers have been fabricated by the laser heated pedestal growth method. Tailored glasses materials as well as polycrystalline YAG have been applied to form claddings on the single crystal doped YAG fibers. Gain has been demonstrated in cladding pumped Yb:YAG fibers. Fusion splicing of unclad YAG fibers to silica has been also been demonstrated.

10192-12, Session 3

High-power pump diode lasers for defense applications

Christopher Ebert, David A. Irwin, Joseph Braker, DILAS Diode Laser, Inc. (United States)

DILAS offers a variety of high power pump diode lasers, optimized for different gain media. Systems optimized for DPAL pumping at 766nm will be discussed, including results demonstrating precise wavelength and spectral width control necessary to optimal overlap with atomic lines. In addition, pump modules optimized at 793 nm for Tm fiber laser pumping have been demonstrated, including a low SWaP module targeted for airborne applications. Lastly, DILAS' line of high-efficiency/low-SWaP pump at 976nm for Yb fiber laser will be presented. Starting with the 330W IS46 module, DILAS has demonstrated >53% efficiency, and has now increased brightness up to 625W from a 225 um/ 0.22 NA fiber. Developments towards a module with >900W output power will also be shown.

10192-14, Session 3

Single and dual-chip high peak-power semiconductor laser

Joshua Myers, Air Force Research Lab. (United States)

To date high power, high energy pulses in the few ns rage have been unobtainable in semiconductor lasers due to the short carrier lifetime in the gain medium and long cavity buildup times. In this paper we show a wavelength and pulse width tunable laser that is able to achieve pulses in the range of a few ns at power levels above 1kW leading to several μJ pulse energies. This was done by inserting a polarizing beam splitter (PBS) and a λ/4 Pockels cell (PC) into the cavity a vertical external cavity surface emitting laser (VECSEL) allowing access to the high energy stored in the VECSEL cavity. Using this method when voltage is applied to the PC the polarized light picks up λ/4 retardation as it passes through the PC. Once the light bounces off of the end mirror it returns through the PC to gain another λ/4 retardation to change the circularly polarized light into linearly polarized light opposite that of the start. This light is then 'dumped' out of the PBS and the VECSEL cavity empties. After this the PC is switched off and the light in the cavity is allowed to build up again. Once the light has built back up, the VECSEL is ready to be 'dumped' again. This has been demonstrated in both single gain chip and dual gain chip setups.

10192-15, Session 3

High-temperature diode laser pumps for directed energy fiber lasers

Manoj Kanskar, Ling Bao, Zhigang Chen, Mark DeVito, Weimin Dong, Mike P. Grimshaw, Xinguo Guan, David M. Hemenway, Robert Martinsen, Jim Zhang, Shiguo Zhang, nLIGHT Corp. (United States)

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.

10192-16, Session 4

A compact dual-wavelength fiber laser for enhanced LRF applications: some design aspects

Christian Ban, Dusan Zadravec, Vectronix AG (Switzerland)

High performance in combination with small size, low weight and low power consumption are the main drivers in modern defense and commercial LRF applications. Consequently, designers of such systems strive for innovative solutions in the field of laser technology. Ten years ago Vectronix pioneered these activities with the fielding of the first fiber laser for hand-held range finders. Present paper will deal with the latest evolution of an eye-safe fiber laser source which can emit two wavelengths for extended range of applications.

In order to comply with high performance requirements the laser on one side has to produce high enough pulse energy and on the other side – especially, due to required compactness – use so called single-stage amplification in combination with bending insensitive fiber solutions. Also, the ASE (amplified spontaneous emission) has to be reduced as much as possible as this light enters the eye safety equation but does not contribute at all in terms of performance. Laser has to meet severe environmental requirements typical for demanding defense applications. Additionally, the laser in its range finding mode has to produce a sequence of high frequency pulses in such a way that no substantial temperature effects would arise and impair either the pulse energy or the alignment.

The second wavelength emitted from the same fiber enables easy boresighting and targeting.

In this paper also a compact double-stage dual-wavelength version of the above laser will be shortly described, which has been developed to generate much stronger pulses for very long range finding applications.

10192-17, Session 4

Direct diode laser illumination and pointing at eye-safe wavelengths

Prabhu Thiagarajan, John Goings, Nick Moor, Brian Caliva, Lasertel, Inc. (United States)

Military, industrial and medical applications have expressed interest using 1550nm laser diodes for illumination/pointing applications due to the reduce eye safety concerns. Military applications have the additional interest due to the covert, out-of-band wavelength 1550nm represents. Illumination applications generally require advanced beam conditioning to meet required power uniformity, stray light mitigation, spectral homogeneity and tight divergence specifications. Likewise, range finding and marking applications desire high power (>0.5W) and low divergence (<1mrad) as this is directly proportional to the device's effective operating range. Minimized size, weight and volumes are addressed with a free-space, direct diode approach in comparison to bulker fiber delivered units. This paper will highlight and discuss a range of illuminator developments that offer high powers (50W to 100'sW) as well as provide a profile of new pointers products (0.5W to 1W) all at 1550nm. Options for customized beam conditioning and results of MIL environmental qualifications will also be presented.

10192-18, Session 4

Analysis of a space debris laser removal system

Evan Gjesvold, Jeremy Straub, North Dakota State Univ. (United States)

Space debris presents a threat to orbital craft and must be located and removed. Lasers may prove to be the ideal method for doing this, as they can operate at a distance from the debris, can make use of a theoretically infinite supply of energy from the sun, and are a readily available technology.

This paper proposes a CubeSat mission that seeks to determine the efficiency of lasers for decommissioning debris. The satellite will be equipped with an internally-mounted simulated debris object. This mounted object will provide the laser with a definite target.

The satellite will contain an impulse laser which will impart momentum to the debris and a ranging laser which will measure the movement rate of the debris. A threshold detection system will be placed at the opening of the satellite, and confirm that the debris has left the satellite. The satellite will also be equipped with an imaging system, for additional data collection.

The mission will consist of a checkout phase, where the satellite will determine that all systems are functioning correctly. After this checkout phase, the impulse laser will be operated for a period of time. After this, the ranging laser will take measurements of the debris' position and velocity. Measurement of the impact of environmental factors on the debris object will also be conducted. The impulse laser will be operated on multiple occasions in order to collect data about the effectiveness of various pulse lengths and frequencies.

10192-19, Session 4

Remote laser drilling and sampling system for the detection of concealed explosives

Dominik Wild, Lukas Pschyklenk, Cathrin Theiss, Gerhard Holl, Hochschule Bonn-Rhein-Sieg (Germany)

The detection of hazardous materials like explosives is a central issue in National Security in the field of counterterrorism. One major task includes the development of new methods and sensor systems for the detection. Many existing remote or standoff methods like infrared or raman spectroscopy find their limits, if the hazardous material is concealed in an object. Imaging technologies using x-ray or terahertz radiation usually yield no information about the chemical content itself. However, the exact knowledge of the real threat potential of a suspicious object is crucial for disarming the device.

A new approach deals with a laser drilling and sampling system for the use as verification detector for suspicious objects. A central part of the system is a miniaturised, diode pumped Nd:YAG laser oscillator-amplifier. The system allows drilling into most materials like metals, synthetics or textiles with bore hole diameters in the micron scale. During the drilling process, the hazardous material can be sampled for further investigation with suitable detection methods.

In the reported work, different spectroscopic and sensor techniques are used to monitor the drilling progress and to classify the drilled material. Also experiments were carried out to show the system's ability to prevent ignition of even sensitive explosives during the laser interaction. The detection of concealed hazardous material is shown for different explosives using liquid chromatography and ion mobility spectrometry.

10192-20, Session 4

Target-in-the-loop phasing of a fiber laser array fed by a linewidth-broadened master oscillator

Milo W. Hyde IV, Air Force Institute of Technology (United States); Glenn A. Tyler, the Optical Sciences Co. (United States); Carlos Rosado Garcia, Air Force Institute of Technology (United States)

In a recent paper [J. Opt. Soc. Am. A 33, 1931-1937 (2016)], the target-in-the-loop (TIL) phasing of an RF-modulated or multi-phase-dithered fiber laser array--fed by a linewidth-broadened master oscillator (MO) source--was investigated. It was found that TIL phasing was possible even on a target with scattering features separated by more than the MO's coherence length as long as the received, backscattered irradiance changed with the array's modulation or phase dither. To simplify the problem and gain insight into how temporal coherence affects TIL phasing, speckle and atmospheric turbulence were omitted from the analysis. Here, the scenario analyzed in the prior work is generalized by including speckle and turbulence. First, the key analytical result from the prior paper is reviewed. Simulations, including speckle and turbulence, are then performed to test whether the conclusions derived from that result hold under more realistic conditions.

10192-21, Session 4

Diamond mirror for high-power laser applications

Haig Atikian, Harvard Univ. (United States); Pawel M. Latawiec, Harvard School of Engineering and Applied Sciences (United States); Xiao Xiong, Harvard Univ. (United States); Marko Loncar, Harvard School of Engineering and Applied Sciences (United States)

High average power lasers place a significant thermal load on typical optical components based on multilayer thin-film coatings. Imperfections in the coating layers, or at the interfaces between the layers, form sites where laser energy can be absorbed, thus generating a tremendous amount of heat. This can result in local melting or extreme thermal stress in the optical coatings creating irreversible damage to the optical component. Diamond exhibits many favorable material properties for optical applications. In particular, it has a relatively high refractive index (2.4), a wide bandgap (5.5eV), and a large optical transmission range from the UV into the mid infrared. Further, diamond is particularly attractive as a material for high power lasers in the visible to mid infrared range due to its excellent optical transmission properties and astonishingly high thermal conductivity at room temperature (2200W/mK). We present a novel advancement, where an all-diamond high reflectivity mirror is etched from a bulk diamond substrate. The fact that the device is made completely from bulk diamond, which is the highest thermal conductivity material, one can realize optical elements with extremely high laser induced damage thresholds (LIDT). We have characterized the diamond mirror to have ~99% reflectivity around 1064nm, and measured its LIDT to a continuous wave Nd:YAG laser to 225MW/cm2 with no damage, orders of magnitude higher than commercially available high energy mirrors.

10192-22, Session PSTue

From visible to mid-infrared supercontinuum generation using tellurite fiber with 1064 nm pump

Rui Song, Chengmin Lei, Kai Han, Dongsheng Pu, Jing Hou, National Univ. of Defense Technology (China)

Supercontinuum has great potential in defense applications due to its wide spectrum, high coherence and high brightness, and it has attracted more and more attention across the world especially in the visible and mid-infrared region like 3-5μm which is the atmospheric transparency window. Higher power, wider spectrum, and better spectrum flatness will be the dominant pursuit for the future development of supercontinuum.

Currently silica based fiber are the dominant host for visible to near-infrared supercontinuum generation, and soft glass like fluoride fiber, chalcogenide fiber and tellurite fiber are widely used for mid-infrared supercontinuum generation due to their lower loss in the mid-infrared region. In this paper, the generalized non-linear Schrödinger equation is used to simulate the visible to mid-infrared supercontinuum generation in a tellurite fiber. A femtosecond laser at 1064 nm worked as the pump source. 1.5 μm and 2 μm lasers are generally first pump candidates to generate mid-infrared supercontinuum in tellurite glass because the zero-dispersion wavelength of the tellurite glasses is around 2.15 μm. However, 1064 nm laser has more advantages in application in terms of cost, structure, and power scaling, so it is meaningful to investigate whether 1064 nm laser can pump tellurite fiber to generate supercontinuum with wide spectrum. The simulation results show that 500 nm-5000 nm supercontinuum can be generated in a tellurite fiber with less than 10 kW peak power for the pump laser, and the length of the tellurite fiber is only several millimeter. The simulation results provide important guidance for future supercontinuum development.

10192-23, Session PSTue

Theoretical analysis of fused tapered side-pumping combiner for all-fiber lasers and amplifiers

Chengmin Lei, Zilun Chen, Jinyong Leng, Yanran Gu, Jing Hou, National Univ. of Defense Technology (China)

Fiber laser systems have important applications in national defense as well as commercial markets. For the design and fabrication of compact and reliable high power fiber laser systems, the efforts on the research about all-fiber components of the highly integrated high power fiber laser and amplifier systems have been increased in recent years. One of the most key components is a pump/signal combiner. According to the existing literature, fused tapered side-pumping combiner is of great prospect in the application of high power fiber laser due to its uninterrupted signal fiber core and unlimited pump points. Though there are many experimental results about this technique, the influence of detailed parameters on the performance of the combiner is rarely discussed and worth further investigated.

In this paper, we report detailed simulations and experiments on the influence of the fused depth, launch mode and taper ratio on the performance of side-pumping combiner. The theoretical analysis indicates that the coupling efficiency and loss mechanism of the combiner is closely related to the fused depth, tapering ratio and the launch mode. Experimentally, we fabricate combiners consisting of two pump fibers (220/242 μm, NA=0.22) and a signal fiber (20/400 μm, NA=0.46) with different structure parameters. The experimental results indicates the fused depth depends on the fused duration time and the position of the flame during the fusion splicing between pump arms and signal arm. After experimentally investigating the effect of different structure characteristics and fused depth on the coupling efficiency and backward isolation of the combiner, we select one combiner with best performance to be applied in a high power fiber amplifier. The combined pump coupling efficiency of two pump port is 97.2% with the maximum power handling of 1.8 kW and the

insertion signal loss is less than 3%. An all-fiber fiber amplifier system with backward pumping configuration is achieved, with an output 1080 nm signal power of 1458 W and an optical-optical efficiency of 81%.

10192-24, Session PSTue

Damage characteristics of the optical element in resonant cavity irradiated by high-power continuous-wave laser

Zhaokai Lou, Kai Han, Rui Song, Baozhu Yan, Zejin Liu, National Univ. of Defense Technology (China)

In high power continuous wave (cw) laser system, damage characteristics of optical elements have attracted a great deal of attention. Thermal effect is the main mechanism for the damage induced by high power cw laser. As the contaminants adhered to the element, surface may cause absorption peaks. These absorption peaks absorb the laser energy, leading to the thermal damage of the optical element. Compared with the element outside the laser cavity, the damage characteristics of the resonating mirror in the laser cavity are more complex. The reflectivity of the resonating mirror decrease at the corresponding positions because of the absorption peaks. As a result, the resonating laser intensity produced in the cavity decreases to some extent. The contaminated element may be safe from thermal damage as the laser intensity irradiating on the contaminated position has decreased. In this paper, a theoretical model was established based on the optical transmission theory to describe the damage characteristic of the contaminated resonating mirror. The influence of the contaminant size, the contaminant number and the cavity structure on the damage characteristic of the resonating mirror is studied. It is found that the damage characteristic is related to many factors, such as the contaminant size, laser wavelength and the cavity structure. The result is of great help for improving the anti-damage capability of the resonating mirror and enhancing the robustness of the high power cw laser system.

10192-25, Session PSTue

Laser ablation molecular isotopic spectroscopy (LAMIS) in the multivariate LODs determination using PLSR of 10B and 11B Boric acid mixtures

Candace D. Harris, Florida Agricultural and Mechanical Univ. (United States); Luisa T. M. Profeta, Alakai Defense Systems, Inc. (United States); Codjo A. Akpovo, Florida Agricultural and Mechanical Univ. (United States); Ashley C. Stowe, Y-12 National Security Complex (United States); Lewis E. Johnson, Florida Agricultural and Mechanical Univ. (United States)

Isotopic analysis has been capitalized in the research and development areas of nuclear forensics and materials sciences. Boron isotopes are of particular interest as a simulant for fissionable products like 235U and 239P in nuclear reactors. Signatures of isotopes are difficult to detect and are limited to the detectors capability in optically resolving spectra attributes that appear from isotopic transitions. One mechanism of analyzing these transitions is Laser Ablation Molecular Isotopic Spectroscopy (LAMIS), an extension of LIBS. LAMIS can examine the molecular ro-vibronic emission lines corresponding to isotopic shifts. Previous literature has shown Boron isotopic shifts of ~ 1 nm in Boron Monoxide (BO) so as a starting point we studied this effect in BO containing matrices (i.e. boric acid) with high and low concentrations of 10B and 11B. Samples were interrogated with a Q-switched Nd:YAG ablation laser operating at 532 nm. For the analytes of interest, the generated plasma has been examined for their 10/11BO molecular bands in the spectral windows of 251-265 nm, 270-284 nm, 293-307 nm and 304-318 nm. A minimum of four band heads of the β system B2Σ⟶x2Σ transitions have been identified. Sample sets were analyzed using partial least squares regression (PLSR) with a IUPAC novel approach for determining a multivariate limit of detection (LOD) interval of the desired isotopic ratio. The model is dependent on the variation of the instrumental signal and other composites in the calibration space.

10193-1, Session 1

Metastability of transient states *(Invited Paper)*

Michael K. Rafailov, Univ. of Alberta (United States)

Ultrashort high intensity pulse creates extreme non-equilibrium condition in bandgap material producing dramatic perturbations in electronic structure that, in its turn, leading to changes in electronic, magnetic, and optical states of condensed matter. Interesting experimental results have recently been reported on transient phenomena ranging from ultrafast laser induced denial of detection to light induced high temperature superconductivity. While single pulse interaction with bandgap material is well observed, explained and documented, one of the major problem is to maintain meta-stability of such matter states well beyond bandgap material relaxation time. The objective of this paper is to discuss approaches to transient states meta-stability-specifically with respect to research topics that have been presented at Ultrafast Bandgap Photonics Conference, Baltimore 2016.

10193-2, Session 1

Relaxation of nonequilibrium populations after a pump: the breaking of Mathiessen's rule *(Keynote Presentation)*

James Freericks, Georgetown Univ. (United States); Alexander Kemper, North Carolina State Univ. (United States)

The lifetime of a quasiparticle of an equilibrium many-body system usually satisfies Mathiessen's rule, where the total scattering rate is equal to the sum of the scattering rates for all different scattering processes. The relaxation time is then represented by $-2 {rm Im} Sigma(omega)$, which determines the dc transport (in linear response) and the width of quasiparticle peaks in the spectral function. For a nonequilibrium system, the population of electrons in different momentum states is different from the equilibrium population; they relax towards the thermal state at long times with a characteristic relaxation time. In this talk, we discuss what determines this nonequilibrium relaxation time, and show that it critically depends on how energy is transferred from the electrons to the phonons. In general, it neither satisfies Mathiessen's rule nor is given as a simple relation with the imaginary part of the self-energy (at a given average time), although it is quantitatively close to this. We discuss issues related to the physics of these systems and describe recent experiments which explicitly exhibit this phenomena This work is supported by the US Department of Energy, Basic Energy Sciences, under grant number DE-FG02-08ER46542.

10193-3, Session 1

Ab-initio calculations for energy transfer from ultrashort laser pulse to dielectrics *(Invited Paper)*

Kazuhiro Yabana, Univ. of Tsukuba (Japan)

Ab-initio density functional theory (DFT) has been successful for calculations of ground state properties of various materials. Time-dependent density functional theory (TDDFT) is an extension of the DFT and can describe electron dynamics in molecules, nano-structures, and solids induced by optical electric fields. We have been developing a computational method to describe electron dynamics in a crystalline solid under an irradiation of an ultrashort laser pulse, solving the time-dependent Kohn-Sham equation in real time. The method can be used for an ab-initio description of light-matter interactions. We further couple the electron dynamics calculation with the macroscopic Maxwell equations in a multiscale implementation. It can describe laser pulse propagation in dielectrics and, in particular,the energy transfer from the laser pulse to electrons in dielectrics without any empirical parameters. We apply the method to analyze recent experiments utilizing attosecond spectroscopy methods. We show a few examples. One is for the ultrafast changes of dielectric properties of diamond during the irradiation of an intense few-cycle laser pulse. We mimic the pump-probe measurement employing the multiscale Maxwell + TDDFT simulation. We clarified that the dynamical Franz-Keldysh effect is responsible for the mechanism. The other is to identify the onset of the energy transfer from the laser pulse to SiO_2 when we increase the intensity of the laser pulse. We are currently extending the analysis to obtain a clear and intuitive understanding for the initial stage of laser damage processes.

10193-4, Session 1

Ultrafast light-induced structural dynamics in hybrid perovskite materials *(Invited Paper)*

Aaron M. Lindenberg, SLAC National Accelerator Lab. (United States) and Stanford Univ. (United States)

This work uses atomic-scale resolution real-time approaches to visualize the first steps following absorption of a photon in a new class of materials for energy conversion. It shows that ultrafast light-induced structural reorganizations are important to take into account in elucidating the unique optoelectronic functionality of these materials.

10193-5, Session 2

Nondegenerate nonlinear refraction, absorption, and gain in semiconductors *(Keynote Presentation)*

David J. Hagan, CREOL, The College of Optics and Photonics, Univ. of Central Florida (United States); Matthew C. Reichert, Princeton Univ. (United States); Peng Zhao, Himansu S. Pattanaik, Eric W. Van Stryland, CREOL, The College of Optics and Photonics, Univ. of Central Florida (United States)

We have shown both experimentally and theoretically that the effect of intermediate-state resonance enhancement causes highly nondegenerate 2-photon absorption, 2PA, to be strongly enhanced in direct-gap semiconductors. Calculations indicate an additional 10x increase in this enhancement is possible for quantum-well semiconductors. This enhancement leads to interesting applications of 2PA, such as mid-infrared detection, where uncooled, large-gap photodiodes can rival the sensitivity of cooled MCT detectors (for short pulses). Additionally, mid-IR imaging and tomography based on this effect have been shown. Even larger enhancement of 3PA is calculated and observed. In the case of optically-pumped semiconductors, we have now demonstrated that the complementary process of nondegenerate 2-photon stimulated emission can be observed. Theoretically, this results in 2-photon gain (2PG) that is enhanced as much as 2PA, leading to the possibility of large gap devices with tunable mid-infrared gain. However, the effect of nondegenerate enhancement of 3PA can be detrimental to the observation of this gain. Additionally, by causality, Kramers-Kronig relations predict that the enhancement of 2PA is accompanied by an enhancement of the nonlinear refractive index, n2, which is very highly dispersive in the region of 2PA. Our latest experimental results confirm this enhancement and strong dispersion.

10193-6, Session 2

Radiation effects testing via semiconductor nonlinear optics: successes and challenges *(Invited Paper)*

Dale McMorrow, Stephen P. Buchner, U.S. Naval Research Lab. (United States); Ani Khachatrian, U.S. Naval Research Lab. (United States) and Sotera Defense Solutions, Inc. (United States); Nicolas J. H. Roche, U.S. Naval Research Lab. (United States) and George Washington Univ. (United States); Joel M. Hales, Sotera Defense Solutions, Inc. (United States) and U.S. Naval Research Lab. (United States); Jeffrey H. Warner, U.S. Naval Research Lab. (United States)

Single-event effects (SEEs) refer to phenomena that arise from the interaction of a single energetic particle with a microelectronic device, as is experienced by electronics in harsh radiation environments (e.g., satellites and radiation facilities). Carrier generation induced by two-photon absorption (TPA) has become a valuable tool for SEE investigations of micro- and nano-electronic structures owing to its unique ability to inject carriers through the wafer, directly into well-defined locations in complex circuits, while avoiding interference from metal over-layers. The qualitative capabilities of this approach include, among others, sensitive node identification, radiation hardened circuit verification, basic mechanisms investigations, model validation and calibration, screening devices for space missions, and fault injection to understand error propagation in complex circuits. Recent effort has built upon the success enabled by these qualitative benefits, and has focused on putting the TPA SEE technique on a more quantitative basis. To do this requires two things: (i) accurate, reproducible characterization of the optical pulse delivered to the surface of the semiconductor, including the pulse energy, temporal width, and focusing characteristics; and (ii) understanding, and modeling the role of various nonlinear-optical phenomena in contributing to the carrier generation in the material. This presentation will address the recent successes in achieving these two goals, as well as the challenges that are faced as the technique moves forward.

10193-7, Session 2

Ultrafast photoconductive devices based upon Er-doped GaAs nanoparticle composite driven at 1550 nm *(Invited Paper)*

Weidong Zhang, Andrea Mingardi, Elliott R. Brown, Wright State Univ. (United States); Ari Feldman, Todd E. Harvey, Richard P. Mirin, National Institute of Standards and Technology (United States)

This paper is to report the progress of developing a new type of ultrafast photoconductive (PC) source that can be driven at 1550 nm but exhibits the robustness of GaAs (e.g., LT-GaAs) driven at 780 nm. The approach is GaAs doped heavily with Er (>4x1020 cm-3 or >2%) such that ErAs nanoparticles form spontaneously during epitaxial growth by MBE. The size of nanoparticles ranges from 2-20nm while the pack density is estimated as high as~4.7x1018/cm3. Yet, the Er doped GaAs epilayer maintains excellent structural quality and smooth surface morphology. Photoconductive switch device with 3-turn square spiral antenna is fabricated and characterized. At least ~24uW Terahertz power is generated when the device is biased “safe” at 80V and pumped with a 1550 nm 90fs-short pulsed laser with average power 73mW. The broadband power increases significantly as the laser beam-spiral antenna coupling is further optimized. In addition to Terahertz performance, we will discuss relevant unusual electronic transport (Metal-to-insulator transition), large photocondurrent (>70mA) comparable to 780-nm-pumped PC switches as well as extrinsic photoconductivity model. This research is of significance to develop 1550nm-technology-compatible, powerful and cost-effective THz sources.

10193-8, Session 3

Carrier multiplication and charge transport in artificial quantum-dot solids probed by ultrafast photocurrent spectroscopy *(Keynote Presentation)*

Victor I. Klimov, Los Alamos National Lab. (United States)

Understanding and controlling carrier transport and recombination dynamics in colloidal quantum dot films is key to their application in electronic and optoelectronic devices. Towards this end, we have conducted transient photocurrent measurements to monitor transport through quantum confined band edge states in lead selenide quantum dots films as a function of pump fluence, temperature, electrical bias, and surface treatment. Room temperature dynamics reveal two distinct timescales of intra-dot geminate processes followed by non-geminate inter-dot processes. The non-geminate kinetics is well described by the recombination of holes with photoinjected and pre-existing electrons residing in mid-gap states. We find the mobility of the quantum-confined states shows no temperature dependence down to 6 K, indicating a tunneling mechanism of early time photoconductance. We present evidence of the importance of the exciton fine structure in controlling the low temperature photoconductance, whereby the nanoscale enhanced exchange interaction between electrons and holes in quantum dots introduces a barrier to charge separation. Finally, side-by-side comparison of photocurrent transients using excitation with low- and high-photon energies (1.5 vs. 3.0 eV) reveals clear signatures of carrier multiplication (CM), that is, generation of multiple excitons by single photons. Based on photocurrent measurements of quantum dot solids and optical measurements of solution based samples, we conclude that the CM efficiency is unaffected by strong inter-dot coupling. Therefore, the results of previous numerous spectroscopic CM studies conducted on dilute quantum dot suspensions should, in principle, be reproducible in electronically coupled QD films used in devices.

10193-9, Session 3

Probing semiconductor interfacial carrier dynamics through time-resolving the photo-induced electric fields *(Invited Paper)*

Matthew C. Beard, Ye Yang, National Renewable Energy Lab. (United States)

Isolating spectral signatures and/or the carrier dynamics that are specific to semiconductor junctions and not just the interface or bulk is challenging. Junctions that form between a semiconductor surface and a contacting layer are the key to their function. Equilibration of chemical potential at such junctions creates an internal electric field and establishes a region where mobile charges are driven away (depletion region). Absorption of light produces electrons and holes within the depletion region where the charges are separated. We developed transient photoreflectance (TPR) as an innovative time-resolved spectroscopic probe that can directly monitor carrier dynamics within and across such junctions. In the TPR method, the change in reflectance (ΔR) of a broadband probe from a specific interface is monitored as a function of pump-probe delay. The spectral nature of the reflected beam provides quantitative information about the built-in field; thus, TPR is a non-contact probe of the electric field at that interface. We applied TPR to study charge transfer at p-type gallium-indium phosphide (p-GaInP2) and n-type gallium-arsenide (n-GaAs) interfaces. We monitored the formation and decay of transient electric fields that form upon photoexcitation within bare p-GaInP2, p-GaInP2/platinum (Pt), and

p-GaInP2/amorphous titania (TiO2) interfaces. A field at both the p-GaInP2/Pt and p-GaInP2/TiO2 interfaces forms that drives charge separation, however, recombination at the p-GaInP2/TiO2 interface is significantly reduced compared the p-GaInP2/Pt interface. On the other hand, n-GaAs forms an ohmic contact with TiO2 while only a small field forms at the n-GaAs/NiO interface that promotes hole transfer to nickel oxide (NiO).

10193-10, Session 4

Ultrafast dynamics of colloidal semiconductor nanocrystals relevant to solar fuels production *(Invited Paper)*

Todd D. Krauss, Cunming Liu, Fen Qiu, Nicole Cogan, Rebecca Burke, Univ. of Rochester (United States)

Artificial conversion of sunlight to chemical fuels has attracted attention for several decades as a potential source of clean, renewable energy. For example, in light-driven proton reduction to molecular hydrogen, a light-absorbing molecule (the photosensitizer) rapidly transfers a photoexcited electron to a catalyst for reducing protons. We recently found that CdSe quantum dots (QDs) and simple aqueous Ni2+ salts in the presence of a sacrificial electron donor form a highly efficient, active, and robust system for photochemical reduction of protons to molecular hydrogen. To understand why this system has such extraordinary catalytic behavior, ultrafast transient absorption (TA) spectroscopy studies of electron transfer (ET) processes from the QDs to the Ni catalysts were performed. CdSe QDs transfer photoexcited electrons to a Ni-dihydrolipoic acid (Ni-DHLA) catalyst complex extremely fast and with high efficiency: the amplitude-weighted average ET lifetime is 69 ± 2 ps, and ~90% of ultrafast TA signal is assigned to ET processes. Interestingly, under high fluence, sufficient to create on average almost 2 excitons per QD, the relative fraction of TA signal due to ET remains well over 80%, and depopulation from exciton-exciton annihilation is minimal (6%). We also found that increasing QD size and/or shelling the core CdSe QDs with a shell of CdS slowed the ET rate, in agreement with the relative efficiency of photochemical H2 generation. The extremely fast ET provides a fundamental explanation for the exceptional photocatalytic H2 activity of the CdSe QD/Ni-DHLA system and guides new directions for further improvements.

10193-11, Session 4

Modeling and spectroscopy of carrier relaxation in semiconductor optoelectronics *(Invited Paper)*

Adam C. Scofield, Andrew I. Hudson, William T. Lotshaw, The Aerospace Corp. (United States)

The end performance of semiconductor optoelectronic devices is largely determined by the carrier dynamics of the base materials comprising the device. When combined with full-scale numerical models, steady-state and time-resolved spectroscopy are capable of providing detailed information about carrier generation and dynamics that is essential to accurate analysis of test structure studies and to translating those results into predictions for device performance. We have applied time-resolved and steady-state luminescence techniques to a variety of III-V materials and reference structures in order to investigate the mechanisms limiting carrier lifetime and to develop the capability to provide actionable feedback to R&D efforts for improvement and optimization of material/device performance. To exemplify our work we will present the results of photoluminescence experiments and model-based analyses designed to assess the carrier dynamics impacts of defects and interface quality in double heterostructure test vehicles, type-II superlattices, and photovoltaic devices.

10193-12, Session 5

Axial InGaAs/GaAs nanowire separate absorption-multiplication avalanche photodetectors *(Keynote Presentation)*

Diana L. Huffaker, Univ. of California, Los Angeles (United States) and Cardiff Univ. (United Kingdom)

In0.53Ga0.47As/InP single photon avalanche detectors (SPADs) have a high photon detection efficiency in the near-IR, however the dark count rate is prohibitively high at room temperature. A nanowire-based In0.3Ga0.7As/GaAs SPAD can significantly reduce the DCR through a nearly three order of magnitude reduction in bulk InGaAs volume, as well as by reducing the indium composition for operation at 1064 nm. As a first step, we have successfully grown axial InGaAs/GaAs heterostructures using catalyst-free selective-area epitaxy. We will present the electrical characterization of a vertically oriented nanowire array InGaAs/GaAs SPADs operating at 1064 nm and use 3-dimensional modeling to aid in the analysis.

10193-13, Session 5

Toward high fidelity spectral sensing and RF signal processing in silicon photonic and nano-opto-mechanical platforms *(Invited Paper)*

Aleem Siddiqui, Charles M. Reinke, Sandia National Labs. (United States); Robert C. Potter, Dominic Riehl, Rockwell Collins, Inc. (United States); Heedeuk Shin, Yale Univ. (United States); Robert L. Jarecki, Andrew L. Starbuck, Sandia National Labs. (United States); Peter T. Rakich, Yale Univ. (United States)

The performance of electronic systems for radio-frequency (RF) spectrum analysis is critical for agile radar and communications systems, ISR (intelligence, surveillance, and reconnaissance) operations in challenging electromagnetic (EM) environments, and EM-environment situational awareness. While considerable progress has been made in SWaP (size, weight, and power) and performance metrics in conventional RF technology platforms, fundamental limits obfuscate continued improvements. Alternatively, we propose employing cascaded transduction processes in a chip-scale nano-optomechanical system (NOMS) to achieve a spectral sensor with exceptional signal-linearity, high dynamic range, narrow spectral resolution and ultra-fast sweep times. By leveraging the optimal capabilities of photons and phonons, the system we pursue in this work has performance metrics scalable well beyond the fundamental limitations in all electronic systems.

In our device architecture, information processing is performed on wide-bandwidth RF-modulated optical signals by photon-mediated phononic transduction of the modulation to the acoustical-domain for narrow-band filtering, and then back to the optical-domain by phonon-mediated phase modulation (the reverse process). Here, we rely on photonics to efficiently distribute signals for parallel processing, and on phononics for effective and flexible RF-frequency manipulation. This technology is used to create optical wavelength-insensitive RF-filters with wide center frequency bandwidth selectivity(1-100GHz), ultra-narrow filter bandwidth(1-100MHz), and high dynamic range (70dB), which we will present. Additionally, using this filter as a building block, we will discuss current results and progress toward demonstrating a multichannel-filter with a bandwidth of < 10MHz per channel, while minimizing cumulative optical/acoustic/optical transduced insertion-loss to ideally < 10dB. These proposed metric represent significant improvements over RF-platforms.

10193-14, Session 5

Ultrafast spontaneous emission sources based on plasmonic nanoantennas *(Invited Paper)*

Gleb M. Akselrod, Intellectual Ventures Lab. (United States)

In the context of optical interconnects, a need exists for sources of spontaneous emission (LEDs) that rival or exceed the modulation speeds possible with stimulated emission sources (lasers). In particular, LEDs offer the advantages of being more compact and lower energy due to the lack of threshold. The fundamental limitation to the modulation speed of LEDs is the slow spontaneous emission lifetime of typical semiconductors (~1 ns or more). In this talk I will show how plasmonic nanoantennas can be used to dramatically modify and enhance the radiative properties of luminescent emitters. Semincoductor quantum dots integrated into the small mode volume, high-field region of the antenna experience ~1,000-fold enhancement in the spontaneous emission rate, resulting in emission lifetimes of ~10 ps. If excited using electrical injection, this emission lifetime points towards LED light sources with modulation rates up to 100 GHz, equaling or surpassing the performance of semiconductor lasers.

10193-15, Session 6

Optical control of polaritons: from optoelectronic to spintronic device concepts *(Keynote Presentation)*

Rolf Binder, College of Optical Sciences, The Univ. of Arizona (United States); Samuel M. H. Luk, The Univ. of Arizona (United States); Nai-Hang Kwong, College of Optical Sciences, The Univ. of Arizona (United States); Ombline Lafont, Ctr. National de la Recherche Scientifique, Ecole Normale Supérieure (France); Emmanuel Baudin, Jérôme Tignon, Lab. Pierre Aigrain, Ecole Normale Supérieure (France); Chris K. P. Chan, Pui-tang Leung, The Chinese Univ. of Hong Kong (Hong Kong, China); Przemyslaw Lewandowski, Martin Babilon, Stefan Schumacher, Univ. Paderborn (Germany)

Exciton-polaritons in semiconductor microcavities have been studied intensely, both with respect to their intriguing fundamental physical properties, for example polaritonic Bose condensation, and with respect to their potential in novel device designs. The latter requires ways to control polaritonic systems, and all-optical control mechanisms are considered to be especially useful. In this talk, we discuss and review our efforts to control various physical attributes. One of those attributes is the polariton density, which can be controlled by optical pump and control beams, utilizing optical instabilities that are based on four-wave mixing processes. Using a double-cavity design, which has two lower-polariton branches, we are able to pump the system in normal incidence and control the output direction with a combination of static system parameters and dynamical off-axis control beams. This allows for an efficient directional and low-energy switching of optical beams. A second example is the control of spin transport phenomena that leads to polarization patterns (or textures) in the far-field emission. We discuss the control of the so-called optical spin Hall effect. Utilizing again our double-cavity design, we are able to rotate the spin/polarization texture of the far field simply by changing the intensity of the pump beam. This effect is based on an optical manipulation of the polariton-spin orbit interaction, and may lead to novel applications in spinoptronic systems.

10193-16, Session 6

Chirped soliton: new type of solitons for photonics *(Invited Paper)*

Vyacheslav A. Trofimov, Tatiana M. Lysak, Irina G. Zakharova, M.V. Lomonosov Moscow State Univ. (Russian Federation)

We investigate a novel type of solitons - chirped solitons- in the various problems of photonics which deals with the femtosecond laser pulse propagation in the media with nonlinear non-stationary absorption. This type of solitons is characterized by the complicated pulse chirp and allows self-similar propagation of laser radiation at the distances up to several dispersion lengths. In our analytical considerations, we develop approximate formulas which describe the nonlinear chip and the soliton shape. We confirm our analytical results by the numerical simulation of the considered problems: femtosecond laser pulse propagation in the media with nanorods or in the fused silica with taking into account non-stationary multi-photon absorption , nonlinear refraction, nanorods melting.

10193-17, Session 6

The bulk photovoltaic effect as a platform for ultrafast nanoscale photosensitive devices *(Invited Paper)*

Steve Young, U.S. Naval Research Lab. (United States)

The bulk photovoltaic effect refers to the generation of photocurrents and photovoltages in bulk single-phase materials. It requires only that the material possess broken inversion symmetry, and occurs due a unique mechanism known as “shift current.” Discovered over a half-century ago, it received little attention decades due to extremely poor observed efficiency. However, in recent years, it has been both theoretically and experimentally investigated in a variety of new systems and materials, and significant improvements in performance have been achieved. In this talk, I will provide a brief overview of the physics of the bulk photovoltaic effect and survey the experimental and theoretical advances that have been made in its understanding and optimization. I will cover in detail the unique properties of the bulk photovoltaic effect that distinguish it from conventional photovoltaic effects, including photovoltages substantially exceeding the material’s band gap, response amplitudes and directions that can depend on both photon energy and polarization, and response that occurs on ultrafast timescales. Finally, I will explore the potential for these features to enable novel and improved photosensitive devices, especially in combination with other functional materials.

10193-18, Session 7

Long range robust multi-terawatt mid-IR atmospheric light bullets *(Keynote Presentation)*

Jerome V. Moloney, Miroslav Kolesik, Kolja Schuh, College of Optical Sciences, The Univ. of Arizona (United States); Paris Panagiotopolous, The Univ. of Arizona (United States); Stephan W. Koch, Philipps-Univ. Marburg (Germany)

Currently there is a strong push worldwide to develop multi-Joule femtosecond duration laser pulses at wavelengths around 3.5-4 and 9-11μm, both within important atmospheric transmission windows. We have shown recently that pulses with a 4 μm central wavelength are capable of delivering multi-TW powers at km range. This is in stark contrast to pulses at near-IR wavelengths where such pulses break up into hundreds of filaments with each carrying around 5 GW of power over distances on the order of a meter.

I will discuss how the physics and mathematical description of such extreme intensity pulses is fundamentally different from that at shorter IR wavelengths. In particular, nonlinear envelope propagators fail to capture the true physics and require the introduction of artificial nonlinear saturation terms. A new field singularity now emerges that operates in concert with the well-known critical self-focusing one to fundamentally change the propagation dynamics. The former leads to the early development of a full optical carrier wave shock that disperses energy from the fundamental wave into a broad spectral harmonic spectrum. This new mechanism acts to limit the peak intensity and sustain a wider waist intense light bullet over hundreds of meter distances. The end result is almost lossless transmission over km ranges. Finally, I will discuss how many electron correlations of weakly ionized electrons further modify the long range pulse delivery especially in the 9-11μm range. The latter act to strongly suppress the intrinsic Kerr effect and support wide beam waist self-trapping rather than intense filament formation.

10193-19, Session 7

Nonlinear guiding of picosecond CO_2 laser pulses in atmosphere *(Invited Paper)*

Sergei Tochitsky, Univ. of California, Los Angeles (United States)

During the last 20 years much attention has been given to the study of propagation of short intense laser pulses for which the peak power exceeds the critical power of self-focusing, Pcr. For a laser power P > Pcr, a dynamic equilibrium between the Kerr self-focusing, diffraction and defocusing caused by laser-ionized plasma result in the production of a high intensity laser filament in air within which a variety of nonlinear optical phenomena are observed. However, research in the 0.8-1 μm range so far has shown a fundamental limitation of guided energy to a few mJ transported within an ~100 μm single channel.

A long-wavelength, 0~10 μm CO_2 laser is a promising candidate for nonlinear guiding because expected high Pcr values according to the modeling should allow for the increase of energy (and therefore power) in a self-guided beam from mJ (GW) to few Joules (TW). During the last decade a significant progress has been achieved in amplification of picosecond pulses to terawatt and recently to >10 TW power level at UCLA and ATF BNL. Such powerful 10 μm lasers open possibility for nonlinear propagation studies in an atmospheric window with high transmission. As a natural first step in a our program on picosecond CO_2 laser filamentation, we have made first measurements of Kerr coefficients of air and air constituents around 10 μm. We also undertook direct measurements of n2 of air by analyzing nonlinear self-focusing in air using a ~3 ps, 600 GW pulses of the BNL CO_2 laser.

10193-20, Session 7

Rogue events in nonlinear propagation of laser pulses through atmospheric turbulence *(Invited Paper)*

John P. Palastro, Joseph R. Peñano, Michael H. Helle, U.S. Naval Research Lab. (United States); Gregory DiComo, Research Support Instruments, Inc. (United States) and Univ. of Maryland, College Park (United States); Bahman Hafizi, U.S. Naval Research Lab. (United States)

A laser pulse propagating through a random or nonlinear medium can exhibit rare, extremely intense fluctuations that far exceed the mean, known as optical rogue events. In random, linear media, these events can occur within caustics formed by the refractive index fluctuations. In random, nonlinear Kerr media, on the other hand, rogue events can emerge when individual filaments, formed during an earlier stage of modulational instability, coalesce. In both cases, the intensity statistics undergo a qualitative change as either the size of refractive index fluctuations or laser power is increased respectively: The high intensity tail of the probability distribution function transitions from a rapid fall off to a gradual decay. This makes the rogue events more probable than would otherwise be expected from central limit theorem considerations.

High peak power laser pulse propagation through atmospheric turbulence appears to possess the necessary ingredients for rogue events, i.e. stochasticity and nonlinearity. The intensity statistics for linear propagation through turbulence have traditionally been characterized by log-normal or gamma-gamma distributions in the weak and strong fluctuation regimes respectively. These distributions have slower high intensity falloffs than, say, a Rayleigh distribution, but neither features a long tail characteristic of rogue event statistics. This suggests that: (1) modifications to scintillation statistics due to caustics have not been well characterized, or (2) rogue events in turbulence require nonlinearity. Here we explore the intensity statistics and possibility of rogue events in the linear and nonlinear propagation of laser pulses through atmospheric turbulence.

10193-21, Session 7

Experiments on nonlinear channeling of ultrashort laser pulses through atmospheric turbulence *(Invited Paper)*

Michael H. Helle, U.S. Naval Research Lab. (United States); Gregory DiComo, Univ. of Maryland (United States) and Research Support Instruments, Inc. (United States); Joseph R. Penano, John P. Palastro, U.S. Naval Research Lab. (United States); Andreas Schmitt-Sody, Jennifer Elle, Air Force Research Lab. (United States)

Numerous existing and potential applications of intense ultrashort pulses require propagation through atmosphere. While nonlinear self-focusing and filamentation ideally allow spot sizes smaller than the diffraction limit to be formed, turbulence-induced phase front distortions can severely modify the propagation physics and limit the spot size achievable at range. Recent simulation efforts by our group indicate that by maintaining a laser spot size smaller than the inner scale of turbulence, these higher-order phase front distortions can be avoided.

We will present recent and ongoing investigations of the propagation of ultrashort laser pulses in atmospheric turbulence. Continuously tunable, indoor turbulence ranges have been constructed. These ranges were designed and built for the purpose of studying nonlinear propagation of high peak power laser pulses in distributed atmospheric turbulence. Experimentally we are able to reliably generate conditions of distributed Kolmogorov turbulence with characteristic Cn2 values ranging from 10-16-10-12m-2/3 similar to that found in maritime or terrestrial environments. At NRL, we have successfully demonstrated nonlinear guiding over 6 Rayleigh lengths in turbulence using the kTFL laser system (20mJ, 1 kHz Ti:Sapphire). Longer range experiments using a newly acquired transportable USPL system, are currently underway and will also be discussed.

10193-22, Session 7

Air lasing through femtosecond filamentation *(Invited Paper)*

Pavel Polynkin, The Univ. of Arizona (United States)

Air lasing is a concept that is based on the utilization of the constituents of air as a gain medium in a standoff, impulsive, laser-like optical source. While both forward-propagating and backward-propagating laser emissions could be generated, the backward-propagating emission is of the most practical significance for its potential to enable single-ended remote sensing schemes. I will review recent results on air lasing from singly ionized nitrogen molecular ions N2+, pumped through femtosecond laser filamentation in air. So far, lasing has been demonstrated only in the forward direction, and the mechanisms that enable population inversion have been highly controversial.

10193-23, Session 8

Interaction of ultrashort laser pulses with epsilon-near-zero materials *(Keynote Presentation)*

Robert W. Boyd, Univ. of Ottawa (Canada)

Abstract: The nonlinear optical response of a material is conventionally assumed to be very much smaller than its linear response. Here we report that the nonlinear contribution to the refractive index of a sample of indium-tin oxide can be much larger than the linear contribution when the optical wavelength is close to the material's bulk plasma wavelength, where the material exhibits epsilon-near-zero behavior. In particular, we demonstrate that a change in refractive index as large as 0.7 can be obtained in an ultra-thin indium-tin oxide film using an optical intensity of 140 GW/cm2.

Nonlinear optical phenomena result from the light-induced modification of the optical properties of a material lead to a broad range of applications, including microscopy, all-optical data processing, and quantum information. However, nonlinear (NL) e?ects are typically extremely weak. The size of nonlinear e?ects is typically limited by the largest intensity that can be used without permanently damaging of the material. Consequently, the resulting change in refractive index is typically of the order of 0.001 or smaller.

A long-standing goal of nonlinear optics (NLO) has been the development of materials that can display a light-induced change in the refractive index of the order of unity. Such materials would lead to exciting new applications of NLO. Indeed, much e?ort in the fields of plasmonics and metamaterials is devoted to the development of such materials. Furthermore, it has been suggested that materials with vanishing permittivity, commonly known as epsilon-nearzero (ENZ) materials, can be used to induce highly nonlinear phenomena and unusual phase-matching behavior. In this work, we describe our studies of indium-tin oxide (ITO) at its ENZ wavelength, and we demonstrate a refractive index change of 0.7.

Materials possessing free charges, such as metals and doped semiconductors, exhibit a vanishing permittivity at the bulk plasmon wavelength. The zero-permittivity wavelength in doped semiconductors typically lies at infrared wavelengths and can be fine tuned by controlling the level of doping. Here we study the case of an ultra-thin layer of ITO exhibiting ENZ behavior at wavelengths around 1.24 μm. We show that in this spectral region the nonlinear response (intensity-dependent change in refractive index, ?n) is enhanced approximately 2000-fold with respect to that observed at shorter wavelengths and that a ?n of the order of unity can be observed.

10193-24, Session 8

Ultrafast bandgap photonics with few cycle pulses *(Invited Paper)*

Enam A. Chowdhury, Noah Talisa, Kevin Werner, Drake R. Austin, The Ohio State Univ. (United States); Vitaly E. Gruzdev, Univ. of Missouri (United States); Kyle R. P. Kafka, The Ohio State Univ. (United States)

The interaction with laser pulses that are only a few optical cycles in duration are of great interest in the field of ultra-fast band gap photonics in general and laser induced damage (LID) in particular, since the laser excitation of electrons can no longer be modelled using pulses with slowly varying amplitudes, and simple Keldysh model of transition from unperturbed valence to conduction band in strong fields at a single frequency breaks down. Although the first few cycle pulse (FCP) laser induced damage threshold (LIDT) experiment was performed nearly two decades ago[1], significant gaps in fundamental understanding of laser-solid interaction in this regime remain[2][3][4]. A common technique for indirectly probing the interaction experimentally is to measure the laser fluence for which damage begins to occur, the LIDT fluence. A complementary technique to more directly probe the interaction is a pump-probe reflectivity measurement, which provides information about that state of the target solid during the interaction. In this work, a preliminary characterization of the light-solid interaction with FCP's (Ephoton ~ 1.65 eV) and semiconductors to dielectrics (E¬gap ~ 1 -13.6 eV) at LIDT using these two techniques is presented and compared to similar measurements made with longer many-cycle pulses. Few cycle pump probe reflectivity in Si and GaAs show sub-femtosecond modification of dielectric functions, which can play a crucial role in future super-fast optical devices with peta-Hz frequency response. A theoretical model incorporating the multi-spectral nature of ionization, and band structure dynamics will also be presented, along with benchmarking experimental results from pump probe and LIDT studies. LIDT physics in this regime is very important also for future ultra-intense laser system development like multi-PW few cycle systems at ELI-ALPS, or the Petawatt Field Synthesizer.

Acknowledgements: This work was supported by the Air Force Office of Scientific Research.

References:

1. M. Lenzner et al., Physical Review Letters 80, 4076-4079 (1998).

2. M. Lenzner, J. Krüger, W. Kautek, F. Krausz, Applied Physics A: Materials Science and Processing 69, 465-466 (1999).

3. B. C. Stuart, M. D. Feit, A. M. Rubenchik, B. W. Shore, M. D. Perry, Physical Review Letters 74, 2248-2251 (1995).

4. B. Chimier et al., Physical Review B - Condensed Matter and Materials Physics 84 (2011).

5. L. V. Keldysh, JETP 20, 1307-1314 (1965).

10193-25, Session 9

Far above bandgap photonics: attosecond dynamics of highly excited electrons in materials *(Keynote Presentation)*

Cong Chen, Zhensheng Tao, Margaret M. Murnane, Henry C. Kapteyn, JILA, Univ. of Colorado Boulder (United States)

abletop-scale coherent EUV generated through high-harmonic generation (HHG) produces light in the form of an attosecond pulse train that uniquely combines characteristics of good energy resolution (≈100-300meV) with sub-fs time resolution. This makes HHG an ideal source for studying the fastest dynamics in materials. Furthermore, using angle-resolved photoemission spectroscopy (ARPES), it is possible to extract detailed information about electron dynamics over the entire Brillouin zone. In recently published work, we combined HHG with ARPES to identify a sub-femtosecond excited-state lifetime for the first time. Photoemission occurs as a three-step process: 1) An electron is photoexcited from the valence band to far above the Fermi energy; 2) it transports to the surface, and 3) it overcomes the work function and exits. If the electron is promoted into a highly-excited unoccupied band in the material (as opposed to an unbound state), we observe the electron emission lifetime to increase in a measurable way—the Ni band 22 eV above the Fermi level has a lifetime of 212±30 attoseconds that we can directly measure through laser-assisted photoemission. Moreover, a strong dependence of lifetime on emission angle is directly related to the final-state band dispersion as a function of electron transverse momentum. This work for the first time demonstrates the relevance of attosecond spectroscopy to the study of intrinsic properties and band structure in materials, as opposed to the strong-field induced dynamics studied extensively to-date.

10193-26, Session 9

Generation and application of bright coherent extreme ultraviolet radiation *(Keynote Presentation)*

Lap Van Dao, Khuong Ba Dinh, Khoa Anh Tran, Peter Hannaford, Swinburne Univ. of Technology (Australia)

Coherent extreme ultraviolet radiation can be produced by high-order harmonic generation of energetic femtosecond laser pulses in noble gases. These sources are small-scale and highly versatile in comparison to synchrotrons and free electron x-ray lasers, and their characteristic output can be tailored according to the experimental requirements. High-harmonic generation in a semi-infinitive gas cell has been considered to obtain high efficiency, high spatial coherence and a good beam profile. High efficiency (up to 10-5) can be obtained by using a 800 nm driving pulse in the wavelength range 30 nm – 9 nm from argon, neon or helium gas. When a 1400 nm driving pulse is used, HHG radiation above the carbon K-edge (4.4 nm) can be obtained from helium gas. We show that a second driving beam can be used to enhance the phase matching and also to create wave mixing and parametric amplification [1]. The combination of two driving fields with controllable intensity ratio opens a new way for the generation of additional frequency components which is a step towards obtaining attosecond pulses with high intensity in the soft x-ray region. Because the HHG spectrum depends on the structure of the atom or molecule a new method for studying coherent processes in atoms and molecules has been proposed and developed [2]. In addition, the use of a table-top HHG source for coherent diffractive imaging is very promising for spatial resolution of sub-10 nm [3].

References:

1. L. V. Dao, Kh. B. Dinh, P. Hannaford, "Perturbative optical parametric amplification in the extreme ultraviolet", Nature Communications 6, 7175 (2015).

2. L. V. Dao, K. B. Dinh, and P. Hannaford, High order harmonic generation for study of atomic and molecular dynamics, Applied Physics Letters 103, 141115 (2013).

3. H. V. Le, K. B. Dinh, P. Hannaford, L. V. Dao, High resolution coherent diffractive imaging with a table-top extreme ultraviolet source, Journal of Applied Physics 116 , 173104 (2014).

10193-27, Session 10

Fiber sources of femtosecond pulses in the mid-infrared *(Keynote Presentation)*

Frank W. Wise, Cornell Univ. (United States)

There is currently broad interest in sources of ultrashort pulses at mid-infrared (3-5 micron) and even long-wave infrared wavelengths. Fiber-based sources of ultrashort pulses potentially offer some performance advantages along with major practical advantages, but also face major challenges. The development of optical fibers that transmit in the mid- and long-wave-infrared enables the design of short-pulse sources at these wavelengths. This talk will focus on sources of coherent femtosecond pulses. The first fiber lasers that directly emit ultrashort pulses around 3 micron wavelength will be reviewed, along with an approach to tunable femtosecond pulses in the 3-6 micron region based on Raman frequency shifting. Thoughts on how to extend the performance to higher energies, broader wavelength coverage, and greater integration will be offered.

10193-28, Session 10

Progress in Cr2+:ZnS/Se mid-IR CW and femtosecond lasers *(Invited Paper)*

Sergey B. Mirov, The Univ. of Alabama at Birmingham (United States) and IPG Photonics - Mid-Infrared Lasers (United States); Sergey Vasilyev, Igor S. Moskalev, Mikhail S. Mirov, Viktor O. Smolski, IPG Photonics - Mid-Infrared Lasers (United States)

We report a breakthrough in high-power CW Cr:ZnS/Se laser systems enabling output power levels of up to 140 W near 2500 nm, and 32 W at 2940 nm with corresponding optical efficiencies of 62% and 29%.

This talk also summarizes recent improvements of output characteristics of polycrystalline Cr:ZnS/Se master oscillators in Kerr-Lens-Mode-Locked regime. At 79 (1000) MHz repetition rate the output characteristics were as follows 1.9 (1.2) W average power at <26 (68) fs pulse duration, 24 (1.2) nJ pulse energy and 1000 (16) kW peak power with efficiency of 20% with regards to 1567 nm pump power from linearly polarized Er-fiber laser.

High nonlinearity of II-IV semiconductors and random quasi-phase-matching in polycrystalline material in combination with MW-level optical power in the gain element of fs laser, offer a number of unique possibilities. The effects of efficient up-conversion of mid-IR fs pulses in the laser medium as well as supercontinuum generation are observed in current experiments. A simple design of mid-IR fs Cr:ZnS power amplifier enabled power scaling to 6.8 W at 79 MHz repetition rate. This was accompanied by a 2 fold spectral broadening to 600 nm at -10 dB level, pulse compression from 44 to 33 fs, and overall 25 % optical to optical efficiency. A single-pass energy amplifier with Er:YAG 1645 nm ns pulsed pumping resulted in energy of amplified pulses of ~10 μJ (single-pass gain of ~500) accompanied by mid-IR supercontinuum generation in the gain element of energy amplifier covering 1900-4500 nm spectral range.

Current research efforts include power scaling of fs Cr:ZnS/Se lasers beyond the 7 W level, development of octave-spanning oscillators, further power and energy scaling of fs Cr:ZnS/Se laser amplifiers, and extension of ultrafast laser oscillations to 3 – 10 μm spectral range.

10193-29, Session 11

Ultrafast microscopy for resolving the efficiency-limiting photocurrent generation dynamics in van der Waals materials (Rising Researcher Presentation) *(Keynote Presentation)*

Matthew W. Graham, Oregon State Univ. (United States)

Presently, there exists no reliable in-situ time-resolved method that selectively isolates both the recombination and escape times relevant to photocurrent generation in the ultrafast regime. Transport based measurements lack the required time resolution, while purely optical measurement give a convoluted weighted-average of all electronic dynamics, offering no selectivity for photocurrent generating pathways. Recently, the ultrafast photocurrent (U-PC) autocorrelation method has successfully measured the rate limiting electronic relaxation processes in materials such as graphene, carbon nanotubes, and transition metal dichalcogenide (TMD) materials. Here, we unambiguously derive and experimentally confirm a generic U-PC response function by simultaneously resolving the transient absorption (TA) and U-PC response for highly-efficient (48% IQE at 0 bias) WSe2 devices and twisted bilayer graphene. Surprisingly, both optical TA and electrical U-PC responses give the same E-field-dependent electronic escape and recombination rates. These rates further accurately quantify a material's intrinsic PC generation efficiency. We demonstrate that the chirality of the incident light impacts the U-PC kinetics, suggesting such measurements directly access the ultrafast dynamics need to complex electronic physics such as the valley-Hall effect. By combining E-field dependent ultrafast photocurrent with transient absorption microscopy, we have selectively imaged the dominant kinetic bottlenecks that inhibit photocurrent production in devices made from stacked few-layer TMD materials. This provides a new methodology to intelligently select materials that intrinsically avoid recombination bottlenecks and maximize photocurrent yield.

10193-30, Session 11

Transient absorption imaging of carrier dynamics in disordered semiconductors *(Invited Paper)*

Erik Grumstrup, Andy Hill, Casey Kennedy, Montana State Univ. (United States)

While low cost and accessible chemical tunability make solution-processed semiconductors an appealing choice for a variety of electronic and optoelectronic devices, chemical and morphological defects intrinsic to the processing conditions can diminish device performance. To unravel the impact of defects, we employ transient absorption microscopy, which couples ultrafast temporal resolution with ~200 nm spatial resolution, to locally interrogate ultrafast cooling, transport, and recombination dynamics of charge carriers in single lead-halide perovskite domains. Ultrafast imaging of charge carrier diffusion shows significant domain-to-domain variation in carrier mobility within a single thin film. Direct correlation of these spectroscopic measurements to scanning electron microscopies reveals a strong dependence on domain size and quality. We further find that carrier density has little impact on the effective mobility. Finally, we discuss the impact of surface states on both mobility and recombination and discuss implications for photovoltaics and other optoelectronic devices.

10193-31, Session 11

Harnessing optical loss for unique microlaser functionality *(Invited Paper)*

Liang Feng, Univ. at Buffalo (United States)

Lasers, as the key driving force in the field of optics and photonics over other photonic components, are now being significantly benefited from the studies of nanophotonics and metamaterials, broadening laser physics and device applications. The properties of light are much more beyond its simple intensity and temporal characteristics. The fruitful nature of light provides a great variety of freedoms in manipulating light for modern photonic applications, including spin (polarization), chirality, angular momentum, and spin-orbit coupling. Unfortunately, all these fundamental properties and functionalities of light have not been fully exploited in micro/nano-laser systems because the conventional principles of laser design in bulk optics cannot be easily scaled down to the micro/nano scale. The capability of creating microlasers with controlled spin/orbital information and chirality in their radiations is expected to revolutionize next generation of photonic systems for computing and communication.

In this talk, I will focus on our recent effort in harnessing optical losses for unique microlaser functionalities, in particular, an orbital angular momentum (OAM) microlaser that structure and twist the lasing radiation at the microscale. The effective generation of OAM lasing, especially at a micro/nano-scale, could address the growing demand for information capacity. By exploiting the emerging non-Hermitian photonics design at an exceptional point, we demonstrate a microring laser producing a single-mode OAM vortex lasing with the ability to precisely define the topological charge of the OAM mode and its polarization state. Our OAM microlaser could find applications in the next generation of integrated optoelectronic devices for optical communications.

10193-32, Session 11

Studying time of flight imaging through scattering media across multiple size scales *(Invited Paper)*

Andreas Velten, Univ. of Wisconsin-Madison (United States)

Light scattering is a primary obstacle to optical imaging in a variety of different environments and across many size and time scales. Scattering complicates imaging on large scales when imaging through the atmosphere when imaging from airborne or space borne platforms, through marine fog, or through fog and dust in vehicle navigation, for example in self driving cars. On smaller scales, scattering is the major obstacle when imaging through human tissue in biomedical applications. Despite the large variety of participating materials and size scales, light transport in all these environments is usually described with very similar scattering models that are defined by the same small set of parameters, including scattering and absorption length and phase function.

We attempt a study of scattering and methods of imaging through scattering across different scales and media, particularly with respect to the use of time of flight information. We can show that using time of flight, in addition to spatial information, provides distinct advantages in scattering environments. By performing a comparative study of scattering across scales and media, we are able to suggest scale models for scattering environments to aid lab research. We also can transfer knowledge and methodology between different fields.

10193-33, Session 12

Spin-photon interfaces and measurement-based quantum information processing *(Invited Paper)*

Sophia Economou, Virginia Polytechnic Institute and State Univ. (United States)

Non-classical states of light, such as single-photon states and entangled states, are essential for novel quantum technologies, including quantum communications and key distribution, photonic quantum computing and quantum internet. Photons carry information between nodes in a network, and can be used for long-distance entanglement swapping via intermediate nodes known as quantum repeaters. Various properties of photons can be used to encode and transmit quantum information: polarization, frequency, photon number and continuous variables to name a few. Some of the most important open problems toward achieving quantum technologies based on photonic degrees of freedom include the generation of photonic entanglement, the creation of spin-photon entanglement, and the routing of photons on chips. In this talk I will introduce basic ideas on measurement-based quantum information processing and present our results on spin-photon interfaces and the deterministic generation of all-photonic quantum repeaters.

10193-34, Session 12

Photonic quantum computing

(Keynote Presentation)

Jeremy L. O'Brien, Univ. of Bristol (United Kingdom)

Of the various approaches to quantum computing, photons are appealing for their low-noise properties and ease of manipulation at the single photon level; while the challenge of entangling interactions between photons can be met via measurement induced non-linearities. However, the real excitement with this architecture is the promise of ultimate manufacturability: All of the components---inc. sources, detectors, filters, switches, delay lines---have been implemented on chip, and increasingly sophisticated integration of these components is being achieved. We will discuss the opportunities and challenges of a fully integrated photonic quantum computer.

10193-35, Session 12

Quantum nanophotonics *(Invited Paper)*

Jelena Vuckovic, Jelena Vuckovic, Stanford Univ. (United States)

Nanophotonic structures that localize photons in sub-wavelength volumes are possible today thanks to modern nanofabrication and optical design techniques. Such structures enable studies of new regimes of light-matter interaction, quantum and nonlinear optics, and new applications in computing, communications, and sensing. The traditional quantum nanophotonics platform is based on InAs quantum dots inside GaAs photonic crystal cavities. Recently, alternative material systems have emerged, such as color centers in diamond and silicon carbide, that could potentially bring the described experiments to room temperature and facilitate scaling to large networks of resonators and emitters. Finally, the use of inverse design nanophotonic methods, that can efficiently perform physics-guided search through the full parameter space, leads to optical devices with properties superior to state of the art, including smaller footprints, better field localization, and novel functionalities.

10193-36, Session 12

Large-scale frequency- and time-domain quantum entanglement over the optical frequency comb *(Invited Paper)*

Olivier Pfister, Univ. of Virginia (United States)

When it comes to practical quantum computing, the two main challenges are circumventing decoherence (devastating quantum errors due to interactions with the environmental bath) and achieving scalability (as many qubits as needed for a real-life, game-changing computation). We show that using, in lieu of qubits, the "qumodes" represented by the resonant fields of the quantum optical frequency comb of an optical parametric oscillator allows one to create bona fide, large scale quantum computing processors, pre-entangled in a cluster state. We detail our recent demonstration of 60-qumode entanglement (out of an estimated 3000) and present an extension to combining this frequency-tagged with time-tagged entanglement, in order to generate an arbitrarily large, universal quantum computing processor.

10193-37, Session 12

Deterministic generation of entangled photonic cluster state from interacting solid state emitters *(Invited Paper)*

Mercedes Gimeno-Segovia, Univ. of Bristol (United Kingdom); Sophia Economou, Virginia Polytechnic Institute and State Univ. (United States); Terry Rudolph, Imperial College London (United Kingdom)

Photons are excellent carriers of quantum information; their polarization remains coherent for long times and it is easy to measure and precisely rotate. The fundamental hurdle with photon-based quantum information processing is the lack of direct photon-photon interactions to provide entanglement between pairs of photons. Recent proposals show the ability to build large cluster states from small entangled states using non-deterministic operations, but the generation of deterministic high-fidelity small entangled states remains a challenge. In this talk, we will show how the necessary cluster-state building blocks for large-scale quantum computation can be created from coupled solid-state quantum emitters without the need for any two-qubit gates and regardless of whether the emitters are identical. We provide a recipe for the generation of two-dimensional, 'cluster-state' entangled photons that can be carried out with existing experimental capabilities.

10193-38, Session 12

Quantum imaging and spatial entanglement characterization with an EMCCD camera *(Invited Paper)*

Matthew C. Reichert, Hugo Defienne, Xiaohang Sun, Jason W. Fleischer, Princeton Univ. (United States)

Entangled photon pairs (biphotons) exhibit entanglement in spatial degrees of freedom. Experiments on spatial entanglement have measured coincidence counts between single point detectors which are each scanned to build up an image. We utilize a single-photon sensitive electron multiplying CCD (EMCCD) camera as a massively parallel coincidence counting apparatus, allowing rapid measurements of spatial entanglement in a fraction of the time required with traditional point-scanning techniques.

We have developed a model to characterize the evolution of spatial entanglement upon propagation; the migration between amplitude and phase. We verify this model using spatial measurements from the near-field to the far-field, showing agreement with the predicted dynamics.

The 512 ? 512 pixel EMCCD camera allows measurements of up to 69 billion dimensional Hilbert space, within which we measure of the 4D biphoton probability distribution, demonstrating simultaneous quantum imaging and entanglement characterization. Rapid and high dimensional measurements may allow for quantum phase retrieval from near- and far-field measurements.

Loss from non-unitary objects results in a change of the quantum state from two entangled photons, to some portion with only a single transmitted photon. We image one- and two-photon parts of the transmitted state and demonstrate that the one-photon intensity contains information on both the non-unitary object and the degree of entanglement.

The massively parallel coincidence capability of the EMCCD makes it perfectly suitable to measure high-dimensional quantum interference. We investigate quantum interference generated between indistinguishable photon pairs propagating through a multimode fiber, which acts as a scattering medium via spatial mode coupling.

10193-44, Session 12

Measuring quantum properties of bright beams of light *(Invited Paper)*

Paulo A. Nussenzveig, Univ. de São Paulo (Brazil)

Quantum properties of light have enabled profound insights on fundamentals of quantum mechanics.Although much focus is devoted to observing single orfew photon effects, there are many interesting quantum effects that can be witnessed with bright beams of light. Quantum entanglement is one such effect which can be used to enable quantum communications.

In our lab, we have investigated the generation of continuous-variable entanglement and perfected methods for its detection. By detecting fluctuations using resonators, instead of usual homodyne measurements, we have increased our ability to extract information from bright beams. In this talk, I will review these methods and present a characterization of hexapartite (six-mode) entanglement from three beams of light.

10193-39, Session 13

Multi-frequency entanglement router system

Reinhard K. Erdmann, Advanced Automation Corp. (United States); David H. Hughes, Air Force Research Lab. (United States)

A free-space Wavelength Division Multiplexed transceiver system is analyzed as to its viability for routing entangled photons in conjunction with the high rate classical optical signals for which it was designed. Quantum state calculations demonstrate that entanglement present in a two-photon collinear input state is retained throughout transit of the Lyot filter based optical system without intrinsic loss. Introducing spatial degrees of freedom with a beam splitter allows entanglement to be manifested at remote locations, as required for varied applications and non-local Bell state measurements. It was found that by interchanging components, the two-photon exit state could be altered from being (discrete) frequency entangled to polarization entangled, with respect to the Hilbert subspace exit paths. Furthermore, an entangled state could be routed to either exit path by selection of the discreet frequencies appropriately matched, or mismatched, with respect to spectral peaks and nulls of the Lyot filters in the system. When frequencies taken from the ITU (International Telecom Union) grid, are generated by a tunable source of entangled photons, a versatile Laser communication system can be used to process classical signals and entangled photons. All quantum state entanglements are maximal and thus suited suitable for applications in Quantum Information Processing or investigation of entanglements in several degrees of freedom.

10193-40, Session 13

Maximal Bell inequality violations by macroscopically occupied quantum states

Ashley Prater, Air Force Research Lab. (United States); Christopher C. Gerry, Richard Birrittella, Lehman College (United States)

Violations of the Bell-CHSH inequality by systems prepared in entangled states serve to test quantum mechanics against realistic local hidden variable theories. Violations of the inequality may occur only for limited ranges of the local detection parameters. For macroscopically occupied quantum states, the allowed range of each of the local detection parameters is the entire complex plane. It is of interest to know which particular sets of parameters yield maximal violations in order to examine the degree to which macroscopically occupied states display non-local correlations. It is one thing for microscopically occupied states to violate a Bell inequality and quite another for macroscopically occupied states to do so. However, no reliable, tractable method for determining all such parameters currently exists. A common approach to approximate the value of the Bell-CHSH function in practice is set all but one or two of the parameters to convenient values, then optimize with respect to the remaining free variables. This approach may yield violations, but they may be far from the optimal one. More precise and robust methods are challenging to implement due to the high-dimensional and highly oscillatory nature of the terms forming the Bell-CHSH inequality. In this paper, we propose a tractable, hierarchical approximation scheme to find parameters yielding optimal violations of the Bell-CHSH inequality, and offer mathematical proofs of its accuracy. We demonstrate the results of this scheme on Schrödinger Cat and compass states and discuss its generalization for use with other common quantum states.

10193-41, Session 13

Continuum limit of topological quantum walks

Daniel Castillo, George Siopsis, The Univ. of Tennessee Knoxville (United States); Radhakrishnan Balu, U.S. Army Research Lab. (United States)

Topological phases of matter have been studied extensively, and classified for non-interacting systems in the presence of particle-hole, time reversal, or chiral symmetry. A promising direction in research on physical realization of topological phenomena is through the use of artificial systems such as networks of cold atoms, photons, quantum dots, etc. A unique, versatile, and controllable platform is provided by quantum walks, which have been realized on different physical arenas (photonic, etc.). The study of topological phenomena using quantum walks is an active field of research. Both discrete-time quantum walks (DTCWs) and continuous-time quantum (CTQWs) walks have been extensively studied. Topological invariants of DTQWs have been discovered and shown to produce topologically protected states. This is of much interest since such states are the basis of topological insulators and topological quantum computing. We show the existence of a continuous time limit of topological DTQWs that preserves their topological phases. We consider both simple-step and split-step topological DTQWs, and derive analytically equations of motion governing their behavior. We obtain simple analytical solutions showing the existence of bound states at the boundary of two phases, and solve the equations of motion numerically in the bulk.

10193-42, Session 13

Time-continuous open quantum walks

Radhakrishnan Balu, U.S. Army Research Lab. (United States); Chaobin Liu, Bowie State Univ. (United States)

Continuous-time open quantum walks (CTOQW) are introduced as the formulation of quantum dynamical semigroups of trace-preserving and completely positive linear maps (or quantum Markov semigroups) on graphs. We show that a CTOQW always converges to a steady state regardless of the initial state when a graph is connected. When the graph is both connected and regular, it is shown that the steady state is the maximally mixed state. The difference of long-time behaviors between CTOQW and other two continuous-time processes on graphs is exemplified. The examples demonstrate that the structure of a graph can affect a quantum coherence effect on CTOQW through a long time run. Precisely, a quantum coherence effect persists throughout the evolution of the CTOQW when the underlying topology is certain irregular graphs (such as a path or a star as shown in the examples). In contrast, a quantum coherence effect will eventually vanish from the open quantum system when the underlying topology is a regular graph (such as a cycle).

10193-43, Session 13

Superdense coding facilitated by hyper-entanglement and quantum networks

James F. Smith III, U.S. Naval Research Lab. (United States)

A method of generating superdense coding based on quantum hyper-entanglement and facilitated by quantum networks is discussed. Superdense coding refers to the coding of more than one classical bit into each qubit. Quantum hyper-entanglement refers to quantum entanglement in more than one degree of freedom, e.g. polarization, energy-time, and orbital angular momentum (OAM). The new superdense coding scheme permits 2L bits to be encoded into each qubit where L is the number of degrees of freedom used for quantum hyper-entanglement. The superdense coding procedure is based on a generalization of the Bell state for L degrees of freedom. Theory describing the structure, generation/transmission, and detection of the generalized Bell state is developed. Circuit models are provided describing the generation/transmission process and detection process. Detection processes are represented mathematically as projection operators. A mathematical proof that that the detection scheme permits the generalized Bell states to be distinguished with 100% probability is provided. Measures of effectives (MOE) are derived for the superdense coding scheme based on open systems theory represented in terms of density operators. Noise and loss related to generation/transmission, detection and propagation are included. The MOE include various probabilities, quantum Chernoff bound, a measure of the number of message photons that must be transmitted to successfully send and receive a message, SNR and the quantum Cramer Rao' lower bound. A method of coding even more than 2L bits into each qubit is discussed. Quantum networks with quantum memory are used to increase the efficiency of the superdense coding scheme.

Conference 10194: Micro- and Nanotechnology Sensors, Systems, and Applications IX

Sunday - Thursday 9 –13 April 2017

Part of Proceedings of SPIE Vol. 10194 Micro- and Nanotechnology Sensors, Systems, and Applications IX

10194-1, Session 1

Uncertainty qualifications (UQ) techniques to improve predictions of laser beam control performance *(Keynote Presentation)*

Richard A. Carreras, Air Force Research Lab. (United States)

Uncertainty quantification (UQ) is the study of the effects of uncertainty on the values of analytical results and the predictions of scientific models. Sources of uncertainty include imprecise knowledge of the exact values of parameters, lack of confidence in the physical models, use of imperfectly calibrated models, and irreducible uncertainties due to physical characteristics.

The particular application of interest to the Air Force Research Laboratory (AFRL) is the analytical prediction of the performance of laser beam control systems under various scenarios, conditions, and missions. The application of rigorous UQ techniques to the models used to predict beam control performance could greatly improve our confidence in these predictions and also improve the acceptance of advanced laser beam control systems within the science and engineering communities. The proposed work would follow a multi-step approach, analyzing the more easily quantified sources of uncertainty, and then including increasingly complicated physical phenomena as the work progresses. Thus, will present the initial results, and the first steps in the incorporation of UQ into our Laser Beam Control Modeling and Simulation environments.

10194-2, Session 1

Compensation in the presence of deep turbulence using tiled-aperture architectures *(Invited Paper)*

Mark F. Spencer, Air Force Research Lab. (United States); Terry J. Brennan, Prime Plexis LLC (United States)

The presence of distributed-volume or "deep" turbulence presents unique challenges for beam-control applications which look to sense and correct for disturbances found along the propagation path. This paper explores the potential for branch-point-tolerant reconstruction algorithms and tiled-aperture architectures to sense and correct for the branch cuts contained in the phase function due to deep-turbulence conditions. Using wave-optics simulations, the analysis aims to parameterize the fitting-error performance of tiled-aperture architectures operating in a null-seeking control loop with piston, tip, and tilt compensation of the individual optical beamlet trains. To evaluate fitting-error performance, the analysis plots normalized power in the bucket as a function of the Fried coherence diameter, the log-amplitude variance, and the number of subapertures for comparison purposes. Initial results show that tiled-aperture architectures with a large number of subapertures outperform filled-aperture architectures with continuous-face-sheet deformable mirrors.

10194-3, Session 1

Fourth generation optics and electro-optics *(Invited Paper)*

Nelson V. Tabiryan, BEAM Engineering For Advanced Measurements Co. (United States); Diane M. Steeves, Brian R. Kimball, U.S. Army Natick Soldier Research, Development and Engineering Ctr. (United States); Timothy J. Bunning, Air Force Research Lab. (United States)

The fourth generation of optics allows combining the broadband nature of conventional lenses, prisms, and other optical components made by shaping an optically transparent material such as glass with the high efficiency of Bragg gratings and the thinness of waveplates. The technology allows obtaining near 100% broadband diffraction efficiency in micrometer thin films. We will review the state-of-the-art of 4G optical components and electro-optical systems for all-electronic large angle beam steering, tunable focusing, and beam shaping systems for visible and infrared wavelengths. Combinations of different functions are obtained by combining layers of different optical properties, switchable and fixed.

4G components are produced as anisotropic thin films – coatings with a twist of optical axis orientation in the plane of the coating. A light beam with patterned polarization is all that is needed for imparting one or another optical function on those coatings. Fabrication times of even large area components are reduced to minutes using PAAD series photoanisotropic materials. We will discuss opportunities of reducing weight and thickness of complex electro-optical systems for numerous applications ranging from vision and augmented/virtual reality systems to optical communications, laser beam control systems, solar concentrators and large telescopes. The components have been tested to withstand high energy laser beams and wide temperature variations.

10194-4, Session 1

Horizontal atmospheric turbulence, beam propagation, and modeling *(Invited Paper)*

Christopher C. Wilcox, U.S. Naval Research Lab. (United States); Edwin S. Ahn, Air Force Research Lab. (United States); Ty Martinez, Sergio R. Restaino, U.S. Naval Research Lab. (United States)

The turbulent effect from the Earth's atmosphere degrades the performance of an optical imaging system. Many studies have been conducted in the study of beam propagation in a turbulent medium. Horizontal beam propagation and correction presents many challenges when compared to vertical due to the far harsher turbulent conditions and increased complexity it induces. We investigate the collection of beam propagation data, analysis, and use for building a mathematical model of the horizontal turbulent path and the plans for an adaptive optical system to use this information to correct for horizontal path atmospheric turbulence.

10194-5, Session 2

Digital fabrication of textile: an analysis of electrical networks in 3D knitted functional fabric *(Invited Paper)*

Richard Vallet, Chelsea Knittel, Daniel Christie, David E. Breen, Antonios Kontsos, Youngmoo Kim, Genevieve Dion, Drexel Univ. (United States)

Digital fabrication methods are reshaping the design and manufacturing processes through the adoption of pre-production visualization and analysis tools. These can help reduce sampling, minimize waste of materials and save time. Despite the increasingly widespread use of digital fabrication techniques, comparatively few of these advances have benefited the design and fabrication of smart textiles. The development of functional fabrics such as knitted touch sensors, antennas, capacitors, and other electronic textiles could benefit from the same advances in electrical network modeling that revolutionized the design of integrated circuits. In this paper, we demonstrate the efficacy of using current state-of-the-art digital fabrication tools over the more common trial-and-error methods currently used in textile design. We then identify gaps in the current state-of-the-art tools that must be resolved to further develop and streamline the rapidly growing field of smart textiles and devices, bringing textile production into the realm of 21st century manufacturing.

10194-6, Session 2

Multi-material optoelectronic fiber devices *(Invited Paper)*

Fabien Sorin, Wei Yan, Marco Volpi, Alexis G. Page, Tung Nguyen Dang, Yunpeng Qu, Ecole Polytechnique Fédérale de Lausanne (Switzerland)

The recent ability to integrate materials with different optical and optoelectronic properties in prescribed architectures within flexible fibers is enabling novel opportunities for advanced optical probes, functional surfaces and smart textiles. In particular, the thermal drawing process has known a series of breakthroughs in recent years that have expanded the range of materials and architectures that can be engineered within uniform fibers. Of particular interest in this presentation will be optoelectronic fibers that integrate semiconductors electrically addressed by conducting materials. These long, thin and flexible fibers can intercept optical radiation, localize and inform on a beam direction, detect its wavelength and even harness its energy. They hence constitute ideal candidates for applications such as remote and distributed sensing, large-area optical-detection arrays, energy harvesting and storage, innovative health care solutions, and functional fabrics. To improve performance and device complexity, tremendous progresses have been made in terms of the integrated semiconductor architectures, evolving from large fiber solid-core, to sub-hundred nanometer thin-films, nano-filaments and even nanospheres. To bridge the gap between the optoelectronic fiber concept and practical applications however, we still need to improve device performance and integration. In this presentation we will describe the materials and processing approaches to realize optoelectronic fibers, as well as give a few examples of demonstrated systems for imaging as well as light and chemical sensing. We will then discuss paths towards practical applications focusing on two main points: fiber connectivity, and improving the semiconductor microstructure by developing scalable approaches to make fiber-integrated single-crystal nanowire based devices.

10194-7, Session 2

Realizing a Moore's Law for fibers *(Invited Paper)*

Yoel Fink, Massachusetts Institute of Technology (United States)

Since the dawn of civilization, fibers and fabrics have comprised some of our most essential crafts and manufactured products, including clothing, tapestries, blankets, bandages, and shelters. The technological function of these fibers and fabrics has advanced very slowly over thousands of years, especially when compared with other fields such as communications and electronics. Recently, a new family of fibers composed of conductors, semiconductors and insulators has emerged. These fibers can achieve similar basic device attributes as their modern wafer-based electronic and optoelectronic counterparts, yet are fabricated using preform-based fiber-processing methods, yielding kilometers of functional fiber devices. Here we will describe both the integration of a multiplicity of functional components into one fiber, and on the multiple-fiber level, the assembly of large-scale two- and three-dimensional geometric constructs made of many fibers. These emerging fiber technologies formed the basis for Advanced Functional Fabrics of America (AFFOA), a broad new collaboration between industry, academia and government. The goal of AFFOA is to enable the transformation of fiber and fabric materials into highly functional devices and systems that will see, hear, sense and communicate, store and convert energy and change color.

10194-8, Session 2

Scalable manufacturing of multimaterial fibers: from fiber drawing to fiber spinning *(Invited Paper)*

Ayman F. Abouraddy, CREOL, The College of Optics and Photonics, Univ. of Central Florida (United States)

Multimaterial fibers combine materials having disparate optical, electronic, and thermo-mechanical properties in intimate contact maintained in the form-factor of an extended microscopic fiber. Such fibers are typically thermally drawn from a macroscopic 'preform', a process well-developed in the optical fiber industry. Over the past decade, multimaterial fibers have offered the prospect of delivering optical, electronic, and optoelectronic functionalities in devices incorporated into clothing fabrics by producing these fiber devices at the length and cost associated with optical fibers. Recently, my group has started to investigate the potential for using fiber-spinning as an avenue for the mass-production of multimaterial fibers from the raw materials directly, thereby reducing the cost and increasing the feasibility of this technology. In this talk, I present our recent results on fiber-spinning of multimaterial polymeric fiber structures and provide a comparison to current achievements of fiber-drawing from a preform. Prospects for future developments will be charted out.

10194-9, Session 3

Computing in the nanoscale era: a Shannon-inspired perspective *(Keynote Presentation)*

Naresh Shanbhag, Univ. of Illinois at Urbana-Champaign (United States)

This talk will describe a Shannon-inspired approach – statistical information processing (SIP) - for the design of energy-efficient and robust information processing systems in nanoscale process technologies. SIP is well-suited to meet the needs of emerging data-rich applications such as those involving machine learning. Extraction of information from data lies at the heart of such applications. However, this process of information extraction consumes much energy. Traditionally, industry has relied on scaling of feature sizes in semiconductor technologies (Moore's Law) to reduce energy, enhance throughput, increase functional densities, and reduce cost/transistor. However, today, energy efficiency and reliability challenges in nanoscale CMOS (and beyond CMOS) processes threaten the continuation of Moore's Law.

This talk will describe our work on developing a Shannon-inspired SIP framework that seeks to address this issue by treating the problem of computing on unreliable device/circuit fabrics as one of information transfer over unreliable/noisy channels. SIP seeks to transform computing from its deterministic roots in von Neumann architecture to a foundation that is systems-driven and statistical in nature. Key elements of SIP are the use of statistical signal processing, machine learning principles, equalization and error-control, for designing error-resilient on-chip computation, communication, storage, and mixed-signal analog front-ends. A number of examples of Shannon-inspired IC prototypes will be described demonstrating the practicality of these ideas.

This talk will conclude with an overview of the Systems On Nanoscale Information fabriCs (SONIC) Center, a multi-university research center based at the University of Illinois at Urbana-Champaign, focused on developing a Shannon and brain-inspired foundations for information processing on CMOS and beyond CMOS nanoscale fabrics. SONIC was launched in 2013 under the STARnet (Semiconductor Technology Advanced Research network) program. The STARnet program is administered by the Semiconductor Research Corporation (SRC) and the Defense Advanced Projects Research Agency (DARPA).

10194-10, Session 3

Context-aware system design *(Invited Paper)*

Tajana Simunic-Rosing, Univ. of California, San Diego (United States)

The Internet of Things envisions a web-connected infrastructure of billions of sensors and actuation devices. However, the current state-of-the-art presents another reality: monolithic end-to-end applications tightly coupled to a limited set of sensors and actuators. Growing such applications with new devices or behaviors, or extending the existing infrastructure with new applications, involves redesign and redeployment. We instead propose a modular approach to these applications, breaking them up into an equivalent set of functional units (context engines) whose input/output transformations were driven by general-purpose machine learning, demonstrating an improvement in compute redundancy and computational complexity with minimal impact on accuracy. In conjunction with formal data specifications, or ontologies, we can replace application-specific implementations with a composition of context engines that use common statistical learning to generate output, thus improving context reuse.

We implement interconnected context-aware applications using our approach, extracting user context from sensors in both healthcare and grid applications. We compare our infrastructure to single-stage monolithic implementations, demonstrating a reduction in latency by up to 65% and execution overhead by up to 50%, with dramatic speedup in deployment.

10194-11, Session 3

Low power real-time data acquisition using compressive sensing *(Invited Paper)*

Linda S. Powers, Peter W. Hall, Jerrie V. Fainbanks, Radik R. Nasibulin, Yiming Zhang, Janet M. Roveda, The Univ. of Arizona (United States)

Exciting new possibilities exist for the development of novel hardware/software platforms having fast data acquisition capability with low power requirements. One application is a high speed Adaptive Design for Information (ADI) system that combines the advantages of feature-based data compression, low power nanometer CMOS technology, and stream computing [1]. Typical data acquisition systems use a sensor together with a mixed signal op-amp and ADC feed to a stream processor. In this approach, the front end analog portion consumes more than half the total chip area and is several orders of magnitude slower than the digital portion of the system.

We have developed a compressive sensing algorithm which linearly reduces the data at the analog front end, an approach which uses analog designs and computations instead of smaller feature size transistors for higher speed and lower power. A level-crossing sampling approach replaces Nyquist sampling. With an in-memory design, the new compressive sensing based instrumentation performs digitization only when there is enough variation in the input and when the random selection matrix chooses this input. Fluorescence data can not only be collected in real-time, but also analyzed in real-time with these methods to provide specific lifetimes. In this case, the linear operator is the decay constant (?) which is extracted by transforming the original N-dimensional data into a subspace of a random matrix where each element of the M-tuple that resides in this subspace is a close approximation to the decay constant ?.

[1] Roveda JM, Powers LS (2015) doi:10.4172/2090-4967.1000e105

10194-12, Session 4

Current trends on 2D materials for photonics devices: an NSF perspective *(Keynote Presentation)*

Mahmoud Fallahi, College of Optical Sciences, The Univ. of Arizona (United States) and The National Science Foundation (United States)

Recent advancements in two-dimensional (2D) materials have opened significant research opportunities in optics and photonics. While the initial focus on 2D materials was on Graphene, new generation of 2D materials such as hexagonal boron nitride (h-BN), transition metal dichalcogenides (TMDCs), monolayer black phosphorous (BP) and other monolayer structures have shown unique electrical and optical properties. For example, h-BN is an insulator, while monolayers of some TMDCs such as MoS2 and WSe2 are direct band-gap semiconductors. Depending on the choice of material compositional and layer variations their optical properties can be engineered, making them particularly attractive as novel light sources, photodetectors, modulators and photovoltaic components, in particular for few photon applications. Plasmonic properties of 2D materials make them suitable for nanophotonics and monolithic integration with other conventional materials.

The National Science Foundation (NSF) is a US federal agency dedicated to promote progress of science and engineering. NSF is the funding source for approximately 24 percent of all federally supported basic research conducted by America's colleges and universities. NSF has recently supported several initiatives related to novel 2D material and device research. In this talk, I will first give an overview of the NSF programs and funding opportunities. The second part of the talk will be focused on the programs related to 2D materials for photonic devices and program specific initiatives. Several highlights of the recent achievements and awards in the field of 2D materials for photonic devices will be presented.

10194-13, Session 4

Black phosphorous optoelectronic devices *(Invited Paper)*

Fengnian Xia, Yale Univ. (United States)

Black phosphorus recently emerged as a promising new 2D material due to its widely tunable and direct bandgap, high carrier mobility and remarkable in-plane anisotropic electrical, optical and phonon properties. It serendipitously bridges the zero-gap graphene and the relatively large-bandgap transition metal dichalcogenides such as molybdenum disulfide (MoS2). In this talk, I will first cover the basic properties of few-layer and thin-film black phosphorus, followed by a discussion of recent observation of highly anisotropic robust excitons in monolayer black phosphorus. Finally I will present a few potential applications of black phosphorus such as radio-frequency transistors and wideband photodetectors.

10194-14, Session 4

Progress in 2D semiconductor optoelectronics *(Invited Paper)*

Xiaodong Xu, Arka Majumdar, Taylor Fryett, Chang-Hua Liu, Jiajiu Zheng, Sanfeng Wu, Pasqual Rivera, kyle Seyler, Gen Clark, Univ. of Washington (United States)

Two-dimensional transition metal dichalcogenides (TMDs) are a recent addition to the 2D electronic materials family. They have shown outstanding electrical and optical properties for new optoelectronic device concepts. In this talk, we will discuss our recent progress on optoelectronics based on monolayers and heterostructures of TMDs. I will first talk about hybrid monolayer/photonic crystal cavity devices. Electroluminescence, photoluminescence, and second order harmonic generation all show coupling with the cavity mode with Purcell enhancement effect. Signature of lasing will be discussed. I will then present light emission from single defects in both monolayers and heterostructures. Intensity correlation measurement confirms the single photon nature of these emitters. Electrically driven single defect light emitting diodes will also be discussed.

10194-15, Session 4

Three-particle annihilation in a 2D heterostructure revealed through data-hypercubic photoresponse microscopy *(Invited Paper)*

Nathaniel M. Gabor, Univ. of California, Riverside (United States)

Van de Waals (vdW) heterostructures – which consist of precisely assembled atomically thin electronic materials - exhibit unusual quantum behavior. These quantum materials-by-design are of fundamental interest in basic scientific research and hold tremendous potential in advanced technological applications. Problematically, the fundamental optoelectronic response in these heterostructures is difficult to access using the standard techniques within the traditions of materials science and condensed matter physics. In the standard approach, characterization is based on the measurement of a small amount of one-dimensional data, which is used to gain a precise picture of the material properties of the sample. However, these techniques are fundamentally lacking in describing the complex interdependency of experimental degrees of freedom in vdW heterostructures. In this talk, I will present our recent experiments that utilize a highly data-intensive approach to gain deep understanding of the infrared photoresponse in vdW heterostructure photodetectors. These measurements, which combine state-of-the-art data analytics and measurement design with fundamentally new device structures and experimental parameters, give a clear picture of electron-hole pair interactions at ultrafast time scales.

10194-16, Session 4

Antenna-coupled light emission from 2D materials *(Invited Paper)*

Palash Bharadwaj, Rice Univ. (United States); Markus Parzefall, Lukas Novotny, Achint Jain, ETH Zürich (Switzerland)

We report the ultrafast conversion of electrons localized in vertical Au-hBN-Au tunnel junctions to free-space photons, mediated by resonant slot antennas. This work marks one of the first demonstrations of electrically excited optical antennas. The slot antennas are excited via inelastic electron tunnelling from a flat Au electrode, and subsequently radiate photons into the farfield that are polarized, directional and resonantly enhanced in their energy spectrum. The tunnel barrier in our devices, made from few-layer crystalline hBN, is remarkably stable even under high biases compared to other tunnel junctions studied thus far. We study the frequency response of our tunnel devices, and demonstrate a direct voltage modulation of the emitted light at frequencies ranging from 10 MHz to 1 GHz. This work establishes a novel platform for studying the interaction of electrons with strong electromagnetic fields in nanoscopic volumes.

10194-17, Session 4

Light scattering and emission from hetero-structures *(Keynote Presentation)*

Andrea C. Ferrari, Univ. of Cambridge (United Kingdom)

Heterostructures based on layers of atomic crystals have a number of properties often unique and very different from those of their individual constituents and of their three dimensional counterparts. The combinations of such crystals in stacks can be used to design the functionalities of such heterostructures. I will show how Raman spectroscopy can be used to fingerprint such heterostructures, and how these can be exploited in novel light emitting devices, such as single photon emitters, and tuneable light emitting diodes

10194-18, Session 5

Plasmonic metamaterials at visible and ultraviolet frequencies *(Invited Paper)*

Henri J. Lezec, National Institute of Standards and Technology (United States)

Artificial metamaterials – metallo-dielectric composites tailored on deep-subwavelength scale – enable implementation of electromagnetic responses not found in nature, leading to potentially useful applications as well as yielding new insights into the fundamental nature of light. Here we show how we have leveraged ultrasmooth planar nanoplasmonic waveguides deposited by ion-beam-assisted sputter deposition to implement easy-to-fabricate bulk metamaterials operating at visible and ultra-violet wavelengths and having refractive indices ranging from highly anisotropic and positive [1] to quasi-isotropic and negative [2]. Exploiting these structures to tailor the flow of light in exotic ways, we realize devices ranging from high-contrast, near-field nanoparticle optical sensors working in the visible, to the first implementation of a Veselago flat lens [3] functioning in the near ultraviolet. Substituting Al for Ag as the constituent plasmonic metal of choice, we investigate the extension of bulk metamaterial operation into the mid-ultraviolet, for lithographic applications beyond the diffraction limit.

[1] T. Xu and H.J. Lezec, Nat. Comm. 5, 4141 (2014). [2] T. Xu, A. Agrawal, M. Abashin, K.J. Chau, and H.J. Lezec, Nature 497, 470 (2013). [3] V.G. Veselago, Sov. Phys. Usp. 10, 509 (1968).

10194-19, Session 5

Deep-subwavelength near-field imaging based on perovskite and doped semiconductors at infrared frequencies (Rising Researcher Presentation) *(Invited Paper)*

Yongmin Liu, Northeastern Univ. (United States)

Infrared light plays an important role in biomedical imaging and sensing, spectroscopy, homeland security, surveillance, information processing and communication. Achieving sub-diffraction-limited imaging at infrared frequencies would promise many applications. In this talk, two types of novel superlenses with imaging resolution of about one tenth of wavelength are presented. First, we demonstrate a low-loss superlens using perovskites in the mid-infrared regime. The combination of an apertureless scanning near-field optical microscope with a tunable free-electron laser allows us to address precisely the polariton modes of perovskite, which are critical for super-resolution imaging. We spectrally study the lateral and vertical distributions of evanescent waves around the image plane of the superlens, and achieve imaging resolution of ?/14 at the superlensing wavelength. Second, we demonstrate a broadband, tunable near-field superlens based on doped GaAs in the mid-infrared regime. The Drude response of the GaAs layer induces a resonant enhancement of evanescent waves accompanied by a significantly improved spatial resolution. Moreover, the superlens is spectrally tunable by accurately controlling the charge-carrier concentration in GaAs via standard semiconductor fabrication techniques. The resonant behavior of the observed superlensing effect is in excellent agreement with simulations based on the Drude?Lorentz model. Our research findings open new avenues for infrared nano spectroscopy, thermal sensors and multifunctional integrated devices.

10194-20, Session 5

Hyperlens for real-time high-throughput biomolecular imaging (Rising Researcher Presentation) *(Invited Paper)*

Junsuk Rho, Dasol Lee, Minkyung Kim, Jungho Mun, Duc Minh Nguyen, Pohang Univ. of Science and Technology (Korea, Republic of)

Super-resolution imaging technology has generated much interest as a powerful tool for imaging in biology and nanotechnology. This technology helps to overcome the diffraction limit of conventional imaging system, wherein two objects located closer than the one-half of the wavelength cannot be resolved in the optical far field. The physical principle for this limit is that the field carrying high spatial frequencies is evanescent and rapidly decays within a distance of the order of one wavelength. Recent progress in metamaterials, which are artificial structure never existing in nature, are able to image beyond the diffraction limit. Hyperlens is the kind of special artificial metamaterials with hyperbolic dispersion that can resolve small objects in the optical far field. Previous efforts have been achieved to resolve features down to sub-diffraction limit in visible range, still restricting to the use of hyperlenses in practical applications. Here, we propose a new design consisting of multiple spherical hyperlenses arranged in hexagonal arrays in wafer scale for high-throughput imaging and robust to sample positioning. With proposed design, we report the first experimental demonstration of sub-diffraction biological imaging on hyperlenses by implementing to conventional microscopy system for imaging biomolecules. Hippocampal neuron cells are imaged by visible light through the hyperlens array with resolution down to 150 nm, much smaller than the diffraction limit. Sucessful observation of biomolecular samples at sub-diffraction size proves the designed hyperlens as a useful method for applications in biology, pathology, medical science and nanotechnology.

10194-21, Session 5

Plasmonics and metamaterials based super-resolution imaging *(Invited Paper)*

Zhaowei Liu, Univ. of California, San Diego (United States)

In recent years, surface imaging of various biological dynamics and biomechanical phenomena has seen a surge of interest. Imaging of processes such as exocytosis and kinesin motion are most effective when depth is limited to a very thin region of interest at the edge of the cell or specimen. However, many objects and processes of interest are of size scales below the diffraction limit for safe, visible wavelength illumination. Super-resolution imaging methods such as structured illumination microscopy and others have offered various compromises between resolution, imaging speed, and bio-compatibility. In this talk, I will present our most recent progress in plasmonic structured illumination microscopy (PSIM) and localized plasmonic structured illumination microscopy (LPSIM), and their applications in bio-imaging. We have achieved wide-field surface imaging with resolution down to 75 nm while maintaining reasonable speed and compatibility with biological specimens. These plasmonic enhanced super resolution techniques offer unique solutions to obtain 50nm spatial resolution and 50 frames per second wide imaging speed at the same time.

10194-22, Session 6

Photoelectrochemistry of III-V epitaxial layers and nanowires for solar energy conversion *(Invited Paper)*

Vijay Parameshwaran, Ryan W. Enck, Roy Chung, Stephen Kelley, Anand V. Sampath, Meredith L. Reed, U.S. Army Research Lab. (United States); Xiaoqing Xu, Bruce Clemens, Stanford Univ. (United States)

III-V materials, which exhibit high absorption coefficients and charge carrier mobility, are ideal templates for solar energy conversion applications. Historically, their use has been limited to multijunction stacks for high-efficiency and high-cost concentrator photovoltaics. Recent research has explored utilizing epitaxial III-V crystals as light absorbers for driving a variety of chemical reactions to generate hydrogen and hydrocarbons as fuels. The ability to grow single crystal nanowire morphologies of these materials opens up the design space to obtain higher efficiency electrodes and stand-alone photocatalysts that utilize less materials for consumption. A basis in development of III-V layers and nanomaterials for solar-driven chemical reactions is the junction between the semiconductor and the electrolyte.

This work describes the photoelectrochemistry research in several III-V/electrolyte junctions as an enabler for device design for solar chemical reactions. Epitaxial phosphide layers are grown on silicon and GaAs to show an extended space charge design to improve the quantum efficiency of heterojunction photocathodes [1]. Studies on microstructured and nanostructured forms of GaN show insights to how morphology determines the nature of the electrochemical junction [2]. Electrochemical photoeffects on both InP and InN nanowires provide a basis on how nanostructured forms of these semiconductors can be engineered for solar fuels while providing fundamentals on the interface [3]. Finally, work in engineering the III-V nitride alloy system with polarization field effects, p-type doping, and ternary alloying will be presented to enable a high-efficiency reduction cathode.

[1] V. Parameshwaran et al, Journal of the Electrochemical Society 163 (8), pg. H714-H721 (2016)

[2] V. Parameshwaran et al, Journal of the Electrochemical Society 163 (10), pg. H958-H963 (2016)

[3] V. Parameshwaran et al, ACS Applied Materials and Interfaces 8 (33), pg. 21454-21464 (2016)

10194-23, Session 6

Photovoltaic cells based on plasmonic structures

Muhammad Anisuzzaman Talukder, Univ. of Leeds (United Kingdom)

While decreasing the thickness of active layers is important in reducing the cost of solar cells, the absorption of incident light is challenging as the thickness becomes smaller than the wavelength. Metal nano-structures can be used on top or bottom of the active layers to couple light to different plasmonic and photonic modes. Metal nano-structures can also be used as an intermediate layer within an active layer or between two active layers as in tandem solar cells. The intermediate layer can be designed for optimum light absorption in both active layers and collection of photo-excited carriers by overcoming current mismatch.

10194-24, Session 6

Metamaterials for novel energy applications *(Invited Paper)*

Willie J. Padilla, Duke Univ. (United States)

The union of mico / nano electromechanical systems with metamaterials offers a new route to achieve reconfigurable devices which control the emission of energy. Here we propose and demonstrate the idea of metamaterial MEMS capable of modifying the emitted energy without changing the temperature. Rather our device only alters the spectral emissivity, thus realize a differential emissivity equivalent to a nearly 20-degree Celsius temperature change across the thermal infrared. We pixelate our device and thereby achieve a spatio-temporal emitter capable of displaying thermal infrared patterns up to speeds of 110 kHz. Our results are not limited to the thermal infrared band, but may be scaled to nearly any sub-optical range of the electromagnetic spectrum, and verify the potential of MEMS metamaterials to operate as reconfigurable multifunctional devices with unprecedented energy control capabilities.

10194-25, Session 7

Wearable technologies for soldier first responder assessment and remote monitoring *(Keynote Presentation)*

Stephen Lee, U.S. Army Research Office (United States)

Embedded combat medical personnel require accurate and timely biometric data to ensure appropriate life saving measures. Injured warfighter's operating in remote environments require both assessment and monitoring often while still engaged with enemy forces. Small wearable devices that can be placed on injured personnel capable of collecting essential biometric data, including the capacity to remotely deliver collected data in real-time, would allow additional medical monitoring and triage that will greatly help the medic in the battlefield. These new capabilities will provide a force multiplier through remote assessment, increased survivability, and in freeing engaged warfighter's from direct monitoring thus improving combat effectiveness and increasing situational awareness. Key questions around what information does the medic require and how effective it can be relayed to support personnel are at their early stages of development. A low power biometric wearable device capable of reliable electrocardiogram (EKG) rhythm, temperature, pulse, and other vital data collection which can provide real-time remote monitoring are in development for the Soldier.

10194-26, Session 7

Electrical bioimpedance enabling prompt intervention for traumatic brain injury *(Invited Paper)*

Fernando Seoane, KTH Royal Institute of Technology (Sweden) and Univ. of Borås (Sweden) and Karolinska Institutet (Sweden); Reza Atefi, Univ. of Borås (Sweden)

Electrical Bioimpedance (EBI) is a well spread technology used in clinical practice around world. Typical spectroscopy applications range from Body Composition analysis in Nutrition and Dialysis to assessment of skin cancer. Advancements in Textile material technology in conductive textile fabrics and textile-electronics integration have allowed exploring the possibilities of so-called Wearable Measurement Sensors and Systems in numerous research project worldwide. The sensing principle of EBI exploits the intrinsic passive dielectric properties of biological tissue. Using a pair of electrodes biological tissue is stimulated and electrical current is distributed within the tissue creating a electrical field. Such electrical field can be sensed with biopotential electrodes, typically at the surface, and with the sensed potential and the known stimulus a 4-point impedance can be estimated for a given channel.

The use of EBI spectroscopy to study the brain has been investigated for the past decade, typically for brain function purposes and for situations when the brain is at risk brain stroke and perinatal asphyxia in newborns. Animal studies and computational simulations have shown that in deed when brain tissue is injured that modifies the dielectric properties of such brain tissue altering the current distribution within the brain and the potential distribution at the surface, i.e. at the scalp.

Like in stroke, head trauma damages brain tissue causing changes in the dielectric properties of brain tissue, of different nature, but producing alterations that should be detected with EBI technology like in the other applications.

In the battlefield Traumatic Brain Injury caused by the blast of Rocket-Propelled Grenade for instance are very common. Brain damage must be assessing promptly to have a chance to prevent severe damage or eventually death. The relatively low-complexity of the sensing hardware require for EBI sensing and the already proven compatibility with textile electrodes suggest the EBI technology is indeed a candidate for developing a handheld device equipped with a sensorized textile cap to produce an examination in minutes enabling medically-guided prompt intervention.

10194-27, Session 7

Wearable sweat sensors *(Invited Paper)*

Ali Javey, Univ. of California, Berkeley (United States)

Wearable sensor technologies play a significant role in realizing personalized medicine through continuously monitoring an individual's health state. To this end, human sweat is an excellent candidate for non-invasive monitoring as it contains physiologically rich information. In this talk, I will present our recent advancement on fully-integrated perspiration analysis system that can simultaneously measure sweat metabolites, electrolytes and heavy metals, as well as the skin temperature to calibrate the sensors' response. Our work bridges the technological gap in wearable biosensors by merging plastic-based sensors that interface with the skin, and silicon integrated circuits consolidated on a flexible circuit board for complex signal processing. This wearable system is used to measure the detailed sweat profile of human subjects engaged in prolonged physical activities, and infer real-time assessment of physiological state of the subjects.

10194-28, Session 7

Human health monitoring technology *(Invited Paper)*

Byung-Hyun Kim, Jong-Gwan Yook, Yonsei Univ. (Korea, Republic of)

Monitoring vital signs from human body is very important to healthcare and medical diagnosis, because they contain valuable information about arterial occlusions, arrhythmia, atherosclerosis, autonomous nervous system pathologies, stress level, and obstructive sleep apnea. Existing methods, such as electrocardiogram (ECG) sensor and photoplethysmogram (PPG) sensor, requires direct contact to the skin and it can causes skin irritation and the inconvenience of long-term wearing. For reducing the inconvenience in the conventional sensors, microwave and millimeter-wave sensors have been proposed since 1970s using micro-Doppler effect from one's cardiopulmonary activity. The Doppler radar sensor can remotely detect the respiration and heartbeat up to few meters away from the subject, but they have a multiple subject issue and are not suitable for an ambulatory subject. As a compromise, a non-contact proximity vital sign sensor has been recently proposed and developed. The purpose of this paper is to review the noncontact proximity vital sign sensors for detection of respiration, heartbeat rate, and/or wrist pulse. This sensor basically employs near-field perturbation of radio-frequency (RF) planar resonator due to the proximity of the one's chest or radial artery at the wrist. Various sensing systems based on the SAW filter, phase-locked loop (PLL) synthesizer, reflectometer, and interferometer have been proposed. These self-sustained systems can measure the near-field perturbation and transform it into DC voltage variation. Consequently, they can detect the respiration and heartbeat rate near the chest of subject and pulse from radial artery at the wrist.

10194-29, Session 7

Temporary-tattoo for long-term high fidelity bio-potential recordings *(Invited Paper)*

Yael Hanein, Tel Aviv Univ. (Israel)

Surface electromyography (sEMG) is a non-invasive method widely used to map muscle activation. For decades, it was commonly accepted that dry metallic electrodes establish poor electrode-skin contact, making them impractical for skin electromyography applications. Gelled electrodes are therefore the standard in sEMG with their use confined, almost entirely, to laboratory settings. Very recently we developed novel dry electrodes, exhibiting outstanding sEMG recording along with excellent user comfort. The electrodes (electronic tattoos) are realized using screen-printing of carbon and silver inks on a soft support. The conformity of the electrodes helps establish direct contact with the skin, making the use of a gel superfluous. The suitability of the electrodes for long-term and stable sEMG from different muscles was demonstrated and emphasizes the potential of the technology for many applications, such as brain-machine interfacing, muscle diagnostics, post-injury rehabilitation, and gaming.

Owing to their skin-like properties, the electronic tattoos are ideally suited for facial sEMG. Facial sEMG is one of the most direct methodologies to perform objective classification of emotional expressions. Unlike image analysis, sEMG captures muscle activation, therefore depicting inner neurological pathways and psychological and neurological pathologies. Moreover, wireless sEMG recordings allow constant monitoring in a natural environment. Accordingly, recording facial sEMG with our electronic tattoos offers many new opportunities in the realm of psychological and neurological evaluation. We use our electrodes to demonstrate for the first time the use of sEMG as a robust and long term platform suitable for facial expression detection. In particular, we used the electrodes to differentiate between real and fake smiles. The potential use of the presented technology for various applications ranging from objective psychological and neurological evaluation to measuring viewer engagement will be discussed.

10194-30, Session 7

Smart photonic materials for theranostic applications *(Invited Paper)*

Sei Kwang Hahn, Do Hee Keum, Pohang Univ. of Science and Technology (Korea, Republic of)

We developed melanoidin nanoparticles for in vivo noninvasive photoacoustic mapping of sentinel lymph nodes, photoacoustic tomography of gastro-intestinal tracts, and photothermal ablation cancer therapy. In addition, we developed cell-integrated poly(ethylene glycol) hydrogels for in vivo optogenetic sensing and therapy. Real-time optical readout of encapsulated heat-shock-protein-coupled fluorescent reporter cells made it possible to measure the nanotoxicity of cadmium-based quantum dots in vivo. Using optogenetic cells producing glucagon-like peptide-1, we performed light-controlled diabetic therapy for glucose homeostasis. Finally, we developed a smart contact lens composed of biosensors, drug delivery systems, and power sources for the treatment of diabetes as a model disease.

10194-31, Session 7

Biosensors for the rapid identification of bacterial subtypes and antibiotic sensitivity determination *(Invited Paper)*

Stan Skafidas, The Univ. of Melbourne (Australia); Daniela Zantomio, Austin Hospital (Australia); Chathurika Abeyrathne, Gursharan Chana, The Univ. of Melbourne (Australia)

Bacterial pathogens are responsible for a variety of infectious diseases ranging from cellulitis to more serious conditions such as septic arthritis and septicaemia. Timely treatment with appropriate antibiotic therapy is essential to ensure clinical defervescence and to prevent further complications such as infective endocarditis or organ impairment due to septic shock. To date, initial antibiotic choice is empirical, using a “best guess” of likely organism and sensitivity- an approach adopted due to the lack of rapid identification methods for bacteria. Current culture based methods take up to 5 days to identify the causative bacterial pathogen and its antibiotic sensitivity. This talk will outline new biosensor, based on functionalized interdigitated electrodes, to detect the presence and detect the subtype of bacteria and ascertain its antibiotic sensitivity rapidly (within 2 hours) in a cost effective manner. The proposed method is label-free and uses non-faradic measurements. The method described has important potential outcomes of faster definitive antibiotic treatment and more rapid clinical response to treatment.

10194-32, Session 7

The human intranet *(Invited Paper)*

Jan Rabaey, Univ. of California, Berkeley (United States)

Some of most compelling application domains of the IoT and Swarm concepts relate to how humans interact with the world around it and the cyberworld beyond. While the proliferation of communication and data processing devices has profoundly altered our interaction patterns, little has been changed in the way we process inputs (sensory) and outputs (actuation). The combination of IoT (Swarms) and wearable devices offers the potential for changing all of this. Yet, realizing full potential requires that a number of barriers are overcome, most notably the non-scalable nature of the current deployments.

The Human Intranet proposes an open scalable platform that seamlessly integrates an ever-increasing number of sensor, actuation, computation, storage, communication and energy nodes located on, in, or around the human body acting in symbiosis with the functions provided by the body itself. The traditional set of senses and interactions is to be augmented by a set of new capabilities, some of which might be hard to even imagine today.

10194-33, Session 7

The power of sound: miniaturized medical implants with ultrasonic links *(Invited Paper)*

Amin Arbabian, Stanford Univ. (United States)

There is great potential for stimulating and recording from the peripheral nervous system and the organs that it controls to understand the neural circuits and organ function control, as well as to enable widespread deployment of these systems for variety of treatments. However, current technologies to do this are severely limited. Implantable stimulators are usually bulky because of the need for batteries and/or antennas/coils large enough to receive power with acceptable efficiency and at depth, and therefore require invasive surgery and multiple implanted cables connected to electrodes on specific nerves. Miniaturization, along with a robust and safe wireless connection, overcomes these limitations and also enables the possibility of having a network of sensor nodes for applications like multisite neural recording and stimulation. However, certain key applications such as optogenetics and electrical nerve stimulation require high power levels, typically 100 μW to a few mW, and this makes the design of the power delivery system even more challenging by simultaneously requiring high power density and efficiency. For this application we utilize acoustic waves in the ultrasonic range for power transfer since it has wavelengths comparable to the size of the implant, which enables focusing of the energy at the device site, leading to a higher link efficiency and lower heating in surrounding tissue as compared to RF powering techniques.

10194-34, Session 7

Inkjet-/3D-/4D-printed autonomous wearable RF modules for biomonitoring, positioning and sensing applications *(Invited Paper)*

Manos M. Tentzeris, Georgia Institute of Technology (United States)

In this paper, numerous inkjet-/3D-/4D-printed wearable flexible antennas, RF electronics, modules and sensors fabricated on paper and other polymer (e.g. LCP) substrates are introduced as a system-level solution for ultra-low-cost mass production of autonomous Biomonitoring, Positioning and Sensing applications. Prof. Tentzeris will briefly touch up the state-of-the-art area of fully-integrated wearable wireless sensor modules on paper or flexible LCP and show the first ever 4D sensor module integration on paper, as well as numerous 3D and 4D multilayer paper-based and LCP-based RF/microwave haptic, wearable and implantable structures, that could potentially set the foundation for the truly convergent wireless sensor ad-hoc “on-body” networks of the future with enhanced cognitive intelligence and “rugged” packaging. Prof. Tentzeris will discuss issues concerning the power sources of “near-perpetual” wearable RF modules, including flexible miniaturized batteries as well as power-scavenging approaches involving thermal, EM, vibration and solar energy forms. The final step of the paper will involve examples from mmW wearable (e.g. biomonitoring) antennas and RF modules, as well as the first examples of the integration of inkjet-printed nanotechnology-based (e.g.CNT) sensors on paper and organic substrates for Internet of Things (IoT) applications. It has to be noted that the paper will review and present challenges for inkjet-printed organic active and nonlinear devices as well as future directions in the area of environmentally-friendly (“green”) wearable RF electronics and “smart-skin” conformal sensors.

10194-35, Session 8

A future Air Force vision of human-machine teaming *(Keynote Presentation)*

Morley O. Stone, Air Force Research Lab. (United States)

Humans have long sought to invent machines to free themselves from physically-demanding, time-consuming tasks and improve product quality. Today, Air Force Research Laboratory scientists and engineers are re-inventing what future human-machine teaming will look like by developing physiological and cognitive tools that will optimize human-machine “mutual situation awareness.”

Employing a Sense-Assess-Augment (SAA) approach that is made possible by new flexible hybrid electronics, remote data capture, innovative data displays, and adaptive machine learning, AFRL seeks to create an in-silico partner for tomorrow’s USAF operator to support human decision making in highly demanding mission environments.

Sense: New flexible hybrid electronics enable AFRL scientists to monitor a range of physiological parameters, such as brain activity, eye movement, respiration rate, and biological performance markers. We envision a future when an airman will use non-invasive, non-intrusive sensors to monitor his/her physical and cognitive state in near-real time. This data will continuously inform the airman’s in-silico partner about the airman’s cognitive load, stress level, and physical readiness. The in-silico partner, in turn, will keep the human-machine team operating at peak performance by providing the operator with the optimal level of decision making support. Sensor suites will feed a “performance dashboard” to track the relative performance levels of the airman and the aggregate human-machine team.

Assess: From the technical perspective, the most challenging step of SAA is “assessment” which involves interpreting data from multiple, individual sensors and merging it into actionable information in an operationally relevant time frame. Researchers must understand how sensor readings (individual and correlated groupings of data) relate to an airman’s cognitive and physical performance over time. A good deal of research, looking at both model and data-driven algorithms, is necessary before this is possible. The SAA process will also need to be incorporated into operational training, tactics, and procedures within USAF units.

Augment: Our understanding of the final piece of the AFRL SAA model, augmentation, has advanced beyond merely creating advanced displays for complex information presentation. The possibilities for augmentation occupy an enormous range, from physical/nutritional enhancements (the concept of “nutritional armor”) to transcranial direct current brain stimulation (tDCS), to increasing the level of in-silico decision making support to the operator. Although the concept of human performance augmentation has been technically feasible for some time, it has under-delivered by not being incorporate into a larger feedback framework. Without the paradigm described above, the sensing and augmentation communities have largely worked independently and the assessment piece has lacked a holistic approach. AFRL’s SSA approach seeks to bridge that gap to enable the most advanced human-machine team – the Quantified Airman.

10194-36, Session 8

Beyond activity tracking: next-generation wearable and implantable sensor technologies *(Invited Paper)*

Patrick Mercier, Univ. of California, San Diego (United States)

Current-generation wearable devices have had success continuously measuring the activity and heart rate of subjects during exercise and daily life activities, resulting in interesting new data sets that can, though machine learning algorithms, predict a small subset of health conditions. However, this information is only very peripherally related to most health conditions, and thus offers limited utility to a wide range of the population. In this presentation, I will discuss emerging sensor technologies capable of measuring new and interesting parameters that can potentially offer much more meaningful and actionable data sets.

Specifically, I will present recent work on wearable chemical sensors that can, for the first time, continuously monitor a suite of parameters like glucose, alcohol, lactate, and electrolytes, all while wirelessly delivering these results to a smart phone in real time. Demonstration platforms featuring patch, temporary tattoo, and mouthguard form factors will be described, in addition to the corresponding electronics necessary to perform sensor conditioning and wireless readout. Beyond chemical sensors, I will also discuss integration strategies with more conventional electrophysiological and physical parameters like ECG and strain gauges for cardiac and respiration rate monitoring, respectively. Finally, I will conclude the talk by introducing a new form of wireless communications in body-area networks that utilize the body itself as a channel for magnetic energy. Since the power consumption of conventional RF circuits often dominates the power of wearable devices, this new magnetic human body communication technique is specifically architected to dramatically reduce the path loss compared to conventional RF and capacitive human body communication techniques, thereby enabling ultra-low-power body area networks for next-generation wearable devices.

10194-37, Session 8

Wireless magnetoelastic transducers for biomedical applications *(Invited Paper)*

Scott Green, Yogesh B. Gianchandani, Univ. of Michigan (United States)

This paper highlights emerging medical applications for magnetoelastic sensing and actuation, each taking advantage of the wireless capabilities and small form factor enabled by the magnetoelastic transduction technique. Magnetoelastic transduction leverages the strong coupling between stress, strain, and magnetization intrinsic to some materials – notably amorphous metals and rare earth crystalline alloys. This coupling provides inherently wireless transduction that does not require any onboard power; these traits are especially advantageous in diagnostic and therapeutic medical implant applications. This paper first describes the basic transduction technique, and considerations for design and fabrication of medical systems which utilize the technique. These considerations include material selection, magnetic biasing, packaging, and interrogation approaches. The first application highlighted is stent monitoring, in which the mass-sensitive magnetoelastic resonator is integrated along the inner sidewall of the stent to provide early detection of stent occlusion. Benchtop, in situ, and in vivo tests of prototypes indicate clinical feasibility and a full scale range of 10x the sensor mass – from zero stent occlusion to full stent occlusion. The second application is wireless strain sensing, which can be useful for orthopedic implants and orthodontia. A differential strain sensor is described, with a dynamic range of 0-1.85 mstrain – accommodating typical palatal expander strain – and a sensitivity of 12.5x10^3 ppm/mstrain. Finally, a wireless actuator intended to agitate fluid for mitigation of encapsulation of glaucoma drainage devices is shown. Peak actuator vibration amplitudes of 1.5 μm – sufficient to affect cell adhesion in other studies – are recorded at a wireless range of 25-30 mm.

10194-38, Session 8

Tapping into tongue motion to substitute or augment upper limbs *(Invited Paper)*

Maysam Ghovanloo, Md Nazmus Sahadat, Zhenxuan Zhang, Georgia Institute of Technology (United States)

Assistive technologies (AT) play an important role in the lives of people with disabilities. Most importantly, they allow individuals with severe physical disabilities become more independence. Inherent abilities of the human tongue originated from its direct connection to the brain through well-protected cranial nerves, its strong representation in the motor cortex, and easy access without a surgery have resulted in development of a series of tongue operated ATs that are tapping into the dexterous, intuitive, rapid, and tireless motion of the tongue. These ATs not only help people with tetraplegia as a result of spinal cord injury or degenerative neurological diseases to access computers/smartphones, drive wheelchairs, and interact with their environments but also have the potential to enhance rehabilitation paradigms for stroke survivors. In this paper, different kinds of tongue operated ATs are discussed based on their working principles and task based performances. Comparisons are drawn based on qualitative measures, such as user feedback and standard quantitative measures, such as throughput, information transfer rate, typing speed/accuracy, tracking error, wheelchair driving time, and navigation accuracy. Finally, the prospects of using variations of these versatile devices to enhance human performance in environments that limit hand and finger movements, such as space or underwater operations are discussed.

10194-40, Session 8

Towards closed-loop neuromodulation: a wireless miniaturized neural implant SoC *(Invited Paper)*

Wentai Liu, Yikai Lo, Univ. of California, Los Angeles (United States)

A closed-loop neuromodulation system is ultimately needed to achieve effective neuromodulation by intelligent control with adaptive mechanisms by real-timely monitoring the biological and physiological response as well as the environmental condition. Nevertheless, at present, there are very limited successful systems available for clinical purposes. This presentation reports the design and validation of a wireless powered SoC and its application to implement closed-loop neuro-prostheses. The SoC is a mixed-mode/mixed voltage integration of bi-directional wireless transceiver, wireless power telemetry, digital control unit, vin-situ bio-impedance characterization, recording unit, and stimulator.

10194-41, Session 8

The bionic man: Not too far away! *(Invited Paper)*

Paul Cederna, Univ. of Michigan (United States)

It has been 35 years since Luke Skywalker (Star Wars) received a prosthetic hand controlled by his peripheral nerves. Unfortunately, this peripheral nerve interface has not been achieved in reality largely due to the difficulty recording multiple independent efferent motor control signals from a nerve inside a moving arm. The current best option is targeted muscle reinnervation (TMR), which moves divided nerves into alternate muscles that then function as signal amplifiers. This has worked very well and has provided a significant advance to our current approaches for prosthetic control. Our group has taken this strategy one step further by performing regenerative peripheral nerve interfaces (RPNI), which consist of a skeletal muscle graft placed on the end of a surgically subdivided nerve (nerve fascicle) to provide more control signals for dexterous hand motion. In addition, the RPNI's can be used as a peripheral nerve interface strategy to provide high fidelity sensory feedback from the terminal device to the sensory afferents. This closed loop neural control strategy has facilitated recordings of efferent motor nerve action potential for motor control and afferent nerve stimulation for sensory feedback, over prolonged periods of time with highly favorable signal-to-noise ratios. To date, we have tested the safety and signal quality thoroughly in over 500 animals, two non-human primates, and four humans. In this presentation, I will share our last 10 years of research developing this novel peripheral nerve interface and discuss the future potential of this disruptive technology.

10194-42, Session 8

Implanted flexible electrodes and sensors for enabling the next-generation human interface *(Invited Paper)*

Chengkuo Lee, National Univ. of Singapore (Singapore)

Implanted flexible biomedical devices currently become popular because they are considered as the viable solution to realize implanted prostheses for novel applications such as human-machine interface and electroceuticals. For example, these flexible electrodes and sensors placed within the peripheral nervous system, the nerves that work throughout our arms and legs. Selective sciatic nerve recording and stimulation are investigated using flexible electrodes with minimal pressure on the nerve, but still provided a good electrical contact with the nerve. Selective muscle stimulation was achieved by two stimulation configurations via nerve electrode and muscle electrode. Other flexible devices, including physiological signal

sensing, energy harvesting and nanomedicine delivery are also developed as novel approaches to further understand disease mechanisms and to explore electroceuticals. Secondly, various optogenetic devices are also demonstrated for sciatic nerve and brain. The technology advance in the implanted flexible biomedical devices will create tremendous applications related to the central nervous system, including the brain and spinal cord, and novel electroceuticals to treat disorders like epilepsy or to stimulate the immune system or tamp down inflammation, etc.

10194-44, Session 8

Using synthetic biology to interface with physical micro and nano-sized sensors *(Invited Paper)*

Russell Hanson, Jason Fuller, Andrew Cheng, Mount Sinai School of Medicine (United States)

This talk will discuss the current goals and efforts of point of care and personal health monitoring systems: what they can do now and what is in the works. These interfaces can be used in a precision medicine context—making diagnoses and getting the right drugs to the right patients at the right time. Many of the same sensors and engineering are being prototyped now for neural interfaces and recording devices with applications in visual, auditory, and motor cortex, allowing basic research along with preliminary applications in actuation and sensing. While miniaturization and electronics development using established manufacturing protocols can provide the current engineering foundations, novel biochemical ligands and molecular detectors can provide the needed flexibility for next-generation devices.

10194-45, Session 9

Conformal electronic sensory skins for vehicles and their human interfaces *(Keynote Presentation)*

John A. Rogers, Northwestern Univ. (United States)

Deterministic hard/soft composite materials form the basis of electronic systems and semiconductor devices in physical forms that match the properties of biological soft tissues, including the skin. Emerging capabilities in skin-like sensors, radios and power supply systems now enable unprecedented capabilities in measuring physiological processes of use not only in healthcare related applications but also as sources of data for cognitive state determination and for human-machine interfaces. This talk will focus on these latter applications, through control systems based on three axis accelerometry, mechano—acoustic signals, electromyography and electroencephalography.

10194-46, Session 9

Intelligent sensors for cyber physical human systems *(Invited Paper)*

Wen J. Li, City Univ. of Hong Kong (Hong Kong, China)

Cyber Physical Human Systems (CPHS) research explores potentially disruptive technologies and novel theories in the integration of sensing, actuation, communication, and computing platforms and algorithms, including robots, sensors, and wireless networks, for advancing human capabilities and improve human lives. CPHS will enable the development of tranformative systems that interact with humans through varied and multiple modes such as motion, haptic, smell, audio, brain-machine interfaces, and other new interaction techniques. CPHS will also broaden the advancedment of human capabilities in several realms, including accessing the micro/nano worlds (e.g., single-cell analysis and nano-scale manufacturing), operating in dangerous or inaccessible environments (e.g., monitoring gigantic structures, firefighting, and deep-sea exploration), and improving medical technologies (e.g., rapid drug discovery and ubiquitous healthcare monitoring/delivery). This lecture presents our team's development of several intelligent sensing platforms based on micro/nano/optical sensors which will enhance diverse CPHS applications spanning from drug discovery to novel interactive technologies and safety monitoring. These platform technologies include human-robot interaction by motion input, hand-gesture recognition for interactive control, mobile human air-bag system, graphene-based motion sensors on wearable flexible substrates, self-powered wireless sensors, and optically-induced electrokinetics for single-cell big data analysis.

10194-47, Session 9

3D printing functional materials and devices *(Invited Paper)*

Michael C. McAlpine, Univ. of Minnesota (United States)

The development of methods for interfacing high performance functional devices with biology could impact regenerative medicine, smart prosthetics, and human-machine interfaces. Indeed, the ability to three-dimensionally interweave biological and functional materials could enable the creation of devices possessing unique geometries, properties, and functionalities. Yet, most high quality functional materials are two dimensional, hard and brittle, and require high crystallization temperatures for maximal performance. These properties render the corresponding devices incompatible with biology, which is three-dimensional, soft, stretchable, and temperature sensitive. We overcome these dichotomies by: 1) using 3D printing and scanning for customized, interwoven, anatomically accurate device architectures; 2) employing nanotechnology as an enabling route for overcoming mechanical discrepancies while retaining high performance; and 3) 3D printing a range of soft and nanoscale materials to enable the integration of a diverse palette of high quality functional nanomaterials with biology. 3D printing is a multi-scale platform, allowing for the incorporation of functional nanoscale inks, the printing of microscale features, and ultimately the creation of macroscale devices. This three-dimensional blending of functional materials and 'living' platforms may enable next-generation 3D printed devices.

10194-48, Session 9

Beyond flexible batteries: aesthetically versatile, printed rechargeable power sources for smart electronics *(Invited Paper)*

Sang-Young Lee, Ulsan National Institute of Science and Technology (Korea, Republic of)

Forthcoming wearable/flexible electronics with compelling shape diversity and mobile usability have garnered significant attention as a kind of disruptive technology to drastically change our daily lives. From a power source point of view, conventional rechargeable batteries (represented by lithium-ion batteries) with fixed shapes and dimensions are generally fabricated by winding (or stacking) cell components (such as anodes, cathodes and separator membranes) and then packaging them with (cylindrical-/rectangular-shaped) metallic canisters or pouch films, finally followed by injection of liquid electrolytes. In particular, the use of liquid electrolytes gives rise to serious concerns in cell assembly, because they require strict packaging materials to avoid leakage problems and also separator membranes to prevent electrical contact between electrodes. For these reasons, the conventional cell assembly and materials have pushed the batteries to lack of variety in form factors, thus imposing formidable challenges on their integration into versatile-shaped electronic devices. Here, as a facile and efficient strategy to address the aforementioned longstanding challenge, we demonstrate a new class of printed solid-state Li-ion batteries and also all-inkjet-printed solid-state supercapacitors with

exceptional shape conformability and aesthetic versatility which lie far beyond those achievable with conventional battery technologies.

10194-49, Session 9

Radio-frequency flexible and stretchable electronics: the need, challenges and opportunities *(Keynote Presentation)*

Zhenqiang Ma, Yei Hwan Jung, Jung-Hun Seo, Univ. of Wisconsin-Madison (United States)

Successful integration of ultrathin flexible or stretchable systems with new applications, such as medical devices and biodegradable electronics, have intrigued many researchers and industries around the globe to seek materials and processes to create high-performance, non-invasive and cost-effective electronics to match those of state-of-the-art devices. Nevertheless, the crucial concept of transmitting data or power wirelessly for such unconventional devices has been difficult to realize due to limitations of radio-frequency (RF) electronics in individual components that form a wireless circuitry, such as antenna, transmission line, active devices, passive devices etc. To overcome such challenges, these components must be developed in a step-by-step manner, as each component faces a number of different challenges in ultrathin formats. Here, we report on materials and design considerations for fabricating flexible and stretchable electronics systems that operate in the microwave level. High-speed flexible active devices, including cost effective Si-based strained transistors, nanotrench transistors, and sophisticated Bi-CMOS transistors, performing at multi-gigahertz frequencies are presented. Furthermore, flexible or stretchable passive devices, including capacitors, inductors and transmission lines that are vital parts of a microwave circuitry are also demonstrated. We also present unique applications using the presented flexible or stretchable RF components, including wearable RF electronics and biodegradable RF electronics, which were impossible to achieve using conventional rigid, wafer-based technology. Further opportunities like implantable systems exist utilizing such ultrathin RF components, which are discussed in this report as well.

10194-50, Session 9

A soft approach to electronics: from stretchable systems to 3D structures *(Invited Paper)*

Sheng Xu, Univ. of California, San Diego (United States)

Wearable device that matches the soft human body represents an important trend for bio-integration; the resulting search for pliable electronic materials calls for strategies to bridge the gap between hard and soft – among which advanced engineering of the geometry and architecture of materials presents unique opportunities. A prominent example of materials engineering is that the compressive straining of an elastic substrate can be used to fabricate previously inaccessible classes of 3D structures in monocrystalline materials. Conversely, rationally designed 2D geometries can buckle to form 3D layouts to accommodate tensile strain, resulting in unprecedented stretchability. This enables a series of device possibilities in stretchable electronics, including lithium ion batteries with record stretchability and integrated soft health monitoring systems.

10194-51, Session 9

Freeform integrated multi-sensory platform for vehicular and robotics technology *(Invited Paper)*

Muhammad M. Hussain, Joanna M. Nassar, Kush Mishra, Galo A. Torres Sevilla, Marlon D. Cordero, Arwa T. Kutbee, King Abdullah Univ. of Science and Technology (Saudi Arabia)

With the emergence of self-driven and unmanned ground and air vehicles, importance of integrated multi-sensory platform is more important than ever. An integrated system capable of handling seamless data management with integrated multi-functional sensors and actuators is a complex system. Due to many asymmetry exist in the automobiles, air vehicles and sea vessels, we need to have free form (physically flexible, stretchable and reconfigurable) multi-sensory high performance integrated electronic system. Additionally, often such systems need to be functioning under harsh environment. Therefore, we will discuss integration strategy, design criteria, material choice and process complexities to develop high performance multi-sensory free form electronic systems involving sensors and actuators.

10194-52, Session 10

Increasing component functionality via multi-process additive manufacturing *(Keynote Presentation)*

Ryan Wicker, The Univ. of Texas at El Paso (United States)

Since the commercial introduction of Additive Manufacturing (AM) technologies nearly three decades ago, considerable advancements in processing speed, accuracy, resolution and capacity have been achieved and the available AM materials have expanded, enabling customized end-use products to be directly manufactured for a wide range of applications. Many AM technologies have been released that use different processes for fabricating the individual layers from a variety of liquid, solid, and powder-based materials including polymers, metals, ceramics, composites, and more. In 2000, the University of Texas at El Paso identified AM as an emerging technology and invested strategically in establishing the W.M. Keck Center for 3D Innovation (Keck Center). The Keck Center has grown to occupy over 13,000 sq. feet with more than 50 commercial and custom AM machines. One particular focus of Keck Center research is on developing the methods and systems required to have automated control over material placement and structure creation to fabricate, for example, complex 3D devices that integrate electronics within mechanical structures. There are myriad issues associated with combining multiple materials to create functional products – from the deposition and processing of different materials to the combined performance of the materials in the resulting product. Despite these issues, the opportunities for AM in aerospace, defense, biomedical, energy and enumerable other applications continue to expand as the achievable length scales in AM decrease, the number of materials available for use in AM increases, the performance of these materials are characterized and controlled in the final product, and new strategies for integrating AM with other manufacturing technologies are successfully demonstrated.

10194-53, Session 10

Projection stereolithography 3D printing of soft robots *(Invited Paper)*

Robert Shepherd, Cornell Univ. (United States)

Synthetic replicas of natural muscle do not exist, though there are some interesting routes towards that goal. In lieu of this technology, we must use artificial muscle that behaves differently than the ratcheting mechanism of biological muscle. We have chosen to use fluidically powered, stretchable actuators that we form into bioinspired robots. To enable haptic and kinesthetic sense in these robots we 'innervate' them with stretchable strain sensors based on optical waveguides. Using this basic strategy, we have formed tentacle, squid mantle, human hand, and even human heart like robots. Recently, we have developed a material system that allows us to 3D print these robots. This talk will describe this system.

10194-54, Session 10

3D printed photodetector arrays *(Invited Paper)*

Sung Hyun Park, Michael C. McAlpine, Univ. of Minnesota (United States)

In some applications, it is desirable to position multiple photodetectors at precise locations on a curved surface defined by an optical system. For example, a hemispherical configuration of photodetector arrays has a uniform focal plane from the center to the edge which reduces aberration and distortion while offering a wider field of view. Yet the brittleness of inorganic material based photodiodes and the rigid, planar nature of photolithography fabrication methods is incompatible with the implementation of photodetectors on a curved surface. The versatility of 3D printing offers an alternative, by directly dispensing organic/inorganic electronic materials into curved or uneven surfaces. It also enables a seamless integration of electronics with the printing of other critical optical device components, such as a lens and protective layers.

We demonstrate for the first time the 3D printed semiconducting conjugated polymers as active materials to form photodetector arrays on a flexible and curved surface for an imaging application. The 3D printed polymer photodetectors (PPDs) is fabricated using phase-separated bulk heterojunction blends, poly(3-hexylthiophene) and (6,6)-phenyl-C61-butyric acid methylester as active materials. The electrodes are printable and formulated with silver nanoparticles and eutectic Gallium-Indium as conductive grids. The current-voltage measured in the dark and under illumination shows the photovoltaic characteristic of the devices. The 3D printed PPD exhibits a high rectification ratio of ~300 in the dark. The imaging test shows that the printed flexible cylindrical and hemispherical 3D PPD arrays have the wide field of view and then can be used for the curved 3D imaging applications.

10194-55, Session 10

3D printing of fiber reinforced composites with SLA *(Invited Paper)*

Randall Erb, Northeastern Univ. (United States)

Composites offer an attractive combination of high strength-to-weight ratios, high stiffness, and remarkable fracture toughness. Though continuous fiber composites offer the highest performance for sheet geometries, highly complex composite geometries generally require using discontinuous reinforcing particles that are amenable to polymer processing technologies like injection-molding, tape-casting, and 3D printing. Unfortunately, discontinuous particles produce weaker composites due, in large part, to poor control over their alignment. Complex composite geometries necessarily need complex reinforcement architectures to achieve maximal properties. Current manufacturing technologies aren't capable of producing complex composite architectures for applications requiring non-simple geometries.

Here, I present our new manufacturing process that we have termed 3D Magnetic Printing. This technique combines real-time magnetic assembly to orient traditional reinforcing ceramic particles (e.g. carbon, fiberglass, alumina) within a polymer during conventional SLA or FDM 3D Printing [1, 2]. Magnetic assembly of these nonmagnetic ceramics is achieved with an ultra-high magnetic response that we discovered in ceramic particles coated with <1 vol% of iron oxide [2]. 3D Magnetic Printing enables the creation of complex composite micro-architectures with an unprecedented 50 µm resolution. These printed composites are produced quickly and enable an investigation of structure-property relationships within composite micro-architectures.

Our vision for 3D Magnetic Printing is that we can optimally design and print any complex composite geometry. Each unique geometry can be loaded into a finite element software and the optimal reinforcement micro-architecture can be determined through simulation before sending it to the 3D Magnetic Printer. Here, we demonstrate this vision for a variety of complex geometries. We use anistropic elasticity models to describe the locally-changing (voxel-by-voxel) reinforcement microarchitectures. Our resultant composite materials demonstrate significant mechanical enhancement over monolithically reinforced materials of the same geometry [4].

[1] J. J. Martin, B. E. Fiore, R. M. Erb, Nature Communications, 2015.

[2] J. J. Martin, R. M. Erb, Soft Matter, 11, 400-405, 2015.

[3] R. M. Erb, et. al, Science, 335, 199-204, 2012.

[4] Unpublished.

10194-56, Session 11

The hype, heartache, and hope of brain-computer interfaces *(Keynote Presentation)*

R. Jacob Vogelstein, Consultant (United States)

Once restricted to the realm of science fiction, brain-computer interfaces are now commodities, sold at shopping malls around the world. However, the old adage remains true - you get what you pay for - and the functionality that can be achieved with today's devices pales in comparison to what many imagine when told it is possible to control computers with one's mind. In this talk, I will briefly recap the historical progress in brain-computer interfaces and highlight a few examples when these devices were shown to be not only interesting, but also useful. I will argue that the common element shared by such examples is not new technology or algorithms, but rather existing techniques being applied to solve problems in a new way. By focusing on the kinds of information that today's brain-computer interfaces can provide, and carefully designing applications around these signals, we can chart a path to a next generation of brain-computer interfaces that are both optimistic and realistic.

10194-57, Session 11

Non-invasive brain-computer interface: challenges and opportunities *(Invited Paper)*

Mark A. Chevillet, Johns Hopkins Univ. (United States); Scott M. Hendrickson, David W. Blodgett, Michael J. Fitch, Erich C. Walter, Johns Hopkins Univ. Applied Physics Lab., LLC (United States); Bruce A. Swett, Johns Hopkins Univ. (United States); Michael P. McLoughlin, Clara A. Scholl, Grace M. Hwang, Johns Hopkins Univ. Applied Physics Lab., LLC (United States)

The development of Non-Invasive Brain Computer Interface (NiBCI) technologies has been motivated by the tremendous success seen with implanted devices, as demonstrated by DARPA's Revolutionizing Prosthetics program, for example. This talk will discuss efforts to overcome several major obstacles to viability including approaches that promise to reduce spatial and temporal resolution. Optical approaches in particular will be highlighted and the potential benefits of both Blood-Oxygen Level Dependent (BOLD) and Fast Optical Signal (FOS) will be discussed. In the context of BOLD sensing, a novel approach based on coherent optics will be presented which so far has shown promise for improving spatial resolution in highly-scattering phantoms that mimic brain tissue; critical factors that lead to deeper penetration depths will be presented and compared to existing techniques. Early-stage research into the correlations between neural activity and FOS will be explored and novel optical techniques will be described that have the potential to enhance our understanding of this yet-understood correlate to neural activation.

10194-58, Session 11

Non-invasive neural stimulation *(Invited Paper)*

William Tyler, Arizona State Univ. (United States)

We are realizing the potential of non-invasively modulating neural circuitry through bioelectronic interfaces. Embodiments of non-invasive neuromodulation include the use of electrical, photonic, magnetic, and ultrasonic energy to modulate brain function. Besides traditional basic research and medical device development, there is a growing “hacker” or DIY community engaged in modulating brain function for self-treatment and recreational or aesthetic purposes. Direct-to-consumer (DTC) neuromodulation devices have also begun to make a market appearance. Conventional indications for neurostimulation have been medical, which poses a unique series of regulatory questions. A number of recreational indications that have begun to emerge are related to Human Performance Enhancement. Implications of these trends will be discussed in the context of opportunities and threats from a National Security perspective. Examples of specific technologies will highlight the development of ultrasonic neuromodulation and transdermal electrical neurostimulation. Ongoing research designed to optimize Human Dimensions including improving Warfighter Psychological Resilience, Vigilance, and Cognitive Dominance will be discussed. Other efforts aimed at developing non-invasive neurostimulation for accelerating training and improving performance outcomes in support of the different Training Doctrines of the U.S. Department of Defense and Intelligence Community will be discussed. In summary, major investments are being made in the space by domestic and foreign government entities, as well as private investors and large companies. Significant opportunities exist to design and engineer technical solutions and biological applications in the field. Some of these oppurtunities will be highlighted to encourage expanded research and development on non-invasive neurostimulation for space, defense, and medical applications.

10194-59, Session 11

Your eyes give you away: pupillary responses, EEG dynamics, and applications for BCI *(Invited Paper)*

Paul Sajda, Columbia Univ. (United States)

As we move through an environment, we are constantly making assessments, judgments, and decisions about the things we encounter. Some are acted upon immediately, but many more become mental notes or fleeting impressions -- our implicit “labeling” of the world. In this talk I will describe our work using physiological correlates of this labeling to construct a hybrid brain-computer interface (hBCI) system for efficient navigation of a 3-D environment.

Specifically, we record electroencephalographic (EEG), saccadic, and pupillary data from subjects as they move through a small part of a 3-D virtual city under free-viewing conditions. Using machine learning, we integrate the neural and ocular signals evoked by the objects they encounter to infer which ones are of subjective interest. These inferred labels are propagated through a large computer vision graph of objects in the city, using semi-supervised learning to identify other, unseen objects that are visually similar to those that are labelled. Finally, the system plots an efficient route so that subjects visit similar objects of interest.

We show that by exploiting the subjects’ implicit labeling, the median search precision is increased from 25% to 97%, and the median subject need only travel 40% of the distance to see 84% of the objects of interest. We also find that the neural and ocular signals contribute in a complementary fashion to the classifiers’ inference of subjects’ implicit labeling. In summary, we show that neural and ocular signals reflecting subjective assessment of objects in a 3-D environment can be used to inform a graph-based learning model of that environment, resulting in an hBCI system that improves navigation and information delivery specific to the user’s interests.

10194-60, Session 11

Beyond intuitive anthropomorphic control: Recent achievements of the revolutionizing prosthetics program *(Invited Paper)*

Michael P. McLoughlin, Brock A. Wester, James D. Beaty, Johns Hopkins Univ. Applied Physics Lab., LLC (United States)

The Revolutionizing Prosthetics Program is an ambitious multiyear effort—funded by the Defense Advanced Research Projects Agency (DARPA)—to create a neurally controlled artificial limb that will restore near-natural motor and sensory capability to upper-extremity amputee patients. In 2006, the state of upper-limb prosthetic technology was far behind lower-limb technology, with many amputees opting not to wear a prosthetic. Advancing upper-limb technology offers the promise of helping injured service members ultimately providing the option to return to active duty. Millions of Americans have lost the ability to utilize their hands and arm due to amputation, spinal cord injury (SCI), stroke, amyotrophic lateral sclerosis (ALS), multiple sclerosis or other near degenerative conditions. The Johns Hopkins University Applied Physics Laboratory (APL) is leading an interdisciplinary team consisting of other Johns Hopkins institutions, government agencies, universities, and private firms to implement DARPA’s vision of providing the most advanced upper-extremity prosthesis. In this talk we will describe recent advances in robotics, human machine interfaces, and neuroscience; and development of prototype systems that are providing great hope to people with arm amputations and to those that have lost the ability to control their natural limbs. Furthermore, we will describe how the technological capabilities developed under this effort are being applied to mobile robotic systems for hazardous operations ranging from manipulating unexploded ordnance to working with potentially radioactive materials, thus keeping both soldiers and American workers out of potentially dangerous situations that could led to limb loss or other injury.

10194-61, Session 12

Research and development program in fiber optic sensors and distributed sensing for high temperature harsh environment energy applications *(Keynote Presentation)*

Robert R. Romanosky, National Energy Technology Lab. (United States)

he National Energy Technology Laboratory (NETL) under the Department of Energy (DOE) Fossil Energy (FE) Program is leading the effort to not only develop near zero emission power generation systems, but to increaser the efficiency and availability of current power systems. The overarching goal of the program is to provide clean affordable power using domestic resources. Highly efficient, low emission power systems can have extreme conditions of high temperatures up to 1600 oC, high pressures up to 600 psi, high particulate loadings, and corrosive atmospheres that require monitoring. Sensing in these harsh environments can provide key information that directly impacts process control and system reliability. The lack of suitable measurement technology serves as a driver for the innovations in harsh environment sensor development. Advancements in sensing using optical fibers are key efforts within NETL’s sensor development program as these approaches offer the potential to survive and provide critical information about these processes. An overview of the sensor development supported by the National Energy Technology Laboratory (NETL) will be given, including research in the areas of sensor materials, designs, and measurement types. New approaches to intelligent sensing, sensor placement and process control using networked sensors will be discussed as will novel approaches to fiber device design concurrent with materials development research and development in modified and coated silica and sapphire fiber based sensors. The use of these sensors for both single point and distributed measurements of temperature, pressure, strain, and a select suite of gases will be addressed. Additional areas of research includes novel control architecture and communication frameworks, device integration for distributed sensing, and imaging and other novel approaches to monitoring and controlling advanced processes. The close coupling of the sensor program with process modeling and control will be discussed for the overarching goal of clean power production.

10194-62, Session 12

Nanostructured sapphire optical fiber for sensing in harsh environments *(Invited Paper)*

Henry Du, Stevens Institute of Technology (United States)

The potential of sapphire fiber for sensing in harsh environments has long been recognized. Development of robust cladding has remained elusive due largely to challenges associated with suitable materials and their deposition. Progress in developing structurally and chemically stable cladding on sapphire fiber will usher in new sensor design and capabilities. This talk will highlight our work on the development of all-alumina nanostructured sapphire fiber sensors: singe crystal sapphire fiber as the waveguide core and nanoporous alumina coating with highly organized pore channels vertically aligned to the fiber surface as the cladding. Our combined theoretical and experimental studies show that (1) the nanostructured sapphire fiber is structurally stable up to 1000oC; (2) the evanescent field can be extended significantly from the surface of the fiber core to the porous cladding structure with stronger field overlap, compared to cladding-free sapphire fiber; (3) the intricate cladding structure of high specific surface area provides an abundance of molecular adsorption sites and allows rapid access of target analytes for evanescent-field laser spectroscopy interrogation; (4) the cladding functions as a host for as well as stabilizer of Ag nanoparticles which would otherwise undergo agglomeration, Ostwald ripening, and evaporation depletion if on a bare sapphire fiber surface at high temperature; and (5) nanostructured sapphire fiber with Ag nanoparticles within the cladding pore channels exhibits robust SERS activity for sensitive chemical sensing upon repeated thermal treatment at 500oC. The prospect of nanostructured sapphire fiber sensors for advanced energy systems will be discussed.

10194-63, Session 12

Combustor deployments of femtosecond laser written fiber Bragg grating arrays for temperature measurements surpassing 1000 °C *(Invited Paper)*

Robert B. Walker, Huimin Ding, David Coulas, Stephen J. Mihailov, National Research Council Canada (Canada); Marc A Duchesne, Robin W Hughes, David J McCalden, Ryan Burchat, Robert Yandon, Natural Resources Canada, CanmetENERGY (Canada); Sangsig Yun, Nanthan Ramachandran, Michel Charbonneau, National Research Council Canada (Canada)

With appropriate exposure conditions, Bragg gratings written into silica based fibers with femtosecond pulse duration infrared lasers and a phase mask can have very high thermal stability at temperatures approaching 1100 °C. The use of phase masks that produce fundamental Bragg resonances in the fiber core along with laser intenisities that promote type II grating formation after the absorption of several laser pulses results in FBGs with low scattering loss that can be concatenated into quasi-distributed sensing arrays. This paper presents the fabrication and deployment of several infrared femtosecond laser written FBG temperature probes, each with more than 40 sensors, for monitoring internal and exhaust temperature gradients of a gas turbine combustor simulator.

Advanced gas turbine engines require accurate measurement of exhaust temperatures at the combustor exit in order to improve efficiency and arrive at more stringent emission targets. These requirements drive the engine operation closer and closer to established limits. The ability to measure temperature under such harsh environments is currently restrained by the lack of sensors and controls capable of withstanding the high temperature, pressure and corrosive conditions present. Thermocouples are most commonly used due to their low cost and simplicity, however their reliability within these harsh conditions is poor. Furthermore where steep temperature gradients exist, their slow response and instrumentation complexity demand alternative solutions. Femtosecond laser induced FBG sensors have inherent advanatages over thermocouples for rapidly measuring high resolution temperature profiles under harsh conditions.

Results of this work include: contour plots of measured internal and exhaust temperature gradients, contrast of FBG measurements with thermocouple data, discussion of deployment strategies, as well as comments on reliability and other important considerations.

10194-64, Session 12

High spatial resolution fiber optical sensors for simultaneous temperature and chemical sensing for energy industries *(Invited Paper)*

Kevin P. Chen, Aidong Yan, Mohamed A. S. Zaghloul, Univ. of Pittsburgh (United States); Michael P. Buric, Paul R. Ohodnicki, National Energy Technology Lab. (United States)

Optical fibers are widely used sensing platforms. Both silica and sapphire fiber optical sensors have been developed to perform various physical measurements such as temperature, strain, and pressures sensing at high temperatures for energy applications. This paper utilizes optical fibers as high-temperature sensor platforms to develop an integrated sensor solution to perform temperature measurements and to probe energy chemistry for high-temperature energy applications for both fossil fuel and nuclear power generation.

A scalable nanofabrication scheme is developed to engineer refractive indices, surface areas, and chemical specificities of a wide range of transition metal oxides and their dopant variants for fiber optical chemical sensing in high temperatures (400-900C). Functional metal oxide sensory materials with proper refractive indices and chemical sensitivities will be integrated on both silica fiber and sapphire fiber platforms. Using distributed fiber sensing schemes such as Rayleigh backscattering Optical Frequency Domain Reflectometry, or fiber Bragg grating arrays, we will develop a unique distributed fiber optical chemical sensing technique to probe energy chemistry at high temperatures with high spatial resolution of 1-cm or better. Using the same distributed fiber sensing scheme, various metal oxides will be integrated on-fiber for real-time multi-species gas measurements in high temperatures (400-900oC) environments.

10194-65, Session 12

Functionalized optical fiber sensor material and device research at the National Energy Technology Laboratory *(Invited Paper)*

Paul R. Ohodnicki Jr., Michael P. Buric, Benjamin T. Chorpening, Zsolt L. Poole, National Energy Technology Lab. (United States)

An overview of functionalized optical fiber sensor material and device research within the National Energy Technology Laboratory Research and Innovation Center will be presented. Current efforts target enabling

materials as functional sensor layers as well as high temperature optical fibers for applications spanning power generation, oil & gas resource recovery, the natural gas midstream infrastructure, carbon sequestration, and power transformer monitoring. New advances in materials, sensing principles, mechanisms for self powered sensors, and first principles calculations seeking to understand basic optical and electronic properties of sensing materials will be discussed.

10194-66, Session 13

Human-machine teaming and intelligent synthetic teammates: vision, requirements, and advances *(Keynote Presentation)*

Micah H. Clark, Office of Naval Research, U.S. Navy (United States)

The promise of highly effective, human-machine teams (and the capabilities and operating concepts enabled thereby) has the attention of senior leaders in the U.S. Department of Defense (DoD) and military. The perceived benefits and importance of human-machine teaming are reflected in the Secretary of Defense's Third Offset Strategy, in DoD roadmaps, and in the strategic plans and future operating concepts of the individual armed services. In order to realize the potential of human-machine teams, it is essential to identify the capabilities that are necessary and enabling for intelligent synthetic and robotic teammates. To that end, seven requirements for synthetic teammates are identified and discussed, namely:

1. Be Informative — convey the right information, the right way, at the right time;
2. Be Transparent — explain actions, decisions, and recommendations;
3. Recognize Limitations — manage uncertainty, risk, consequences, and contingencies;
4. Recognize Others — their needs, goals, beliefs, abilities, and activities;
5. Communicate — using situated dialogue, gesture, and touch;
6. Learn, Adapt, & Accept Instruction — regarding context, environment, self, and others;
7. Do what is "Right" — with respect to authority, responsibility, and morality.

These requirements target aspects of synthetic and robotic intelligence that are critical to the construction of cognitively and socially compatible intelligent systems and interfaces. Furthermore, these requirements will help us avoid the continual evolution toward systems that are physically sophisticated but intellectually stupid.

10194-67, Session 13

Building a framework to manage trust in automation *(Invited Paper)*

Jason S. Metcalfe, U.S. Army Research Lab. (United States); Amar R. Marathe, U.S. Army Research Lab. Human Research and Engineering Directorate (United States); Victor J. Paul, U.S. Army Tank Automotive Research, Development and Engineering Ctr. (United States); Gregory M. Gremillion, U.S. Army Research Lab. Sensors and Electron Devices Directorate (United States); Kim Drnec, U.S. Army Research Lab. Human Research and Engineering Directorate (United States); Corey Atwater, DCS Corp. (United States) and U.S. Army Tank Automotive Research, Development and Engineering Ctr. (United States); Justin R. Estepp, Air Force Research Lab. (United States); Jamie Lukos, Space and Naval Warfare Systems Command (United States); Evan C. Carter, U.S. Army Research Lab. Human Research and Engineering Directorate (United States); William D. Nothwang, U.S. Army Research Lab. Sensors and Electron Devices Directorate (United States); Benjamin A. Haynes, U.S. Army Tank Automotive Research, Development and Engineering Ctr. (United States)

All automations must, at some point in their lifecycle, interface with one or more humans. Whether operators, end-users, or bystanders, human responses can determine the perceived utility and acceptance of an automation. It has been long believed that human trust is a primary determinant of most human-automation interactions and further presumed that calibrating trust can lead to appropriate choices regarding automation use. However, attempts to improve joint system performance by calibrating trust have not yet provided a generalizable solution. To address this, we identified several factors limiting the direct integration of trust, or metrics thereof, into an active mitigation strategy. The present paper outlines our approach to addressing this important issue, its conceptual underpinnings, and practical challenges encountered in execution. Among the most critical outcomes has been a shift in focus from trust to basic interaction behaviors and their antecedent decisions. This change in focus inspired the development of a testbed and paradigm that was deployed in two experiments of human interactions with driving automation that were executed in an immersive, full-motion simulation environment. Moreover, by integrating a behavior and physiology-based predictor within a novel consequence-based control system, we demonstrated that it is possible to anticipate particular interaction behaviors and influence humans towards more optimal choices about automation use in real time. Importantly, this research provides a fertile foundation for the development and integration of advanced, wearable technologies for sensing and inferring critical state variables for better integration of human elements into otherwise fully autonomous systems.

10194-68, Session 13

Situation awareness-based agent transparency for human-autonomy teaming effectiveness *(Invited Paper)*

Jessie Y. C. Chen, Michael J. Barnes, U.S. Army Research Lab. (United States); Kimberley Stowers, Univ. of Central Florida (United States); Julia L. Wright, U.S. Army Research Lab. (United States); Shan G. Lakhmani, Univ. of Central Florida (United States)

As autonomous agents become more sophisticated and independent, it is critical for their human counterparts to understand their actions and plans, the reasoning process, and the expected outcomes to properly calibrate their trust in the systems and make appropriate decisions]. We developed a model of agent transparency to support operator situation awareness of the mission environment involving the agent, the Situation awareness-based Agent Transparency (SAT) model, which includes the agent's current actions and plans (Level 1), its reasoning process (constraints and affordances being considered; Level 2), and its projection of future outcomes (including uncertainty; Level 3). Human-in-the-loop simulation experiments have been conducted (RoboLeader, Autonomous Squad Member, and IMPACT) to illustrate the utility of the model for human-autonomy team interface designs (the Autonomous Squad Member project and the IMPACT project were funded by the OSD Autonomy Research Pilot Initiative). Across studies, the results consistently showed that human operators' task performance improved as the agents became more transparent. They also perceived transparent agents as more trustworthy. The SAT model is currently being expanded to incorporate the Teamwork aspect (agent's understanding of its roles and responsibilities) and the Bi-directional aspect (transparency from the human to the machine agent), which can be applicable to all three levels of SAT.

10194-69, Session 13

Curious Partner: an autonomous system that proactively dialogues with human teammates *(Invited Paper)*

Emily Doucette, J. Willard Curtis, Air Force Research Lab. (United States); Siddhartha S. Mehta, Univ. of Florida (United States)

To leverage the full capabilities of autonomous agents in a dynamic and uncertain battlefield, bi-directional understanding must exist between all agents, both human and autonomous, when an unexpected event occurs. If the human commander of a team of human and unmanned agents changes an unmanned agent's intended plan, current technology does not permit the autonomous agent to query the human commander as to why the plan has changed. Although the human and autonomy receive identical information from the team of agents in the environment, there may be inconsistencies in the representation of the environment due to difference in their perception and expert knowledge. If autonomous agents were able to acquire insight from human commanders as to what motivated the change in the pre-determined mission plan, their ability to adapt to a dynamic battlespace would greatly improve and consequently support mission success.

Conversely, suggestions from autonomous agents must be transparent in order to aid in human decision-making. A dialog-based three phase human-autonomy interaction approach is presented. The Curious Partner interaction framework is presented to resolve model-level differences between the human and the autonomy to establish common ground by proactive and retroactive dialogue. The framework includes a learning component where the dialog acts as a feedback mechanism to adapt the autonomy's Bayesian belief network representation of the environment. The dialogue is cued when a divergence in consistency is detected or predicted between the world models of the human and autonomy.

10194-70, Session 13

Toward experimental validation of a model for human sensorimotor learning and control in teleoperation *(Invited Paper)*

Samuel A. Burden, Eatai Roth, Univ. of Washington (United States)

Humans, interacting with cyber-physical systems (CPS), formulate beliefs about the system's dynamics. It is natural to expect that human operators, tasked with teleoperation, use these beliefs to control the remote robot. For tracking tasks in the resulting human-cyber-physical system (HCPS), theory suggests that human operators can achieve exponential tracking (in stable systems) without state estimation provided they possess an accurate model of the system's dynamics. This internalized inverse model, however, renders a portion of the system state unobservable to the human operator—the zero dynamics. Prior work shows humans can track through observable linear dynamics, thus we focus on nonlinear dynamics rendered unobservable through tracking control. We propose experiments to assess the human operator's ability to learn and invert such models, even as the cyber-physical system intervenes by altering the model to improve performance.

10194-72, Session 14

IMPACT machine learning efforts *(Invited Paper)*

Douglas S. Lange, John D. Reeder, SPAWAR Systems Ctr. Pacific (United States)

Amplifying human ability for controlling complex environments featuring autonomous units can be aided by learned models of human and system performance. In developing a command and control system that allows a small number of people to control a large number of autonomous teams, we employ an autonomics framework to manage the networks that represent mission plans and the networks that are composed of human controllers and their autonomous assistants. Machine learning allows us to build models of human and system performance useful for monitoring plans under intermittent communications and managing human attention and task loads. In this paper, we present our application of the Rainbow Autonomics Framework for plan monitoring and task management within a command and control system. We describe our utilization of machine learning for the purpose of managing plans under intermittent communications in the plan monitoring application. We also describe the use of machine learning for building a model of human performance useful in managing the attention and task load of users, and aiding in the strategy selection within the framework to choose task allocation methods and initiate repair strategies. We also show how machine learning aids in the selection of strategies in a non-deterministic environment.

10194-73, Session 14

Acting as a scalable team in unstructured environments *(Invited Paper)*

Thomas Apker, Benjamin Johnson, David W. Aha, U.S. Naval Research Lab. (United States)

We have found a scalable way to significantly increase the likelihood that robots perform useful behaviors in unstructured environments by combining formally correct-by-construction finite state automata (FSA) with swarm behaviors based on Physicomimetics. This allows us to solve two major problems facing the deployment of swarming robotics, namely that swarms are notoriously difficult to control from an external agent such as a human operator or artificial intelligence and address the fact that most swarm algorithms are only robust to complete agent failure, not all predictable failure modes common to networked robotics. We describe how to design a Vehicle Agent using a set of Linear Temporal Logic templates that specify an FSA over the behavior space of a mobile robot that ensures the robot can perform its intended actions and how such a vehicle can interact with Task Agents whose parameters are set using Goal Refinement. that allow an operator or AI to command a particular behavior rather than assuming the desired behavior will emerge from the swarm's interaction with the environment.

10194-74, Session 14

Decentralized asset management for collaborative sensing *(Invited Paper)*

Raj Malhotra, Air Force Research Lab. (United States)

There has been increased impetus to leverage Small Unmanned Aerial Systems (SUAS) for collaborative sensing applications in which many platforms work together to provide critical situation awareness in dynamic environments. Such applications require critical sensor observations to be made at the right place and time to facilitate the detection, tracking, and classification of ground-based objects. This further requires rapid response to real-world events and the balancing of multiple, competing mission objectives. In this context, human operators become overwhelmed with management of many platforms. Further, current automated planning paradigms tend to be centralized and don't scale up well to many collaborating platforms. We introduce a decentralized approach based upon information-theory and distributed fusion which enable us to scale up to large numbers of collaborating SUAS platforms. This is exercised against a military application involving the autonomous detection, tracking, and classification of critical mobile targets. We further show that, based upon monte-carlo simulation results, our decentralized approach out-performs more static management strategies employed by human operators and achieves similar results to a centralized approach while being scalable and robust to degradation of communication. Finally, we describe the limitations of our approach and future directions for our research.

10194-75, Session 14

Priming for autonomous cognitive systems *(Invited Paper)*

Mary Anne Fields, U.S. Army Research Lab. (United States); Michael K. Martin, Carnegie Mellon Univ. (United States)

Considering context and the relationship between objects and events in the environment is a key component to developing a level of situational awareness necessary to accomplish abstract goals or effectively share information with human and non-human teammates. In this paper we will discuss our efforts to exploit cognitive models of priming to enable intelligent systems combine perception and cognitive reasoning to understand the implications of the spatial arrangement of objects a to a specific task. We focus on two tasks. The first task involves finding a secured observation position near a designated building. While state of the art perception algorithms can identify specific objects in the vicinity of the building, cognitive reasoning can identify ad-hoc and natural arrangements of those objects that could impact the choice of an observation position. In our second task, identifying dangerous items in the building is a combination of state of the art perception supported by an efficient search strategy. Cognitive reasoning can contribute to this search strategy by identifying potential hiding spots for items relevant to the mission. More broadly, we will discuss the interaction between cognitive tools and machine perception.

10194-76, Session 15

Tier-scalable reconnaissance: the future in autonomous C4ISR systems has arrived *(Invited Paper)*

Wolfgang Fink, Mark A. Tarbell, The Univ. of Arizona (United States)

Autonomous reconnaissance missions are called for in extreme environments, as well as in potentially hazardous (e.g., the theatre, disaster-stricken areas, etc.) or inaccessible operational areas (e.g., planetary surfaces, space). Such future missions will require increasing degrees of operational autonomy, especially when following up on transient events. Operational autonomy requires: (1) Automatic characterization of operational areas from different vantages (i.e., spaceborne, airborne, surface, subsurface); (2) automatic sensor deployment and data gathering; (3) automatic feature extraction including anomaly detection and region-of-interest identification; (4) automatic target prediction and prioritization; (5) and subsequent automatic (re-)deployment and navigation of robotic agents. This talk touches on several aspects of autonomous C4ISR systems, including: patented and NASA-awarded multi-tiered mission architectures, robotic platform development (air, ground, water-based), and autonomous decision making based on a Caltech-patented framework comprising sensor-data-fusion (feature-vectors), anomaly detection (clustering and principal component analysis), and target prioritization (hypothetical probing).

10194-77, Session 15

Integrating autonomous distributed control into a human-centric C4ISR environment *(Invited Paper)*

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

This paper considers the incorporation of autonomy into human-centric Command, Control, Communications, Computers, Intelligence, Surveillance and Reconnaissance (C4ISR) environments. These environments are typically mission-critical and are often safety-critical and may have more far reaching (national security and similar) implications. In many cases, humans operating in the C4ISR realm are overloaded with information, which they must (consequently) process heuristically, not always resulting in the ideal outcome. Automation and autonomous command and control technologies can augment and replace human actors in these challenging environments. However, at least in the short term, human involvement in C4ISR is expected. Thus, it is necessary to integrate human workers and decision makers and autonomous decision makers and robotic workers.

To this end, this paper focuses on identifying ways that current autonomy technologies can augment human control. Approaches including autonomous oversight, autonomy enhancement of humans and autonomous replacement of human decision makers are presented. The challenges that incorporating autonomy can present are considered and discussed.

Three different approaches to this challenge are considered, stemming from prior work in converging areas In the first, the problem is approached as augmenting what humans currently do with automation. This approach assumes that existing human processes already are optimized, through repetition and performer-refinement and seeks to enhance the process in a way that is well-received by performers. In the alternate approach, the problem is approached as treating humans as actors within a cyber-physical system-of-systems (stemming from robotic distributed computing). A third approach, combining elements of the aforementioned is also considered.

10194-78, Session 15

IT-security challenges in IoT environments and autonomous systems *(Invited Paper)*

Ulrich Heun, CARMAO GmbH (Germany)

The presentation will start with an overview of current and future services based on IoT-Infrastructures in conjunction with autonomous algorithms and systems. A look at current threats and endangements will lead over to the most relevant challenges with regards IT security vulnerabilities of such infrastructures and highlights the impact on business and social consequences.

10194-79, Session 16

Space technology for healthcare and medicine: early detection of cancer *(Keynote Presentation)*

Sudhir Srivastava, National Cancer Institute (United States)

Objective: Early detection of cancer faces challenges in finding the early indicators of disease because it is like finding the needle in the haystack. At an early stage of cancer there are fewer abnormal cells among millions of normal cells. Space research has faced similar challenges where a variety of sensors are used to study a variety of objects, but the developed technologies can visualize, analyze and interpret objects and images a million miles away. These technologies can be repurposed for medicine, especially for diagnostics. Our collaboration with the Jet Propulsion Laboratory (JPL) has helped develop The Knowledge Systems by seamlessly integrating vast amount of disparate data generated through genomics and proteomics approaches and biospecimen banks. A clinically annotated image reference library is being developed for interpreting the experimental data. Imaging technologies, such as computed tomography (CT), positron emission tomography (PET), magnetic resonance imaging (MRI) and optical-based imaging for visualization of lesions, are increasingly being used in cancer diagnostics. New molecular technologies, such as Next Generation Sequencing (NGS), proteomics, genomics and metabolomics, are paving the path for more sensitive detection that is promising, but also generating many false positives contributing to overdiagnosis and unnecessary invasive diagnostic work-ups. Learning from space research in handling vast amount of data using computational tools is valuable for combining imaging information with biological markers and developing machine learning algorithms. This may help address unmet clinical needs including the differentiation of lethal cancers from non-lethal disease, reducing overdiagnosis, lowering the number of false-positive and false-negative test results and developing more accurate tests to detect and assess breast, prostate, ovarian, pancreas, esophageal, lung and other cancers.

10194-80, Session 16

Overview of the Inland California Translational Consortium *(Invited Paper)*

Linda H. Malkas, City of Hope Comprehensive Cancer Ctr. (United States)

The mission of the Inland California Translational Consortium (ICTC), comprising a unique hub of regional institutions (City of Hope [COH], California Institute of Technology [Caltech], University of California Riverside [UCR], and Claremont Colleges Keck Graduate Institute [KGI]), is to establish a new paradigm within the academic culture to accelerate translation of innovative biomedical discoveries into clinical applications that positively affect human health and life. The ICTC supports clinical and translational research as well as the implementation and advancement of novel education and training models for the translational research workforce at all levels. The overall purpose of our combined efforts is to expedite the translation of basic discoveries into workable products and practices that preserve and improve human health while training and educating at all levels of the workforce using innovative forward-thinking approaches. We have developed ICTC research programs that are designed to extend from the earliest phase of basic discovery to final realization in the population. ICTC also will develop new approaches to clinically test cutting-edge technologies and practices in underserved, pediatric and aging populations. Over the next five years, ICTC will leverage each of the consortium member's strengths, ranging from new product and device discovery to clinical research applications, health equity development and implementation. ICTC will practice advocacy (or community) engaged team science to rapidly transfer discoveries from the laboratory to bedside and into both the clinical and entrepreneurial sectors.

10194-81, Session 16

A novel space ocular syndrome is driving technology advances on and off the planet *(Invited Paper)*

Dorit Donoviel, National Space Biomedical Research Institute (United States); Richard Clayton, Annidis Corporation (Canada)

Astronauts are experiencing ophthalmological changes including optic-disc edema, globe flattening, choroidal folds, and significant hyperopic shifts. In a handful of cases in which it was measured, intracranial pressure was elevated postflight. The severity of symptoms is highly variable and the underlying etiology is unknown, but a spaceflight associated cephalad-fluid shift is thought to play a role. NASA requires portable, non-invasive, clinically-validated diagnostic approaches to assessing the ocular and the cerebral physiological, anatomical, and functional changes. Multispectral Imaging (MSI) that enables instruments installed on satellites to observe Earth from space was applied in a medical device that is being evaluated for use on humans in space. The Annidis RHA™ uses narrow band light emitting diodes (LEDs) to create discrete slices of anatomical structures of the posterior pole of the eye. The LEDs cover a frequency range from 520 to 940 nm, which allows for specific visualization of the different features of the posterior eye including retinal, choroid and optic nerve head. MSI creates slices derived from illumination of specific regions of interest from LEDs across the spectrum and the images are stacked and viewed. Interestingly, infrared illumination at 940 nm reflects from the posterior sclera and gives retro-illumination which provides enhanced imaging of the choroidal vasculature without the need for invasive contrast agents. Abnormalities in retinal, choroid or cerebral venous drainage and/or arterial flow may contribute to the ocular syndrome in astronauts; hence this space technology may prove to be invaluable for diagnosing not only the health of our planet but also of the humans living above it.

10194-82, Session 16

John Glenn, electronics nose, and record setting space walks *(Keynote Presentation)*

Scott Parazynski M.D., Fluidity Technologies (United States)

The challenging conditions of human spaceflight and other extreme environments serve as ideal catalysts for disruptive innovation. A physician astronaut, having flown five space shuttle missions and conducted seven spacewalks, he has climbed some of the world's tallest mountains and overseen healthcare for the US Antarctic Program. Scott will discuss examples of technologies he has developed that are now making their way to the marketplace. He will address the challenges of taking an invention all the way to patients and consumers, and the importance of multidisciplinary teams to bring this about.

10194-83, Session 16

NASA-JPL overview, space technology and relevance to medicine *(Keynote Presentation)*

Jakob van Zyl, Jet Propulsion Lab. (United States)

There is special synergy between NASA space instruments and medical devices, especially those that may be implanted in the human body. For example, in both cases instruments have to be small, typically have to consume little power and often have to operate in harsh environments. JPL has a long history in using this synergy to leverage from the technology developed for space missions for application in medical fields. In this talk, we discuss the general overlap of technological requirements in the medical field and space science. We will highlight some examples where JPL instrumentation and engineering has been transferred successfully.

10194-84, Session 16

Building a knowledge system for cancer biomarker research *(Invited Paper)*

Daniel Crichton, Jet Propulsion Lab. (United States); Ashish A. Mahabal, California Institute of Technology (United States)

The opportunities and challenges of data-driven computing will define a major component of research in the 21st century. The National Research Council, in its report, "Frontiers in the Analysis of Massive Data" (2013), identified many of the challenges in scientific analysis for data-driven disciplines such as are occurring in cancer biomarker research. The National Cancer Institute's Early Detection Research Network (EDRN) has been active in planning, researching and developing capabilities to support data intensive science for cancer biomarker research by developing an informatics infrastructure to systematically capture, process, management, distribute and analyze data acquired during cancer biomarker research through an advanced knowledge system. As the data across such areas as proteomics, genomics, and imaging increase, the need to systematically capture, manage and analyze data through an advanced knowledge system, such as the EDRN Knowledge System, is continue to increase. Furthermore, the use of automated data processing, intelligent algorithms for data reduction, inference and analysis, and consistent data pipleines from laboratory data management and analysis through to analysis across distributed, collaborative research teams, is requiring that informatics ensure that systematic capabilities are in place to support the reproducibility challenges presented in biomedical research. Through its collaboration with NASA/JPL, the EDRN and the science community, are well positioned to take on many of the challenges that will be presented in cancer biomarker research as the need for data intensive science increases. Integrating informatics into science research is going to continue to be critical as EDRN and other NCI programs move forward in pioneering new approaches to discovery and validation of cancer biomarkers.

10194-85, Session 16

A dual use case study of space technologies for terrestrial medical applications *(Invited Paper)*

Ioana Cozmuta, NASA Ames Research Ctr. (United States)

Many challenges exist in understanding the human body as a whole, its adaptability, its resilience, its immunological response, its healing and regeneration power. New knowledge is usually obtained by exploring unique conditions and environments and space is one such variable.

Primarily, these attributes have been studied in space for the purpose of understanding the effect of the space environment on long duration space travel. However a myriad of lessons learned have emerged that are important for terrestrial medicine problems such as cardiovascular changes, intracranial pressure changes, vision changes, reduced immunity, etc.

For medical study purposes, the changes induced by the space environment on the human body are in general fast and predictable; they persist while in the space environment but also revert to the initial pre-flight healthy state upon return to Earth. This provides a unique cycle to study wellness and disease prediction as well as to develop more effective countermeasures for the benefit of people on earth.

At a scientific level, the environment of space can be used to develop new lines of investigations and new knowledge to push the terrestrial state of the art (i.e. study of phase diagrams, identification of new system's states, etc). Moreover, the specialized requirements for space medicine have driven advances in terrestrial medical technologies in areas such as monitoring, diagnostic, prevention and treatment.

This talk will provide an overview of compelling examples in key areas of interest for terrestrial medical applications.

10194-86, Session 16

Fluorescence and reflectance measurements in the ultraviolet, visible, and near infrared using delta-doped silicon arrays with custom coating for medical applications *(Invited Paper)*

Samuel R. Cheng, Dana K. Budzyn, Shouleh Nikzad, Jet Propulsion Lab. (United States)

Imaging and Imaging Spectroscopy in the ultraviolet (UV), visible, and near infrared (NIR) part have a wide range of applications in astrophysics, planetary studies, heliophysics, commercial and medical diagnostics. A major part of system performance is contributed by the detector metrics. JPL-developed sensors developed using 2D-doping and custom coatings provide high performance across the UV, visible, and NIR region of the spectrum. Applying these 2-D surface and interface engineering technologies to detector structures with gain (e.g., Avalanche Photodiodes or APDs or electron multiplying charged-coupled devices or EMCCDs) enables photon-counting capabilities in solid state format rather than image tube detectors. Initially developed for space exploration applications for detecting faint signals in harsh environments while using low voltage and low power, these high efficiency detectors can be repurposed for medical applications that have much of the same requirements. For example, endogenous and induced fluorescence signatures in tissues as emergent diagnostic tools for abnormal tissue behaviors can potentially be detected using these detectors with high efficiency.

Using JPL high efficiency imaging arrays, transient fluorescence signatures could be detected with small amount of stimulation. This brings the added advantage of precise fluorescence signature quantification, without damage to the host organism or tissue. In this work, we present fluorescence detection of phantom samples that serve as proof of concept demonstration while calibrating the instrument.

10194-106, Session PWed

Magnetic dark modes in terahertz plasmonic metamaterials for ultrafast switching

Arash Ahmadivand, Raju Sinha, Burak Gerislioglu, Mustafa Karabiyik, Nezih Pala, Florida International Univ. (United States)

Terahertz (THz) plasmonic metamaterials with the ability to sustain both symmetric and antisymmetric resonant modes have received growing interest for practical applications. By inducing Fano resonances and electromagnetically induced transparencies in THz plasmonic metamaterials, they provide new promising platforms for various technologies such as slow light technology, photodetectors with high-responsivity, and sensors with high sensistivy. In this work, we study the plasmonic response of metallic (Fe) structures deposited in arrays on a high-resistivity silicon substrate. Using both experimental and numerical analysis, we have shown that the proposed microstructures can be tailored to support strong magnetic dark modes with ultrasensitive polarization dependency. Accordingly, for the incoming longitudinal polarization of THz radiation, the structure support ultrasharp dark modes across the sub-THz band, while for the transverse polarization, the structure does not support significant resonances and acts as a transparent unit with trivial absorption. Such a giant dependency allows for tailoring highly fast and efficient plasmonic THz switches.

10194-107, Session PWed

Characterization and applications of VO2 thin film synthesized by a vapor-solid method in tube furnace

Jijun Zou, East China Univ. of Technology (China)

Transition metal oxides offer a wide spectrum of properties which provide the foundation for a broad range of potential applications. We synthesized large area VO2 thin film on different substrates, such as SiO2/Si, Si3N4, Si and quartz, by vapor-solid (VS) method in an electric tube furnace for the first time. The as-synthesized VO2 film is structurally uniform and single crystalline. The thicknesses for most of thin films vary from 500 to 1500 nm. Crystal structure and surface morphology of thin films have been characterized by X-ray diffraction (XRD) and scanning electron microscopy (SEM). The resistance of VO2 thin films changes by more than four orders of magnitude across the metal-insulator-transition (MIT), demonstrating their high quality. Their growth mechanism, phase transition, and stability are discussed. We fabricated some VO2thin film devices and some very interesting results O2thin films have wide applications in electronic devices, optical devices, and sensors.

10194-108, Session PWed

Demonstration of an integrated optic banded notch-filter for RF signal processing

Steven R. Laxton, Dwayne D. Macik, Christi K. Madsen, Texas A&M Univ. (United States)

The design and measurement of a photonic integrated circuit in LioniX's TriPleX waveguide technology for banded notch-filtering is presented. The circuit uses thermo-optic phase shifters placed along a ring with a free spectral range of 20GHz to tune the notch-filter to specific frequencies for the filtering out specific frequencies after a bandpass filter. These tuneable notch-filters have valuable roles in several different signal processing applications including the filtering out of a high-amplitude noise signals, the filtering out of frequencies introduced by interfering or jamming devices for the purpose of disrupting communications, and the filtering out of undesired frequencies picked up by detectors used by devices in space applications. Simulations demonstrating how these tuneable notch-filters can be designed with different specifications and how they can be used together to create a tuneable band-reject filter are also briefly discussed.

10194-109, Session PWed

Frequency selective infrared optical filters for micro-bolometers

Timothy A. Creazzo, Mathew J. Zablocki, Lenin Zaman, Ahmed S. Sharkawy, Lumilant, Inc. (United States)

Current bolometers are broadband detectors and tend to absorb a broad window of the IR spectrum for thermal imaging. Such systems are limited due to their lack of sensitivity to blackbody radiation, as well as the inability to spectrally discern multiple wavelengths in the field of view for hyperspectral imaging (HSI). As a result, many important applications such as low concentration chemical detection cannot be performed. One solution to this problem is to employ a system with thermoelectrically cooled or liquid nitrogen cooled sensors, 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 largely challenges their use in small platforms such as, UAVs or handheld imagers. Further, spectral filtering is commonly performed with large hardware and mechanically tuned gratings, greatly increasing the SWaP of the system. To this point, Lumilant's effort is to develop wavelength selective uncooled IR filters that can be integrated onto a micro-bolometer, to exceed the sensitivity imposed by the blackbody radiation limit. We have demonstrated narrowband absorbers and electrically tunable filters addressing the need for low-SWaP platforms.

10194-111, Session PWed

The effects of ionic liquid to water ration as a composite medium for the synthesis of LiFePO4

Rany Tith, Jaydeep K. Dutta, Alfredo A. Martinez-Morales, Univ. of California, Riverside (United States)

LiFePO4 is one of the most dominant cathode material that can be found in many lithium ion batteries sold in the market today. Currently, there are a number of different methods to synthesize LiFePO4, including hydrothermal, solid state, spray pyrolysis, and coprecipitation. One method with the potential to provide additional benefits because of its ecologically friendly and economically competitive approach is combining water with ionic liquids as a synthesis medium. Ionic liquids are used to direct crystal growth and morphology of synthesized LiFePO4 material. Adding water to the ionic liquid can be beneficial as it can act as a mineralizer to bring insoluble precursors to seed crystals. Such a method gives users an option of recycling the ionic liquid for repeated synthesis processes. In this work we study ionic liquid to water ratio effects on the crystallinity and morphology of the synthesized material using X-ray Diffraction (XRD) and Scanning Electron Microscopy (SEM), respectively.

10194-113, Session PWed

Energy harvesting based on piezoelectric AlN and AlScN thin films deposited by high rate sputtering

Hagen Bartzsch, Fraunhofer-Institut für Elektronenstrahl- und Plasmatechnik (Germany); Peter Frach, Fraunhofer-Institut für Organische Elektronik, Elektronenstrahl-und Plasmatechnik FEP (Germany); Stephan Barth, Daniel Gloess, Fraunhofer-Institut für Elektronenstrahl- und Plasmatechnik (Germany)

Aluminum nitride (AlN) is a piezoelectric material often used as thin film in SAW/BAW devices. Furthermore, there is an increasing interest in its use for energy harvesting applications. Despite it has a relatively low piezoelectric coefficient, it is a suitable choice for energy harvesting applications because it is lead-free and due to its low dielectric constant and good mechanical properties.

The films were deposited by reactive pulsed magnetron sputtering using the Double Ring Magnetron DRM 400. This sputter source together with suitable powering and process control allows to deposit highly piezoelectric AlN very homogeneously on 8" substrates with deposition rates of up to 200 nm/min. With the developed technology film thicknesses of several ten microns are technically and economically feasible. Moreover, by adjusting process parameters accordingly, it is possible to tune properties, like film stress, to application specific requirements.

Additionally, it is known that the doping of AlN with Scandium results in a significantly increased piezoelectric coefficient. The influence of process parameters and Sc concentration on film properties were determined by piezometer-, pulse echo-, SEM-, XRD-, EDS- and nanoindentation-measurements.

Energy harvesting measurements were done using an electromechanical shaker system for the excitation of defined vibrations and a laservibrometer for determination of displacement of the samples. The generated power was measured as function of electric load at resonance. A rms power of 140µW using AlN films and of 350µW using AlScN films was generated on Si test pieces of 8*80mm2.

10194-114, Session PWed

Lead-free piezoelectrics for energy harvesting applications

Iasmi Sterianou, Cristina Pascual Gonzalez, Antonio Feteira, Sheffield Hallam Univ. (United Kingdom)

Piezoelectric materials have a great advantage in harvesting energy from motion and vibration sources in terms of simplicity in device structure with relatively high power density, since they directly convert elastic to electric energy. Lead-free piezoceramics are competitive in terms of performance for particular energy harvesting devices, in addition to fulfilling environmental requirements especially for devices likely to be spread around the environment with little chance of being recycled. The effect of non-stoichiometry and compositional modifications of lead-free piezoelectric materials on the figures of merit for piezoelectric energy harvesting is investigated.

10194-115, Session PWed

Approaches to energy harvesting and to energy scavenging for energy-autonomous sensor and micro-instrument networks

Peter Trizcinski, Univ. of Waterloo (Canada); Arokia Nathan, Univ. of Cambridge (United Kingdom); Vassili Karanassios, Univ. of Waterloo (Canada)

In many applications (e.g., environmental monitoring; mobile micro-instruments; wearable sensors and electronics for health applications), energy autonomy and independence from a power outlet is utmost importance. But for such applications, where would appropriate electrical power come from? In this presentation, a survey of energy harvesting (e.g., using approaches ranging from textile electronics to taking advantage of pH differences) and energy scavenging (e. g., thermoelectric or piezoelectric approaches), will be described in detail.

10194-116, Session PWed

Star-shaped anchor for MEMS vibrating ring gyroscope in (100) silicon for minimizing mode mismatch in resonant frequency

Daniel Choi, Boohyun An, Jisung Lee, Masdar Institute of Science & Technology (United Arab Emirates)

This paper presents a highly symmetric structure of a (100) silicon vibrating ring gyroscope with an octagonal star-shaped anchor to minimize the mode mismatch in operational resonance frequencies. Due to the mechanical anisotropy of a (100) silicon, Young's modulus varies in different directions and affects the stiffness of the support springs. We report a fine-tuned VRG on a (100) single crystalline silicon using an octagonal star-shaped anchor. The unique shape of the anchor is introduced to facilitate the independent controls of widths and radii of the support-springs that enable fine tuning of wine-glass modal frequencies between <110> direction and <100> direction which has 45° difference to each other. The octagonal star-shaped anchor in the vibrating ring gyroscope enables to adjust the radius and width of the support springs in the crystallographic directions of <110> and <100> to compensate the anisotropy of a (100) silicon. The extensive parametric study of various designing parameters was done with MEMS+® and MATLAB®. In order to simulate VRG with interface electronics, we imported the MEMS+® model to Simulink with Simscape tools of transimpedance amplifier and demodulator as shown in Fig. 5. The differential capacitance changes between the sensing electrodes in different directions (45° and 135°) according to angular velocity input is measured by voltage meter after the amplifier. Then the amplified voltage signal is passed through a filter and demodulated. We achieved a significant decrease in the mode mismatch from 1.56 kHz to 11.6 Hz (<0.05 % of 24.5 kHz resonant frequency)

10194-87, Session 17

Parylene neural probe arrays for large-scale high-density recording *(Invited Paper)*

Ellis Meng, The Univ. of Southern California (United States)

Reliable chronic electrophysiological recordings remain elusive due to persistent biological failure affecting the electrode-tissue interface. While large scale recordings (>100 channels) have been demonstrated using microwire and silicon-based intracortical electrodes, overtime the stiff composition of such devices damage soft neural tissue, contributing to chronic immune response and eventual glial encapsulation. The use of soft polymers in place of stiff metal or silicon reduces the mechanical mismatch by two orders of magnitude, however, polymer neural probe technology has lagged behind that of silicon in electrode density per shank and integration with microelectronic circuitry. Through advances in polymer micromachining, we have demonstrated multi-electrode probes and probe arrays comprising thin shanks of poly(para-chloro-xylylene) (Parylene C) integrated with a high density of platinum recording sites. These devices have been successfully deployed for deep brain recordings in the hippocampus with minimal immune response owing to the thin, flexible substrate, and a novel insertion method that obviates the need for bulky insertion shuttles or stiffening agents. Overall, these technical advances seek to achieve large-scale, high-density arrays of polymer-based neural probes for chronic large scale recording of neural activity.

10194-88, Session 17

Switches for multiple behavioral states and a viral-based approach to non-invasive whole-brain cargo delivery *(Invited Paper)*

Viviana Gradinaru, California Institute of Technology (United States)

Over the past years we have worked on:

(1) Viral-based approaches to non-invasive whole-brain cargo delivery: Genetically-encoded tools that can be used to visualize, monitor, and modulate mammalian neurons are revolutionizing neuroscience. These tools are particularly powerful in rodents and invertebrate models where intersectional transgenic strategies are available to restrict their expression to defined cell populations. However, use of genetic tools in non-transgenic animals is often hindered by the lack of vectors capable of safe, efficient, and specific delivery to the desired cellular targets. To begin to address these challenges, we have developed an in vivo Cre-based selection platform (CREATE) for identifying adeno-associated viruses (AAVs) that more efficiently transduce genetically defined cell populations. Our platform's novelty and power arises from the additional selective pressure imparted by a recovery step that amplifies only those capsid variants that have functionally transduced a genetically-defined, Cre-expressing target cell population. The Cre-dependent capsid recovery works within heterogeneous tissue samples without the need for additional steps such as selective capsid recovery approaches that require cell sorting or secondary adenovirus infection. As a first test of the CREATE platform, we selected for viruses that transduced the brain after intravascular delivery and found a novel vector, AAV-PHP.B, that is 40- to 90-fold more efficient at transducing the brain than the current standard, AAV9. AAV-PHP.B transduces most neuronal types and glia across the brain. We also demonstrate here how whole-body tissue clearing can facilitate transduction maps of systemically delivered genes. Since CNS disorders are notoriously challenging due to the restrictive nature of the blood brain barrier our discovery that recombinant vectors can be engineered to overcome this barrier is enabling for the whole field. With the exciting advances in gene editing via the CRISPR-Cas, RNA interference and gene replacement strategies, the availability of potent gene delivery methods provided by vectors such as our reported AAV-PHP.B is key to advancing the field of genome engineering.

• Deverman BE, Pravdo P, Simpson B, Banerjee A, Kumar, S.R., Chan K, Wu WL, Yang B, Gradinaru V. Cre-Dependent Capsid Selection Yields AAVs for Global Gene Transfer to the Adult Brain. Nature Biotechnol. 2016 Feb 34(2):204-9. PMID: 26829320

• Yang B, Treweek JB, Kulkarni RP, Deverman BE, Chen CK, Lubeck E, Shah S, Cai L, Gradinaru V. Single-cell phenotyping within transparent intact tissue through whole-body clearing. Cell. 2014 Aug 14;158(4):945-58. PMCID: PMC4153367.

(2) The mesopontine tegmentum, including the pedunculopontine and laterodorsal tegmental nuclei (PPN and LDT), provides major cholinergic inputs to midbrain and regulates locomotion and reward. To delineate the underlying projection-specific circuit mechanisms, we employed optogenetics to control mesopontine cholinergic neurons at somata and at divergent projections within distinct midbrain areas. Bidirectional manipulation of PPN cholinergic cell bodies exerted opposing effects on

locomotor behavior and reinforcement learning. These motor and reward effects were separable via limiting photostimulation to PPN cholinergic terminals in the ventral substantia nigra pars compacta (vSNc) or to the ventral tegmental area (VTA), respectively. LDT cholinergic neurons also form connections with vSNc and VTA neurons; however, although photo-excitation of LDT cholinergic terminals in the VTA caused positive reinforcement, LDT-to-vSNc modulation did not alter locomotion or reward. Therefore, the selective targeting of projection-specific mesopontine cholinergic pathways may offer increased benefit in treating movement and addiction disorders.

• Xiao C, Cho JR, Zhou C, Treweek BJ, Chan K, McKinney SL, Yang B, and Gradinaru V. Cholinergic Mesopontine Signals Govern Locomotion and Reward Through Dissociable Midbrain Pathways. Neuron 2016 Apr 20;90(2)33-47. PMCID: PMC4840478

10194-89, Session 17

Recent developments in wireless recording from the nervous system with ultrasonic neural dust *(Invited Paper)*

Michel M. Maharbiz, Univ. of California, Berkeley (United States)

The emerging field of bioelectronic medicine seeks methods for deciphering and modulating electrophysiological activity in the body to attain therapeutic effects at target organs. Current approaches to interfacing with peripheral nerves and muscles rely heavily on wires, creating problems for chronic use, while emerging wireless approaches lack the size scalability necessary to interrogate small-diameter nerves. Furthermore, conventional electrode-based technologies lack the capability to record from nerves with high spatial resolution or to record independently from many discrete sites within a nerve bundle. We recently demonstrated (Seo et al., arXiV, 2013; Seo et al., Neuron, 2016) "neural dust," a wireless and scalable ultrasonic backscatter system for powering and communicating with implanted bioelectronics. There, we showed that ultrasound is effective at delivering power to mm-scale devices in tissue; likewise, passive, battery-less communication using backscatter enabled high-fidelity transmission of electromyogram (EMG) and electroneurogram (ENG) signals from anesthetized rats. In this talk, I will review recent developments from my group and collaborators in this area.

10194-90, Session 17

Micro and nanofabricated systems to monitor brain dynamics in health and disease *(Invited Paper)*

Sotiris Masmanidis, Univ. of California, Los Angeles (United States)

The coordinated activity of neural ensembles across multiple interconnected brain regions has been challenging to study in the mammalian brain with cellular resolution using conventional recording tools. For example, neural systems regulating learned behaviors often encompass multiple distinct structures that span the brain. Thus there is a need for new technologies that allow recordings from many neurons and brain areas in parallel with high spatiotemporal resolution. To address this issue, my lab has developed microfabricated silicon-based electrode arrays (silicon microprobes) that offer state-of-the-art features in terms of number of electrodes and miniaturization. Silicon microprobes can be mass-produced at commercial MEMS foundries and are thus well suited for widespread use in systems neuroscience research. Furthermore, they can be easily combined with conventional optical fibers for multifunctional applications. These devices routinely provide access to dozens or hundreds of simultaneously recorded neurons, providing unique opportunities to study the dynamics of large neural ensembles during behavior. I will also demonstrate some recent applications from my lab of how this technology is being used to advance our understanding of brain function in mice.

10194-92, Session 18

Advances in Fabry-Perot and tunable quantum cascade lasers *(Keynote Presentation)*

C. Kumar N. Patel, Pranalytica, Inc. (United States)

I will describe the progress in performance and capability improvement of mid wave infrared (MWIR) and long wave infrared (LWIR) quantum cascade lasers, which continues without any pause. MWIR and LWIR QCLs are now capable of provide watt-level or higher continuous wave or average power outputs at room temperature. Improvement in capability with Fabry-Perot configuration also translates into similar improvements when these lasers are incorporated into tunable systems, either using traditional diffraction gratings or using all electronic acousto-optic modulator (AOM) tuning systems. Of these, the AOM tuned QCL systems provide unparalleled speed of tuning as well as capability of simultaneous operation of the laser at two independently tunable and switchable wavelengths. The simultaneous two wavelength operation, for the first time, provides a way of measuring homogeneous broadening and lasing level lifetimes in a high power QCL under operating conditions, which will permit comparison of the effectiveness of different QCL designs and lead to further improvements in power output and wall plug efficiency.

10194-93, Session 18

New quantum cascade laser sources for sensing applications *(Invited Paper)*

Mariano Troccoli, AdTech Optics, Inc. (United States)

In this presentation we will review our most recent results on development of Quantum Cascade Lasers (QCLs) for analytical and industrial applications. QCLs have demonstrated the capability to cover the entire range of Mid-IR, Far-IR, and THz wavelengths by skillful tuning of the material design and composition and by use of intrinsic material properties via a set of techniques collectively called "bandgap engineering". The use of MOCVD, pioneered on industrial scale by AdTech Optics, has enabled the deployment of QCL devices into a diverse range of environments and applications. QCLs can be tailored to the specific application requirements due to their unprecedented flexibility in design and thanks to the leveraging of well-known III-V fabrication technologies inherited from the NIR domain. Nevertheless, several applications and new frontiers in R&D need the constant support of new developments in device features, capabilities, and performances.

We have developed a wide range of devices, from high power, high efficiency multi-mode sources, to narrow-band, single mode devices with low-power consumption, and from non-linear, multi-wavelength generating devices to broadband sources and multi-emitter arrays. All our devices are grown and processed using MOCVD technology and allow us to attain competitive performances across the whole mid-IR spectral range. This talk will present an overview of our current achievements.

References

1. M. Troccoli, "High power emission and single mode operation of quantum cascade lasers for industrial applications", J. Sel. Topics in Quantum Electron., 21 (6), 1-7 (2015). Invited Review.

2. Seungyong Jung, Aiting Jiang, Yifan Jiang, Karun Vijayraghavan, Xiaojun Wang, Mariano Troccoli, and Mikhail A. Belkin, "Broadly Tunable Monolithic Terahertz Quantum Cascade Laser Sources", Nature Comm. 5, 4267 (2014)..

3. Mariano Troccoli, Arkadiy Lyakh, Jenyu Fan, Xiaojun Wang, Richard Maulini, Alexei G Tsekoun, Rowel Go, C Kumar N Patel, "Long-Wave IR Quantum Cascade Lasers for emission in the ? = 8-12?m spectral region", Opt. Mat. Expr., 3 (9), 1546-1560 (2013).

10194-94, Session 18

Monolithic designs of quantum cascade lasers *(Invited Paper)*

Kwok Keung Law, Naval Air Warfare Ctr. Weapons Div. (United States)

Quantum cascade lasers (QCLs) are increasingly incorporated into a variety of systems and sensing applications. Significant advances have been made recently in mid-wave infrared and long-wave infrared QCLs technologies. We will discuss in this presentation an update status on a portfolio of Navair's programs and efforts on significantly improving QCLs' performance, affordability and reliability by means of monolithic integrations.

10194-95, Session 18

Recent results on performance optimization of QCLs for high peak and average power and broad spectral coverage *(Invited Paper)*

Richard Maulini, Ilia Sergachev, Dana Turcinkova, Alfredo Bismuto, Stéphane Blaser, Tobias Gresch, Antoine Müller, Alpes Lasers SA (Switzerland)

We will present our latest results on high power and extended tuning quantum cascade lasers (QCLs). Lasers optimized for high peak or average power and broad spectrum were realized to provide extensive coverage of the mid-wave infrared (MWIR) and long-wave infrared (LWIR) regions for applications such as remote chemical sensing. The tuning range of the devices was studied in an external cavity configuration.

Watt-level mid-infrared quantum cascade lasers were realized in the second atmospheric window, at a wavelength of 9.75 µm. Thermoelectrically-cooled devices emit a continuous-wave output power in excess of 2.0 W and 1.2 W at temperatures of -20ºC and +20ºC, respectively, and conductively-cooled devices emit an average power of 1.05 W at room temperature without the need for a thermoelectric cooler.

We also report gain-guided broad area QCLs emitting at the wavelength of 4.55 ?m. The devices were processed in a buried heterostructure configuration with a narrow current injector section and the mode size is determined by lateral current spreading in the active region. With this novel device configuration, we demonstrate 23.5 W peak power at a temperature of 20ºC and duty cycle of 1%, with a far field consisting of a single symmetric lobe centered on the optical axis. These experimental results are supported well by 2D numerical simulations of electric currents and optical fields in a device cross-section.

10194-96, Session 18

High performance 40-stage and 15-stage quantum cascade lasers based on two-material active region composition *(Invited Paper)*

Arkadiy A. Lyakh, Univ. of Central Florida (United States)

5.6 µm quantum cascade lasers based on $Al_{0.78}In_{0.22}As/In_{0.69}Ga_{0.31}As$ active region composition with measured pulsed room temperature wall plug efficiency of 28.3% are reported. Injection efficiency for the upper laser level of 75% was measured for the design by testing devices with variable cavity length. Threshold current density of 1.7kA/cm2 and slope efficiency of 4.9W/A were measured for uncoated 3.15mm x 9µm lasers. Threshold current density and slope efficiency dependence on temperature in the range from 288K to 348K for the structure can be described by characteristic temperatures T_0 ~ 140K and T_1 ~710K, respectively. The data demonstrate that it is possible to achieve a very high laser performance utilizing active region designs based on only two different active region materials, which simplifies technology transition to production.

High reflection-coated 15-stage devices with the same design and 2.1 mm x 10.4 µm active region dimensions had pulsed slope efficiency, threshold current density, and wallplug efficiency of 1.45 W/A, 3.1 kA/cm2, and 18%, respectively. Corresponding continuous wave values for the same parameters were measured to be 1.42 W/A, 3.7 kA/cm2, and 12%. Further design optimization for quantum cascade lasers with a reduced number of stages is projected to bring continuous wave efficiency above 15%. The combination of the high performance and significantly reduced thermal resistance for these devices paves the way to continuous wave optical power scaling with lateral device dimensions.

10194-97, Session 19

Ultimate limits for highest modulation frequency and shortest response time of field effect transistor *(Keynote Presentation)*

Michael S. Shur, Rensselaer Polytechnic Institute (United States); Greg Rupper, Sergey Rudin, U.S. Army Research Lab. (United States)

The ultimate speed of electronic devices is the key issue for future communications and data processing systems. The 300 GHz communication links are already being actively developed. The pursuit of higher operating frequencies and shorter switching times focused attention on higher mobility semiconductors, such as Ge, InGaAs, InAs and, more recently, graphene. However, at short device features sizes typical for high speed devices, the conventional notions of the mobility determining the device speed and of the transit time dominated cutoff frequencies no longer apply. The quasi-ballistic and ballistic transport starts playing the dominant role. The electron inertia and the viscosity of the two-dimensional electron fluid in the field effect transistor (FET) channels become very important. Our analytical estimates and detailed hydrodynamic simulations reveal that the electron response becomes faster with the mobility increase only in a limited range of relatively low mobility values. With a further increase in the electron mobility, the plasmonic ringing determines the characteristic response time that becomes of the order of the momentum relaxation time. Therefore, the response time actually starts increasing proportionally to the mobility values up to the point, where this dependence saturates due to the dominant effect of the electron viscosity. The minimum response time and the maximum device modulation frequency correspond to the subpicosecond and terahertz ranges, respectively. The recent experiments of the FET switching using femtosecond optical laser pulses are in good agreement with the predicted subpicosecond switching times.

10194-98, Session 19

Uncooled terahertz real-time imaging 2D arrays developed at Leti: present status and perspectives *(Invited Paper)*

François Simoens, CEA-LETI (France); Jérôme Meilhan, Commissariat à l'Énergie Atomique (France)

Whatever the technology, similarly to any imaging sensor market, the commercial spread of terahertz (THz) cameras has to fulfil simultaneously the criteria of high sensitivity and low cost and SWAP (size, weight and power). Monolithic silicon-based 2D sensors integrated in uncooled THz real-time cameras are good candidates to meet these requirements.

Over the past decade, CEA-Leti has been studying and developing such arrays with two complimentary technological approaches, i.e. antenna-coupled silicon bolometers and CMOS Field Effect Transistors (FET), both being compatible to standard silicon microelectronics processes.

LETI has leveraged its know-how in thermal infrared bolometer sensors in developing proprietary architecture for THz sensing. High technological maturity has been achieved as illustrated by the demonstration of fast scanning of large field of view and the recent birth of a commercial camera.

In the FET-based THz field, recent works have been focused on innovative CMOS read-out-integrated circuit designs. The studied architectures take advantage of the large pixel pitch to enhance the flexibility and the sensitivity: an embedded in-pixel configurable signal processing chain dramatically reduces the noise. Video sequences at 100 frames per second using our 31x31 pixels prototyped 2D FPAs have been tested.

The authors describe the present status of these developments and perspectives of performance evolutions are discussed. Several experimental imaging tests are also presented in order to illustrate the capabilities of these arrays to suit industrial applications such as non-destructive testing (NDT), security or quality control of food.

10194-99, Session 19

Detection and identification of substances using noisy THz signal *(Invited Paper)*

Vyacheslav A. Trofimov, Irina G. Zakharova, Dmitry Y. Zagursky, Svetlana A. Varentsova, M.V. Lomonosov Moscow State Univ. (Russian Federation)

We discuss an effective method for the detection and identification of substances using a high noisy THz signal. In order to model such a noisy signal, we add to the THz signal transmitted through a pure substance, a noisy THz signal obtained in real conditions at long distance (more than 3.5 m) from the receiver in the air with non-zero humidity. The insufficiency of the standard THz-TDS method is demonstrated. The discussed method is based on time-dependent integral correlation criteria calculated using spectral dynamics of medium response. A new type of the integral correlation criterion, which is less dependent on spectral characteristics of a noisy signal under investigation, is used for identification. To explain a physical mechanism for false absorption lines appearance in the signal we make a computer simulation using 1D Maxwell's equations and density matrix formalism.

For the detection and identification of substance we propose using a substance emission at high frequencies corresponding to high energy levels excitation due to cascade mechanism of their excitation under the THz pulse action.

10194-100, Session 19

Overview of CMOS technology for radiometry and passive imaging (Rising Researcher Presentation) *(Invited Paper)*

Adrian J. Tang, Jet Propulsion Lab. (United States) and Univ. of California, Los Angeles (United States)

While CMOS receivers have achieved high enough frequency operation to implement microwave and potentially even mm-wave radiometers for atmospheric sensing and passive imaging systems, many challenges remain related to calibrating and stabilizing CMOS receiver systems enough to achieve meaningful noise temperature resolution.

This paper describes the major issue of ?G/G gain fluctuations, the dominant source of stability problems in CMOS receivers for radiometry and passive imaging, and discusses its effects on attainable noise temperature resolution. The paper then discusses several key approaches to removing these gain fluctuations including Dicke switching to capture and remove low frequency noises, and correlated receivers which exploit quadrature relationships to track fast changes in system gain. Several examples of recently developed CMOS radiometers in 65nm are presented.

10194-101, Session 20

Progress in standoff surface contaminant detector platform *(Invited Paper)*

Julia R. Dupuis, Jay P. Giblin, John Dixon, Joel M. Hensley, David J. Mansur, William J. Marinelli, Physical Sciences Inc. (United States)

Progress towards the development of a longwave infrared quantum cascade laser (QLC) based standoff surface contaminant detection platform is presented. The detection platform utilizes reflectance spectroscopy with application to optically thick and thin materials including solid and liquid phase chemical warfare agents, toxic industrial chemicals and materials, and explosives. The platform employs an ensemble of broadband QCLs with a spectrally selective detector to interrogate target surfaces at 10s of m standoff. A version of the Adaptive Cosine Estimator featuring class based screening is used for detection and discrimination in high clutter environments. Detection limits approaching 0.1 ug/cm2 are projected through speckle reduction methods enabling detector noise limited performance.

The design, build, and validation of a breadboard version of the QCL-based surface contaminant detector are discussed. Functional test results are presented and reconciled with analytical predictions. Developmental testing spanning a range of contaminant surface coverage morphology and loading as well as surface type are presented. Future development and transition plans for the QCL-based surface detector platform are discussed.

10194-102, Session 20

Standoff detection of explosives and other hazards using quantum cascade laser arrays *(Invited Paper)*

Mark F. Witinski, Pendar Technologies (United States)

This presentation introduces the spectroscopic concepts and results enabled by arrays of Distributed Feedback (DFB) QCLs, with each element at a slightly different wavelength than its neighbor. In portable optical systems, such as standoff threat detectors and in situ gas analyzers, this increases analyte sensitivity and selectivity by broadening spectral source coverage while also allowing for extremely fast all-electronic wavelength tuning with no moving parts.

This talk will first present the QCL array and its packaging, then move into the description of an integrated prototype standoff detection system, and finally show standoff detection results from a handheld system from over 2 meters.

The data show how monolithic and all-electronic tuning enables next-generation spectroscopes that are not only more robust and miniature than those that utilize external cavity-tuned lasers, but that are inherently more stable in terms the shot-to-shot amplitude and wavelength parameters. This enhanced stability increases signal to noise for a given configuration (pathlength, averaging time, concentration, etc...). Some discussion of how to maximize the benefits of high speed, highly reproducible tuning is presented, including detector, preamplifier, and digitization considerations for both backscattered and closed path configurations.

10194-103, Session 20

A new quantum cascade laser-based molecular sensor platform configurable for diverse sensing requirements *(Invited Paper)*

Miles J. Weida, David B. Arnone, David B. Caffey, Bruce Coy, Timothy Day, Daylight Solutions Inc. (United States)

Quantum cascade laser (QCL)-based sensors continue to evolve in response to the increasing demand and benefits they provide for molecular sensing in the mid-IR 'fingerprint' region. We report on a new sensor platform that can be configured to address diverse sensing application requirements. This new platform can cover a wide performance envelope that includes: probe wavelengths in the range 2.9 to >12 microns; ppb to % sensitivity; >10^3 dynamic range; and >1 Hz update rate. Recent developments in high-speed, broadly tunable QCLs, combined with advances in mid-IR detection and chemical identification algorithms, are enabling real-time measurements of multiple chemical species.

10194-104, Session 20

ECQCL developments for rapid standoff chemical sensing *(Invited Paper)*

Mark C. Phillips, Brian E. Brumfield, Pacific Northwest National Lab. (United States)

We present recent results on development of swept external cavity quantum cascade lasers for rapid and precise measurements of trace gases. Rapid tuning of an ECQCL over its entire tuning range at rates up to 200 Hz and a spectral resolution of < 0.2 cm-1 provides an important capability for detection of gas mixtures in transient sources such as chemical plumes. We present examples of using the swept ECQCL for quantitative measurements of multicomponent gas-phase mixtures in turbulent plumes for standoff detection applications.

10194-105, Session 20

Active infrared imaging spectroscopy for standoff detection of trace explosives *(Invited Paper)*

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

We are developing a technology for detection based on active broadband infrared imaging spectroscopy. This approach leverages micro-fabricated IR quantum cascade lasers, tuned through signature absorption bands (6-11 microns) in the analytes while illuminating a surface area of interest. An IR focal plane array captures the time dependent surface response. The image stream forms a hyperspectral image cube comprised of spatial, spectral and temporal dimensions as vectors within a detection algorithm. We present the results of recent tests regarding standoff detection of trace explosives on relevant substrates using a mobile platform. Exploiting the surface response in the time domain increases sensitivity to explosives and selectivity between different analyte types. Methods to optimize the active illumination and process the image cube are also discussed. We have previously demonstrated standoff trace detection at several meters 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 on relevant glass, plastic, metal and painted substrates.

References: C. Kendziora et al., in Laser-Based Optical Detection of Explosives, P. M. Pellegrino, E. L. Holthoff, and M. E. Farrell, eds. (CRC Press, 2015); C. Kendziora et al., Proc SPIE, Vol. 9836, 98362G (2016); C. Kendziora et al., Proc. of SPIE Vol. 9467 94672R (2015); R. A. McGill et al.; US Patent #8,101,915 B2 (2012). This research is sponsored by ONR/NRL.

Tuesday - Thursday 11–13 April 2017

Part of Proceedings of SPIE Vol. 10195 Unmanned Systems Technology XIX

10195-1, Session 1

Assessment of RCTA research

Craig Lennon, Marshal Childers, Mary Anne Fields, U.S. Army Research Lab. (United States); Richard Camden, Engility Corp. (United States); Leonid Sapronov, Robotic Research LLC (United States); Michael K. Martin, Andrew Dornbush, Christian Lebiere, Carnegie Mellon Univ. (United States); Ed Weller, General Dynamics Land Systems (United States)

The Army Research Laboratory's Robotics Collaborative Technology Alliance 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 robotic perception, intelligence, manipulation, mobility, and human-robot interaction. We present the results of assessments conducted in 2016 to evaluate the capabilities of a cognitive architecture (ACT-R), and of a new robot, the Robotic Manipulator (RoMan). The cognitive architecture was evaluated as to how well it could learn an appropriate set of features for a classification task. The task was to classify emotions which had been encoded using the facial action coding system, with ACT-R learning to select the most effective set of features for correct classification. The RoMan platform was evaluated on its ability to conduct a search and grasp task under a variety of conditions, in which it was required to search for and recognize a gas can placed on the floor, and then pick it up.

10195-2, Session 1

Using deep learning to bridge the gap between perception and intelligence

Arne J. Suppe, Martial Hebert, Carnegie Mellon Univ. (United States)

Unmanned ground vehicles operating in complex environments require detailed understanding of the world around the robot, which involves both perception and reasoning capabilities. Unfortunately, the link between these two components is not well understood. Perception often generates data that are too primitive (labeled pixels or point-clouds) for Intelligence, and Intelligence often requires data that are more abstract than is currently available. This gap is now filled by ad-hoc rules to digest large amounts of perception data into primitives intelligence can use, for example, fitting walls to point-cloud data and fitting points to landmark objects. Such techniques are brittle, tedious, and also discard a large amount of information.

We introduce techniques that utilize Deep Reinforcement Learning as one way to push the boundary where traditional perception tasks end so that more abstract and accessible data are naturally provided to Intelligence, providing a more natural and flexible interface without using ad-hoc rules. We demonstrate this technique on the task of facade labeling, a task that is important to ground vehicles in an urban environment. Current semantic labeling techniques can label pixels that represent windows, doors and walls, but the results are noisy, low-level, and do not convey the latent structure of the façade. We show how Deep Reinforcement Learning can be used to fit a grammar to label facades in a much more compact, abstract, and ultimately more useable form to Intelligence tasks. This work was funded as part of the Robotics Collaborative Technology Alliance (RCTA).

10195-3, Session 1

Gait design and optimization for efficient running of a direct-drive quadrupedal robot

Charles Carbiener, John Nicholson, Florida State Univ. (United States); Kaylee Geidel, Univ. at Buffalo (United States); Jonathan E. Clark, Florida State Univ. (United States)

Over the years legged robots have utilized a number of strategies for developing running gaits. Even within the family of diagonally- symmetric trotting gaits there are a large number of possible strategies for developing fast, stable and efficient running. While individual robots' gaits have been optimized for various criteria, little work has been done to systematically compare fundamentally different strategies or to identify which features in the gait design result in optimal running.

In this study we examine Minituar, a direct-drive quadrupedal robot. The hollow-core motors and 5-bar linkage peculiar to its design allow for the generation of high torques at very high speeds. One weakness of this design, however, is the lack of passive energy storage elements in the legs. The resulting gaits tend to suffer with respect to energetic efficiency. Furthermore the best hand-tuned gaits developed thus far for Minitaur result in running speeds of only 1.5m/s. Studies with the biologically-inspired reduced-order dynamic SLIP model predict that a robot this size should be able to run at up to 2.5m/s. While fast and stable gaits have been developed with single legged hoppers, in this study we focus on how well these approaches carry over to the whole-body dynamics associated with a quadruped. In particular, we compare trajectory optimization with a speed-weighted cost function to the SLIP-based Adaptive-Energy Removal (AER) strategy developed for maximizing stability over rough terrain. We examine the role of leg posture, stroke length, compliance, and frequency on the resulting running speed and efficiency.

10195-4, Session 1

Ground-based self-righting using inertial appendage methods

Chad Kessens, U.S. Army Research Lab. (United States); James Dotterweich, Engility Corp. (United States)

As robots are deployed in more dynamic and uncertain environments, the ability to recover from tip-over events is critical. Previously, a framework for generating quasi-static self-righting solutions for generic robots in two dimensions was developed. This work extends that framework to include the use of inertial appendage methods. It begins by reviewing the basic framework and discussing how it may be extended to incorporate dynamic solutions. It then discusses the generation of appendage momentum in the presence of ground reaction forces by utilizing the zero moment point concept. This concept is further extended to controlling the momentum transfer between the appendage and the body such that a desired tip-over event results. In addition, this work analyzes the energy basin of attraction of the resulting ground contact to determine whether the roll will continue (desirably or undesirably). After initiating the tip-over event, the motion of the appendage may further be controlled to reduce the energy of the impact to land within the basin of attraction, or to increase the energy to intentionally land outside that basin and continue the roll. Four strategies based on this methodology are discussed, permuting appendage acceleration or deceleration and whether or not the appendage is involved in the resulting ground contact. The strategies are compared based on the following optimization metrics: kinetic energy required, impact energy, and stability margin. Finally, the proposed methods are validated on a physical robot, and the improvement to its rightability is quantified as compared with quasi-static solutions.

10195-5, Session 2

Experimental verification of distance and energy efficient motion planning on a skid steered platform

James Pace, Aneesh Sharma, Camilo Ordonez, Nikhil Gupta, Mario Harper, Emmanuel G. Collins Jr., Florida State Univ. (United States)

Mobile robots operating in the field need to be aware of the terrain and use this information to select the proper motion planning modality. For example, in very benign terrain it might be desirable to navigate to a goal following the shortest path. However, in challenging terrain, such maneuvers might be prohibitively expensive in terms of energy consumption. This paper summarizes field experiment results corresponding to a comparison between distance optimal and energy optimal motion planning on a skid-steered robot. The results show that there is substantive energy savings associated with energy optimal motion planning.

10195-6, Session 2

Neural network based kinematic modeling of a running legged robot

Mario Harper, James Pace, Camilo Ordonez, Nikhil Gupta, Emmanuel G. Collins Jr., Florida State Univ. (United States)

Motion planning for highly dynamic legged machines such as the XRL (X-Rhex Light) is far less developed than motion planning for wheeled vehicles. One of the main reasons for this is the lack of kinematic and dynamic models for such platforms. Physics based models are difficult to develop for this type of robot as incidental factors can play a very large role in vehicle stability and motion. For example, small changes in effective leg stiffness can directly impact linear and angular robot velocities. This paper presents a data driven approach to develop an extended kinematic model for the XRL platform. The methodology utilizes a Feed-Forward Neural Network to relate gait parameters to vehicle velocities. The paper experimentally shows the effectiveness of the developed models on various surfaces.

10195-7, Session 2

Autonomous UAV search planning with possibilistic inputs

Emily Grayson, Carnegie Mellon Univ. (United States); Paul Elmore, Donald Sofge, Fred Petry, U.S. Naval Research Lab. (United States)

Many aspects of decision making processes for autonomous systems involve human subjective information in some form. Methods for enhancing decision making processes with human information are needed to inform probabilistic information used in an autonomous system. This can provide better decisions and permit a UAV to more quickly and efficiently complete tasks. Specifically we use possibility theory to represent the subjective information and apply possibilistic conditioning of the probability distribution. In particular we focus on path planning for autonomous systems, specifically deciding where to move in order to quickly complete a task, given human sources of information. A prime example where time is a factor and human information is often provided is a search and rescue mission. Such a mission will require missing individuals be found as quickly as possible, and sources of human information may include where they were last seen, local inhabitants' insights into the area and so forth.

The focus of this work was developing a simulation platform on which to test the effectiveness of methods for informing a priori information in a search and rescue scenario. This involved developing a reactive path planner which moved the UAV towards the area of highest certainty within the sensor footprint, taking sensor measurements along the way until a detection threshold is reached and the target is detected. Results showed that some of the methods of informing a prior information were more effective than the uninformative prior of maximum entropy.

10195-8, Session 2

Online location recognition for drift-free trajectory estimation and efficient autonomous navigation

Deepak Khosla, Jiejun Xu, Kyungnam Kim, Yang Chen, HRL Labs., LLC (United States)

Autonomous navigation is a desired capability for mobile robotic platforms, such as UAVs and UGVs. Efficient autonomous navigation, especially in unknown environments, requires accurate localization based on online location recognition. Traditional monocular camera-based location recognition methods can suffer from accuracy, speed and robustness issues. In this paper, a novel online location recognition (OLR) algorithm based on fast and efficient interest-point detection and feature-based keypoint matching is presented. The OLR incrementally constructs a database of visited locations and robustly recognizes revisited locations, even in complex and cluttered scenes. The OLR capability is quantitatively evaluated using a mobile robot setup in a multi-room office building environment. We further present and validate two applications based on the proposed OLR algorithm. In the first application, the OLR algorithm is integrated with conventional SLAM and an efficient trajectory correction algorithm for drift-free trajectory estimation (DTE) and qualitatively evaluated in the same environment. In the second application, the OLR algorithm is integrated with an exploration strategy for efficient autonomous navigation (EAN) and evaluated using a UAV model in a simulated warehouse environment. Our experiments demonstrate the accuracy and efficiency of the proposed location recognition algorithm and its utility for drift-free trajectory estimation and efficient autonomous navigation.

10195-9, Session 2

Development of a small satellite primarily inertial autonomous self-correcting attitude determination and control system

Mark McDonald, Jeremy Straub, North Dakota State Univ. (United States)

This paper discusses the software for a primarily inertial autonomous self-correcting attitude determination and control system (ADCS) for a satellite. The inputs to this system are provided by the accelerometers and solar cells (the voltage levels provide sun orientation data). The mathematical models used and the challenges that have arisen are discussed.

The ADCS has to automatically update its control profile after deployment, continuously. This autonomous updating approach facilitates compensating for a potentially changing center of mass (as propellant is depleted or hardware is moved to deployed configurations) and removes the requirement to test the system in the orbital environment to develop the initial profile.

Rough estimation is provided by the accelerometers and solar cells (also serving as a fallback, in case of primary camera sensing failure). Then, an outward-facing camera is used to operate a star tracker to set and periodically update the believed-orientation. The accelerometer data is used to update the believed-orientation over time, as well.

A key use of the attitude control for this and many missions requires orientation to be stationary (for non-sensing payload operations and power generation) but not precise. A limited functionality mode (with significantly reduced computational requirements) has been developed for this purpose (and also as a fallback operating mode). In this mode, the satellite will rotate

a full 360 degrees first on one axis, and then on the second axis and, from this, project the orientation providing the highest electrical generation. The spacecraft will be placed and maintained in this position.

10195-10, Session 3

Rapid abstract perception to enable tactical unmanned system operations

Stephen P. Buerger, Anup Parikh, Steven J. Spencer, Mark W. Koch, Sandia National Labs. (United States)

As unmanned systems (UMS) proliferate for security and defense applications, autonomous control system capabilities that enable them to perform tactical operations are of increasing interest. These operations, in which unmanned systems must match or exceed the performance and speed of people or manned assets, even in the presence of dynamic mission objectives and unpredictable adversary behavior, are well beyond the capability of even the most advanced control systems demonstrated to date. In this paper we deconstruct the tactical autonomy problem, identify the key technical challenges, and place them into context with the autonomy taxonomy produced by the US Department of Defense's Autonomy Community of Interest. We argue that two key capabilities beyond the state of the art are required to enable an initial fieldable capability: rapid abstract perception in appropriate environments, and tactical reasoning. We summarize our work to date in tactical reasoning, and present initial results from a new research program focused on abstract perception in tactical environments. This approach seeks to apply semantic labels to a broad set of objects via three core thrusts. First, we use physics-based multisensor fusion to enable generalization from imperfect and limited training data. Second, we pursue methods to optimize sensor perspective to improve object segmentation, mapping and, ultimately, classification. Finally, we assess the potential impact of using sensors that have not traditionally been used by UMS to perceive their environment, for example hyperspectral imagers, on the ability to identify objects. Our technical approach and initial results are presented.

10195-11, Session 3

Biologically-inspired approach to automatic processing fly eye radar antenna array patterns with convolutional neural networks

Iryna Dzieciuch, SPAWAR Systems Ctr. Pacific (United States)

Autonomous Unmanned Vehicle Systems (UVS) are used for survey, patrol and exploration purposes. Command and control of such vehicles is usually done by a human operator through use of joystick and visual camera. Most of the perception, target detection, and maneuvering is also done by a human. This approach does not allow for autonomy to evolve much further. Additionally, path planning algorithms are also limited in scope and do not account for real-time events.

Proposed fly eye antenna array system, provides automatic simultaneous surveying its surroundings and detection of multiple targets. It consists of angularly – spaced directional and overlapping antennas with wide –area coverage. Each directional antenna is coupled with front end circuit, and connected by digital interface to processor. Radio Frequency (RF) signals coming from such antenna array record provide information about position, direction, and range with a good penetration through scattered media.

Detection of object in high scattered media by using radio frequency signals from directional antennas is challenging. The electromagnetic signal, reflected from object coming from multitude of the directional antennas. Determination of object location made based on the correlative values obtained from the antennas, shape and size of the object must include antenna pattern shape. Such patterns are recorded and used for convolutional neural network for training purposes. Measurement of positional information of the directional antennas provides a valuable information on the pattern system. Nine sensors covering entire sky: 360 degree field of view and can be recorded as correlative signal strength matrix. The objectiveness of using signals from antenna array together with artificially labeled data makes a system intelligent. Proposed application of fly eye radar antenna patterns with convolutional neural networks. This approach is much simpler and will provide autonomous automatic objects detection with better generalization, higher position and range accuracy measurement performance.

10195-12, Session 3

A testbed for evaluating LIDAR as a sense and avoid sensor for autonomous aerial systems

Wade W. Brown, Ned Tabat, Semaphore Scientific, Inc. (United States); Timothy J. Vogt, St. Cloud State Univ. (United States)

LIDAR is seen by many as a panacea as at least a partial solution for Sense and Avoid (SAA) sensing for autonomous vehicles both land, air, and space. LIDAR has had significant success as a SAA sensor for land vehicles, but the same is not true for unmanned autonomous systems (UAS). Actual flight testing has been difficult because only recently has the FAA allowed UAS to fly in the national air space (NAS) and the available LIDAR systems are not appropriate for small UAS. In time, LIDAR systems will have the size and coverage needed for small UAS. Given the assumed explosion in numbers of UAS that will be flying in the NAS work to evaluate LIDAR's efficacy as a SAA sensor needs to performed. We discuss a simulation built to use as a testbed for testing LIDAR for SAA evaluation. It is our desire that requirements for LIDAR can be determined from the simulation as an aid to system engineers and designers.

10195-40, Session PTue

Wireless energy and data transfer to munitions using high power laser diodes

Harbans S. Dhadwal, Jahangir S. Rastegar, Philip Kwok, Omnitek Partners, LLC (United States)

Most wireless energy transfer (charging) systems are based on electromagnetic inductive principles and satisfy a wide range of continuous power requirements from a few watts for charging smart phones to kW for charging large commercial vehicles. Solar charging systems are well developed for a wide range of power requirements and are in commercial use. An alternative technology based on photonic power converters (PPC), and optimized for use with the high power laser diodes, is finding utility for niche applications, such as, power transfer to UAVs. In addition to range, these PPC devices can be configured for secure and robust energy and data transfer over short distances.

This manuscripts describes the design of a photonic wireless system for transferring energy to a munition shell, just prior to deployment. In these time critical power up applications, such as, providing power and guidance information to a munition shell just prior to deployment. For these applications energy of the order of 100 J needs to be transferred in under 5 s and concurrently guidance and other control data is uploaded to on-board memory devices. Current inductive and solar based technologies are not effective in these environments.

Comparative data is presented for two types of photovoltaic power converters. One is a 16-cell array comprising of 2 mm2 6V-PPC cells and the second is a module comprising of two 1 cm2 PPCs connected in series. A charging collar, which sits on the cone shaped cell provides for alignment free charging solution for rapid deployment of multiple shells.

10195-41, Session PTue

Development of an app-on-demand capability for unmanned systems

Brandon Rudisel, Jeremy Straub, North Dakota State Univ. (United States)

The ability to upload a space or unmanned aircraft mission as a self-contained software application can enable multiple users to share an aerial, orbital sensing, or other platform. This capability provides the benefit of allowing customized software to be added to the spacecraft or aerial craft after launch to perform specific mission objectives. However, incorporating this mechanism presents the risk of uploading malicious software to the device and damaging or impairing the system (particularly if craft-level control systems can be accessed).

The App-On-Demand capability provides an answer to this. It allows applications to be uploaded to the craft, run, and have their data be returned to the ground, safely and securely.

To accomplish this, open source sandboxing software is used. This will be augmented by transmission security mechanisms and a scheduling system (that determines how the craft's time is shared).

This paper provides an overview of the design and development of the App-On-Demand functionality for the OpenOrbiter I spacecraft. This deployment is also a proof of concept. By demonstrating the ability to safely upload and run applications on the CubeSat, the door to sharing the resources of other larger satellites and unmanned aerial vehicles is opened. This would provide a significant resource for a fraction of the cost of having to develop, launch and operate a satellite or UAV. Allowing anyone to upload their own software to a satellite or UAV for research, education or other purposes makes these platforms more accessible to a larger group of prospective users.

10195-42, Session PTue

A testing and demonstration mission for an automated spacecraft repair system

Alex Wiitamaki, Jeremy Straub, North Dakota State Univ. (United States)

Most spacecraft, particularly those with long-duration missions, will encounter a hardware fault at some point in their flight. In many cases, this fault will need to be addressed in order for the spacecraft to function as it was originally intended to. This paper presents work on the creation of a system that can detect these errors, determine the proper way to fix the fault, then go about repairing the error. A small spacecraft test mission will be used to demonstrate these capabilities in the orbital environment and refine the hardware and software system components.

In order to do this, the system must first detect the errors. On-board software will detect logical faults stemming from errors in the electrical components and circuits. Imaging and independent image processing software will be used to detect physical faults in components that do not have an electrical function or faults in electrical circuits or components that haven't presented a logical fault manifestation. Once a fault is detected, the system will then attempt to fix it. The Automated Spacecraft Repair System will include a knowledge-based system containing types of errors and repair instructions. This system will also contain the steps required for performing repairs and have the ability to generate the set of commands used to perform the fix. Finally, the system will contain hardware with actuation capabilities that can be used to fix the fault and sensors to find the fault. A testing capability, to assess the completeness of the fix will also be included.

10195-43, Session PTue

UAV path planning in absence of GPS

Hassan El-Sallabi, Abdulaziz Aldosari, Qatar Air Force (Qatar)

Un-manned aerial vehicles (UAVs) is growing technology that have a huge potential future applications in both military and civilian scenarios. UAVs use GPS signals for navigation and path planning. UAVs can be controlled by pilot remotely for guidance, navigation and control to determine its maneuvering during flying and traveling path. UAVs can also fly based on determined coordinates of destination and follow optimized path based on GPS signal to allow the vehicle to move along a predetermined guidance path developed from pre-programmed waypoints. However, there many situations where the GPS signal might not be available either due to interference, or lack of enough numbers of available satellites at the desired area. Inertial measurement unit is not an option due to its high cost. UAV needs to navigate with affordable aids for localization. In urban environment, the GPS signals may not be available due to high rise building. However, such environment is usually dense with cellular signals from largely distributed cellular tower all around the area. The cellular signals from different technologies such as CDMA and LTE are already available in addition to long time existing GSM technology. In this work, we will present how to use the cellular signals from different towers and sectors to provide localization information to the UAV in addition to environment canopy database where heights of building, trees, etc are used in path planning algorithm. The work is to show how to build three dimensional radio frequency maps for different modes of technologies and how these RF maps can be used by the guidance, navigation and control system of the UAV to position itself and determine trajectory selection in three dimension space of an urban environment.

10195-44, Session PTue

Size and rotation invariant alphabet recognition

Junho Rim, Chulhee Lee, Yonsei Univ. (Korea, Republic of)

As more vehicles and devices are equipped with cameras, computer vision technologies can significantly enhance product applications and create new markets. Among various computer vision applications, alphabet recognition has been an important operation. Alphabet recognition is a basic operation in text recognition of natural images, which can be used to obtain vital information in surrounding environments. It can be used for vehicles or autonomous moving machines such as drones or robots to understand scenes. A main difficulty with alphabet recognition is that alphabets can take various sizes and orientation, and it is desirable to develop algorithms that are size and rotation invariant. In this paper, we propose alphabet recognition algorithms based on an angle-distance histogram. Recently, the angle-distance map and histogram have been proposed, which are robust against size-variation and rotation. Then, the centroid is calculated for homogeneous regions. Then, the distances and angles of the centroid are calculated. Using these two features (distance and angle), the angle-distance map and angle-distance histogram are generated and a rotation invariant matching algorithm is applied. Since we normalize the distance, this histogram is size-invariant. The proposed method also use shape information and color characteristics. Experimental results show promising results.

10195-45, Session PTue

UAV's: on development of fuzzy model for categorization of countermeasures during threat assessment

Shashank Kamthan, Harpreet Singh, Wayne State Univ.

(United States); Thomas J. Meitzler, U.S. Army TARDEC (United States)

The necessity of Unmanned Aerial Vehicle in near future is increasing day-by-day and that leads to share air space with manned air vehicles. However, avoiding collisions and/or countermeasures during threat detection are a most crucial issue in most of the unmanned aerial vehicles [1] or similar. There will be a need for a Sense, Avoid or React [2] system to track objects of potential collision risk or determine any action to avoid or mitigate a collision and, react with countermeasures after detection of hazardous situations i.e., during midair attack, collisions, flight path obstacles or dense clouds. This paper will be presenting an algorithm for decision making system based on countermeasures during collision avoidance scenario or threat detection. This paper is giving general framework to deal with non-linear dynamic systems and will develop a system consists of various collision and risks scenarios with moving and stationary threats which is based on straight future projection. The solution will include the algorithm that captures the path prediction of the threat. The proposed optimization problem resolution will aim to maintain minimum separation between two vehicles or threats and applying necessary countermeasures if the collision becomes unavoidable. The multi-sensor fusion system, will generate the object status signal, merges vehicle status, will release an assessment of collision in the form of warning level. A fuzzy controller for countermeasure of friendly maneuver will be presented to generate active and passive measure signals based on the response from assessment signal and vehicle sensor signals. The design implementations and simulations using FPGA will be included.

10195-13, Session 6

ONR 30 AGS Program overview

Michael Bruch, SPAWAR Systems Ctr. Pacific (United States)

In 2010 the ONR Code 30 Irregular and Expeditionary Warfare Department began a long-term strategic investment in ground system autonomy focused on supporting our Expeditionary forces, namely the United States Marine Corps (USMC). The Marine Corps' mission and challenges are unique and as such require unique capabilities of the autonomous systems they will employ. For the past six years ONR Code 30 has been executing the Multi-role Autonomous Ground Vehicle (MAGV) program which has focused on developing core technologies to enable the operation of autonomous ground vehicles in expeditionary environments. The key overarching tenets of the program have been to develop a ground autonomy system that is affordable, can operate in those expeditionary (off-route) environments, and which will be the technological foundation for future DoD programs both in S&T and acquisition. Those three key tenets have driven many of the investment decisions of the program including a focus on low-cost sensors and computation (e.g., vision systems), congested environment motion planning, operation under degraded GPS conditions, multi-vehicle coordination, and using a rapid development and evolutionary systems engineering approach with rigorous and consistent performance evaluations. This paper describes the goals and objectives of the ONR 30 ground autonomy program and provides an overview of the technical accomplishments that have been achieved over the past six years.

10195-14, Session 6

A perception pipeline for expeditionary autonomous ground vehicles

Josh Zapf, Gaurav Ahuja, SPAWAR Systems Ctr. Pacific (United States); Jeremie A. Papon, Daren Lee, Jeremy Nash, Scott Tepsuporn, Greg Griffin, Jet Propulsion Lab. (United States)

The majority of research in self-driving cars concerns on-road driving. Nevertheless, numerous applications exist for autonomous ground vehicles in expeditionary scenarios. This paper discusses a perception pipeline designed for these environments. The system was created under the Multirole Autonomous Ground Vehicle (MAGV) program sponsored by the Office of Naval Research (ONR) (Code 30 Maneuver Thrust Area). The objective of the program is to provide autonomous capability to the warfighter in rugged and undeveloped environments.

Expeditionary environments create special challenges for autonomous sensor processing and mapping systems. For example, these environments typically lack a priori map data. Thus, the system cannot rely on previously obtained measurements to fill in holes or discard noise left by the sensor measurements. Furthermore, these environments often exhibit greater uncertainty in the type and structure of surfaces and objects. To address these issues, the MAGV program has developed a perception pipeline that fuses data from multiple sensors (color, thermal, LIDAR) with different sensing modalities and spatial resolutions. The proposed design leverages the strength of each sensor, while mitigating its weakness. The paper begins with in-depth discussion of the multi-sensor calibration procedure. It then follows the flow of data through the perception pipeline, detailing the process by which the sensor data is combined in the world model representation. Topics of interest include stereo filtering, stereo and LIDAR ground segmentation, pixel classification, 3D occupancy grid aggregation, and cost map generation. Results on real world data are provided via a variety of automated testing tools.

10195-15, Session 6

Domain adaptation for semantic segmentation in offroad driving scenarios

Jeremie A. Papon, Jet Propulsion Lab. (United States)

Deep convolutional neural networks have been shown to dramatically outperform existing methods in most visual recognition and classification tasks. Unfortunately, this dramatic increase in performance comes at a cost; deep networks require large hand-annotated datasets to train. These datasets are expensive and time-consuming to create, especially for semantic segmentation, which requires hand-annotated per-pixel labels. As recent research in perception for autonomous driving has focused on cities and their unique visual challenges, the large annotated datasets created have focused exclusively on urban driving.

To overcome this, in this work we show how the amount of application-specific training data required can be reduced by pre-training a network on a large dataset created for another task. Once the network has been pre-trained, the final network layers are then adapted to a new application using a small amount of domain specific training data. We experiment with different strategies for adapting a pre-trained network, and show that the choice of strategy has a significant impact on the performance of the resulting network. Results show that our pre-training procedure and various adaptation mechanisms yield a significant performance boost over a network trained directly on the small dataset. Additionally, we present experiments showing the effect of using different datasets for pre-training on the final result. These results demonstrate that using data from a variety of domains, not just urban driving, can be helpful in training a network for off-road semantic segmentation.

10195-16, Session 6

Adaptive terrain traversability estimation using passive sensing

Mark Allmen, Neya Systems LLC (United States); Mark Hassman, Neya Systems LLC (United States)

A major contributor to path planning failure is costmap and world model noise and errors, which result when the characteristics of the current environment deviate from the data used to train the sensor perception system. Our adaptive traversability capability improves costmap estimation from purely passive sensing using an online learning strategy that uses successful traversal by the vehicle as a training signal to improve estimation over time. This adaptation mitigates the negative effects of noise and errors in generation of the world model and costmap and decreases dependency and sensitivity to fixed or user-set parameter values. Our system learns the association between traversability and a diverse set of descriptors that characterize the world model and costmap. These descriptors include single voxel-based quantities such as color and temporal coherence and collections of voxels over small local areas such as ground smoothness. By measuring or learning the data characteristics in the fixed sensor perception system and resulting world model, principled estimation of the correctness of the world model and costmap can also be incorporated. We avoid duplicating sensor processing directly in favor of characterizing the derived world model data. This allows the system to directly mitigate the noise and errors that can negatively impact path planning. The system design is general and modular, allowing easy exploration of different learning approaches. Both linear and non-linear methods have been examined, with non-linear methods showing more stable and better performance. We show successful terrain traversability estimation in a diverse set of environments, including unimproved road and expeditionary.

10195-17, Session 6

Wheel placement reasoning in complex terrain

Jimmy S. Gill, Andrew Capodieci, Mark D. Ollis, Neya Systems LLC (United States)

To achieve accurate navigation in off-road terrain without risk of rollover or damage to the chassis or suspension, state-of-the-art planning systems should be designed to reason about individual wheel placement. By employing selective reasoning for wheel placement on uneven terrain, planning systems can minimize roll, pitch and z-acceleration while maximizing vehicle underbody clearance along generated trajectories. This adaptation results in safer autonomous vehicles that reduce overall mission risk and expands the applicable mission portfolio for autonomous vehicles by enabling them to navigate previously untraversable terrain.

Wheel placement is a natural extension for our Adaptive Modular Multi-terrain Mobility Planner (AM3P), which leverages model-based receding-horizon control to accurately model vehicle dynamics along feed-forward trajectories. By incorporating additional data sources that describe the ground terrain with AM3P's existing kinodynamic vehicle models, AM3P can compute all relevant metrics for wheel placement during analysis of the aforementioned feed-forward trajectories. We have shown successful wheel placement reasoning in a diverse set of environments, including unimproved roads and expeditionary scenarios.

We quantify the performance improvement by measuring the path and control deviation from the human-selected best route, ride safety measures (vertical acceleration, vibration and chassis power absorption), and measures for chassis roll and pitch relative to established thresholds for vehicle rollover.

10195-18, Session 6

Augmenting autonomous vehicle sensor processing with prior data

Elliot Johnson, Marc Alban, Richard D. Garcia, Kristopher Kozak, Southwest Research Institute (United States)

Sensor augmentation with a priori data effectively expands the sensing range and adds new sensing modalities. The ONR 30 Autonomous Ground System augments live sensor data with a priori elevation data from 3rd party sources, and stored sensor data from previous operations from a persistent map.

High resolution elevation maps are registered to the vehicle based on live estimates of the ground height from sensor data. The registration provides a robust a absolute position estimate in mountainous terrain and allows the vehicle to avoid steep slopes, which may be difficult to observe directly by sensors.

Live sensor data is used to build persistent maps that are continuously relaxed and updated with new information. The relaxation step allows the map to correct for drift in the vehicle's relative odometry, filter out errors in GPS samples, and account for loop closures to create a map that improves each time more data is collected. The persistent map provides a robust location estimate based on the registration between stored and live data. Stored data can also be fused with the current live costmap to fill in gaps behind obstacles and beyond the sensing horizon, allowing the navigation system to effectively plan and re-route the vehicle over large distances.

10195-19, Session 7

Mission planning, execution and modeling for teams of unmanned vehicles

Jean-Pierre de la Croix, Grace Lim, Joshua Vander Hook, Amir Rahmani, Jet Propulsion Lab. (United States); Greg N. Droge, Alexander L. Xydes, Christopher J. Scrapper Jr., SPAWAR Systems Ctr. Pacific (United States)

Mission design consists of high-level descriptions of objectives to be accomplished while satisfying certain constraints. State of the art mission executives for unmanned systems require encoding the missions programmatically. This approach is not only complex and cumbersome for a developer of this system, but also is inaccessible to someone without direct domain knowledge. This paper develops a novel graphical and user friendly framework for mission design to address this issue.

Mission Planning, Execution and Modelling (MPEM) extends a subset of the Business Process Modelling and Notation (BPMN) 2.0 for robotic applications. Hierarchical abstractions fundamental to BPMN allow the mission, designed graphically, to be naturally decomposed into interdependent parallel sequences of Sub-Processes, Activities, Gateways, and Signals. In MPEM, activities consist of atomic behaviors or collaborative control modalities using a role-based framework for defining required and optional resources for execution. Data-driven Gateways are used to access situational data, Signals allow for external stimuli to influence process flow, and User Tasks allow a user to directly interact with the autonomous system while it is executing its mission.

The graphically defined mission is encoded as a mission model diagram and stored in a machine readable (BPMN XML standard) format. It is parsed and processed by the MPEM executive. The executive consists of a resource manager used to assign resources to roles within each activity and an execution engine for commanding the behavior defined by each activity to the appropriate robots and/or resources.

10195-20, Session 7

Adaptive formation control for route-following ground vehicles

Greg N. Droge, Alexander L. Xydes, Christopher J. Scrapper, SPAWAR Systems Ctr. Pacific (United States); Amir Rahmani, Jet Propulsion Lab. (United States)

For problems such as route inspection or snow removal, vehicles must coordinate spatially and temporally to ensure clearance of the route and avoid inter-vehicle collisions. In such expeditionary missions, spatial constraints are made difficult due to environmental conditions and/or the possibilities of unknown areas or ill-defined roads. The spatial relationship of vehicle paths will require adaptation to navigate around previously unknown obstacles and adjust for varying width of the route. Temporal constraints are important to ensure vehicles do not collide. They are exacerbated by sluggish accelerations of large vehicles typically performing the clearance work. In this paper, receding horizon planning is combined with a modified platooning approach to cooperatively adapt to the environment while maintaining spatial and temporal constraints.

The presented work utilizes a reference frame define along the route to decouple spatial and temporal constraints. Spatial constraints are maintained by planning paths on orthogonal offsets to the route. A distributed two-step planner is used to perform a discrete search through the obstacle topology and employ control theoretic splines to quickly satisfy vehicle kinematic constraints. Temporal constraints are considered by employing a virtual spring-damper system longitudinally along the route to maintain vehicle temporal spacing. The approach balances real-time obstacle avoidance, spatial structure of the formation, and inter-vehicle safety considerations.

10195-21, Session 7

Designing an operator control unit for cooperative autonomous unmanned systems

Paul Candela, SPAWAR (United States); Greg N. Droge, Adam F. Nans, Alexander L. Xydes, SPAWAR Systems Ctr. Pacific (United States)

Interfacing with and supervising a team of heterogeneous, modular robotic systems across various, dynamic mission sets poses significant demands on the design of an operator control unit (OCU). This paper presents an architecture and OCU design which focuses on three key elements addressing this problem: 1. A well-defined system architecture for external interfacing, 2. Dynamic device discovery to advertise current capabilities, and 3. A flexible front-end to convey situational awareness.

The system architecture and external interface is influenced by work done in 4D/RCS (Four Dimensional Real-time Control System) to provide a hierarchical decomposition of the system autonomy. The platform independent, web-based OCU is capable of interacting with any level of the system-of-systems from low-level teleoperation of a single vehicle to section-level concerns such as commanding coordinated tactical behaviors across multiple vehicles. The architecture design facilitates dynamic discovery of the team of vehicles and their respective payloads. The OCU subscribes to pertinent data from these advertised systems, providing multiple human supervisors the ability to interact with and receive concurrent visual representation of them and their status. System failures, payload detections, and user decision prompts are displayed in a prominent yet unobtrusive manner.

The OCU was used to control a heterogeneous team of five vehicles performing coordinated route clearance operations in a set of four demonstration vignettes. Results of a technical exercise using this system are described herein.

10195-22, Session 7

A systematic approach to autonomous unmanned system experimentation

Ryan Halterman, Chris Scrapper, SPAWAR Systems Ctr. Pacific (United States)

Regimented experimentation of autonomous unmanned vehicles is an important enabler for performance assessment, issue identification, and root-cause analysis. As autonomous capabilities improve, these are increasingly problems of needles and haystacks; large amounts of test data are often required to fully identify and analyze erratic events. Acquisition and analysis of this test data can be arduous, error prone, and inefficient.

Driven by a philosophy that test methods should be repeatable, reproducible, and as automated as possible, we have developed an experimentation regime for expeditionary autonomous unmanned vehicles. This regime represents a method of decomposing functionality, analyzing component results, and building up evidentiary information on overall system performance despite the challenge of testing to sufficient statistical significance. We have also developed a set of tools that automate data collection and analysis to facilitate experimentation. This paper describes this test and experimentation philosophy, regime, and associated tools developed under the Office of Naval Research, Code 30 Autonomy Program.

10195-23, Session 7

Best practices for autonomous vehicle configuration management

Thomas A. Denewiler, SAIC (United States)

Autonomous systems present many challenges during development, including safety, repeatability of results, and the high cost of system testing. These challenges are compounded because of the nature of autonomous systems, which are composed of interconnected components encompassing a broad spectrum of disciplines, including mechanical, electrical, computer vision, fusion algorithms, networking and communications. By necessity, all components are often under simultaneous development.

Because of the close coupling of components, changes in one component can have wide ranging effects.

In this paper we describe a set of processes, tools, and workflows that allow a distributed team to develop, evaluate, and deploy software for autonomous systems while ensuring that parallel development can continue without introducing system instability or performance regressions.

These include processes and tools for sharing software configurations, deploying software to autonomous system computers that lack internet, building software in parallel across multiple machines, verifying software configurations, and automatically ensuring a specified level of

quality exists using static analysis, unit tests, and regression tests. We build on existing best practices to ensure a stable baseline software configuration necessary for quantitatively assessing software changes without the need for an intractable amount of data collection to be performed.

These practices and tools give an increased confidence that the results from each test case capture the desired data due to proper software configuration and that the configuration can be merged successfully into the baseline system if warranted by results. The processes described allow for many parallel development paths to proceed simultaneously with easily resolved conflicts.

10195-24, Session 8

CARACaS multi-agent maritime autonomy for unmanned surface vehicles in the Swarm II harbor patrol demonstration

Michael Wolf, Amir Rahmani, Jean-Pierre de la Croix, Gail Woodward, Joshua Vander Hook, David I. Brown, Steve Schaffer, Christopher Lim, Philip Bailey, Scott Tepsuporn, Marc I. Pomerantz, Viet Nguyen, Cristina Sorice, Michael Sandoval, Peter Cheung, Jet Propulsion Lab. (United States)

This paper describes new autonomy technology that enabled a team of unmanned surface vehicles (USVs) to execute cooperative behaviors in the “USV Swarm II” harbor patrol demonstration and provides a description of autonomy performance in the event. The new developments extend the NASA Jet Propulsion Laboratory’s CARACaS (Control Architecture for Robotic Agent Command and Sensing) autonomy architecture, which provides the foundational software infrastructure, the core executive functions, and several default robotic technology modules. In USV Swarm II, CARACaS demonstrated higher levels of autonomy and more complex cooperation than previous on-water exercises, using full-sized vehicles and real-world sensing and communication. The core autonomous behaviors to support the harbor patrol scenario included Patrol, Track, Inspect, and Trail, providing the capability of finding all vessels entering the patrol area, keeping track of them, inspecting them to infer intent, and trailing

suspect vessels. Significantly, CARACaS assumed responsibility for not only executing tasks safely and efficiently but also recognizing what tasks needed to be accomplished, given the current state of the world. As the heterogeneous USV team's shared world model evolved, such as due to (dis)appearance of vessels in the area or a change in health or availability of a USV, CARACaS replanned to generate and reallocate the new task list. Thus, human intervention was never required in the loop to task USVs during mission execution, though a supervisory role was supported in the autonomy system for monitoring and exception handling. Finally, CARACaS also ensured the USVs avoided hazards and obeyed the applicable rules of the road, through its local motion planning modules.

10195-26, Session 9

Joint communications architecture for unmanned systems (JCAUS) *(Invited Paper)*

Shad M. Reese, TWS, Office of the Under Secretary of Defense for Acquisition, Technology and Logistics (United States); William Chang, Booz Allen Hamilton Inc. (United States)

The DoD unmanned systems communities face continuing challenges of enhancing operational efficiency in technology adaptations, acquisitions, and logistics for their communications capabilities. Several DoD unmanned system platforms use proprietary radios that are platform specific and not interoperable with other platforms. These proprietary designs introduce upgrade risks when modifications are needed to react to threats. For critical missions, many of these radios do not have government approved features sufficient to support efforts that demand higher security assurance.

To address the above challenges and help advance the pace of technology transition, the Office of the Under Secretary of Defense (OUSD) for Acquisition, Technology, and Logistics (AT&L) Joint Ground Robotics Enterprise (JGRE) has established a new program along with a new generation communications architecture, called Joint Communications Architecture for Unmanned Systems (JCAUS). It reconciles common features across more than two dozens of ground and small aerial systems, including the capabilities of frequency allocation, spectrum supportability, interoperability, waveform policy, information assurance, and environmental requirements.

Adopting an approach aiming to improve the technology insertion flexibility and encourage competitive business environment, the JCAUS team is developing an architecture framework using open standards and modularity that meets the DoD Net-Ready and Cyber Security Key Performance Parameters (KPPs). A series of prototypes is introduced to demonstrate the benefits of reduced total ownership cost, accelerated transition, and increased innovation through the creation of a family of systems, by partnerships from government research organizations and the industry. This paper provides the background and technology highlights of this effort.

10195-27, Session 9

Development of an advanced cybersecure radio for small unmanned ground vehicles

Hoa G. Nguyen, Narek Pezeshkian, John Yen, SPAWAR Systems Ctr. Pacific (United States)

The Space and Naval Warfare Systems Center (SSC) Pacific is developing a prototype cybersecure network radio for the Man-Transportable Robotic System (MTRS) MK2 Mod 0 explosive-ordnance-disposal (EOD) robot that will also be compatible with the Advanced EOD Robotic System (AEODRS) Increment-2 robot, programs of record managed by the Indian Head EOD Technology Division (IHEODTD).

Until recently, cybersecurity has not been an emphasis in the development and fielding of unmanned vehicles, specifically small unmanned ground robots. Technical challenges for a secure radio for small robots include: (1) the size, weight, and power (SWaP) of traditional encryption devices and cross-domain solutions, (2) the need to keep Controlled Cryptographic Items (CCIs) under physical control at all times, which runs counter to the concept of operation of unmanned systems, and (3) the lengthy approval processes, which have often been overridden by urgent Warfighter needs.

This paper describes SSC Pacific's solution, the MTRS/AEODRS Radio for Cybersecure Operation with Network Integration (MARCONI), a modular ad hoc networking radio developed in parallel with the Joint Ground Robotics Enterprise (JGRE)'s Joint Communication Architecture for Unmanned Systems (JCAUS). The radio architecture includes a Payload Host Module (which is the heart of the system and provides translations and interfaces to various other modules and payloads), a Communication Module based on frequency-shifted 802.11 wireless technology with ad hoc networking, and a Cybersecurity Module (which uses the latest technologies—including Tactical Key Management—to meet the SWAP and non-CCI preference for unmanned systems).

10195-28, Session 9

Cybersecurity for unmanned systems

John Yen, SPAWAR Systems Ctr. Pacific (United States)

Unmanned systems present unique challenges to Cybersecurity developers due to:

• The need to secure these systems and protect classified information in the unmanned operational environment, where the unmanned systems are often outside the visual range and physical control of the operator.

• The very low Size, Weight, and Power (SWaP) consumption constraints imposed by the smaller unmanned systems.

• The long and costly approval processes for deploying any high assurance cryptographic products, Cross Domain Solutions (CDS), Military Grade Global Positioning System (GPS), and other security solutions in the military operational environment.

Additionally, modularizing the communications architecture to take advantage of rapid technological advancements often results in the need to move plaintext information between classification domains, which is a CDS requirement.

This paper describes work at SSC Pacific supporting unmanned systems Cybersecurity that includes:

• Investigating current approved cryptographic and CDS tactical products to assess their suitability for unmanned systems operations. While some current products can meet the larger unmanned systems' SWaP requirements, most approved products do not meet SWaP requirements for the smaller unmanned systems.

• Investigating potential new technologies that have not yet reached the operational stage but show promise for meeting the smaller unmanned systems' SWaP requirements.

• Proposing a way ahead that can meet the three challenges of deploying Cybersecurity solutions onboard unmanned systems supporting military operations.

10195-29, Session 9

Seamless cryptography and key management for secure and agile UxS communication

Roger Khazan, Benjamin Nahill, Danil Utin, Mankuan Vai, David Whelihan, David Wilson, MIT Lincoln Lab. (United States)

Our goal is to enable the realization of advanced unmanned and autonomous systems that are dependable and trustworthy from the cyber-security perspective, without requiring the people who work on such systems become cybersecurity experts.

To realize this goal, we need self-contained, easy-to-integrate, and easy-to-operate cybersecurity components or "building blocks" that could provide desired security guarantees while seamlessly supporting various UAS use-cases, including concepts like agility and dynamism.

There is a lot of work still to be done in the area of such seamless cybersecurity. But we have an early success story:

In this paper, we are going to describe Lincoln Open Crypto and Key-Management Architecture (LOCKMA). LOCKMA is a software component designed to significantly simplify the task of adding cryptographic protections and underlying key management to software applications and embedded devices, such as UAS. LOCKMA provides a "seamless crypto" solution by combining powerful, modern cryptography, standards-based identity management, and advanced dynamic key management.

We are also going to describe several UAS-inspired use-cases and show how LOCKMA could naturally support these use-cases to ensure security of UAS communications.

10195-30, Session 10

Multi-modal interaction for robotic mules

Glenn Taylor, Michael Quist, Matt Lanting, Robert Marinier, Cory Dunham, Soar Technology, Inc. (United States); Paul L. Muench, U.S. Army Tank Automotive Research, Development and Engineering Ctr. (United States)

To lighten the load of dismounted infantry, research is being conducted into the use of "robotic mules" that can help carry equipment and supplies for small units as they conduct their operations. While autonomy and perception features of robotic systems are steadily improving, the way in which people interact with them is still fairly rudimentary. The operator control units (OCUs) for these robotic mules are typically hand-held gaming controllers for tele-operation, or worn ruggedized portable computers or tablets with point-and-click interfaces. These control devices add more weight to the operator, and often require them to hold the controllers in their hands and to spend considerable time looking down at the OCU screen to enter commands or to understand what the robot is doing. Furthermore, these interfaces often require specialized training to understand how to operate the OCUs. This paper describes research aimed at reducing the physical, cognitive, and training burdens that robotic systems place on operators above and beyond the their regular jobs as warfighters. We first present an analysis of relevant infantry communication to identify interaction requirements, and an analysis of technologies that might be used to support these interactions. We then describe a prototype heads-up, hands-free system for controlling robotic mules using a lightweight, worn interaction device based on a smartwatch that facilitates natural two-way interaction (including speech and gesture input) between the robotic mule and the user. We describe the challenges in building this system and some formative evaluations of the technology.

10195-31, Session 10

Head-worn display for control of unmanned vehicles

Mikhail Belenkii, Lawrence H. Sverdrup Jr., Larry DiRuscio, Yoshi Taketomi, Trex Enterprises Corp. (United States)

Remotely controlled or tele-operated robots are playing an increasing role in military, law enforcement and industrial operations. In order for a remote operator to rapidly and efficiently control an unmanned vehicle (UV), the operator must be able to view the robot surroundings as if they were actually present at the location of the robot. The current limiting factor to providing this level of presence is the visual display utilized by the operator, which for portability, size and weight is optimally a head-worn display (HWD). When in addition local situational awareness of the operator must be maximized, the HWD is should be of the optical see-through (OST) type. The ideal requirements for the OST-HWD for UV control include a large binocular display field-of-view, methods to prevent development of cyber sickness and appropriate brightness for use in all relevant lighting conditions. Limitations of current OST-HWDs are reviewed, and a new type of OST-HWD is described, which offers significant advantages for remote control of UVs. An initial prototype has been constructed, and its performance is quantified. The prototype provides large field-of-view, large eye box, and high brightness. It uses low cost commercial off-the-shelf components. When the operator of the unmanned vehicle must use their hands for other purposes, a hands-free control interface for both the display and robot is highly desirable. Hands-free control interfaces compatible with the use of a HWD are reviewed. An implementation of a hands-free control interface based on eye tracking is described.

10195-32, Session 10

Intelligent shared control of a small UGV

Jared Giesbrecht, Defence Research and Development Canada, Suffield (Canada)

This paper overviews the development and operator testing of a shared autonomy system for small unmanned ground vehicles operating in indoor environments. The project focused on creating driving assistance technologies to reduce the burden of performing low-level tasks when operating in cluttered or difficult areas by sharing control between the operator and the autonomous software. The system also provides a safety layer to prevent the robot from becoming disabled due to operator error or environmental hazards. Examples of developed behaviours include obstacle proximity warning, centering the vehicle through narrow doorways, wall following during long traversals, stair climbing aid, and retreat from communications loss. The software was integrated on a QNA Talon IV robot and tested by military operators in a relevant environment.

10195-33, Session 10

Unobtrusive assistance of obstacle avoidance to tele-operation of ground vehicles

Mingfeng Zhang, MDA Corp. (Canada); Piotr Jasiobedzki, MacDonald, Dettwiler and Associates Ltd. (Canada)

Tele-operating unmanned ground vehicles (UGV) through video relay in remote environments poses challenges due to limited situational awareness, constraints in vehicles' kinematics and dynamics, proximity to objects, challenging terrain, and often non-intuitive controls. Shared control provides a safety layer as the vehicle reacts to unsafe conditions allowing the operator to focus on mission objectives. This paper presents a new obstacle avoidance algorithm that provides unobtrusive assistance to tele-operation of UGVs. By projecting an operator's steering commands into short-term trajectories of a tele-operated vehicle through an inversed kinematic model of the vehicle, it can determine whether the commands are safe in the presence of obstacles and can automatically adjust unsafe commands in an unobtrusive manner to avoid proximate obstacles to ensure the vehicle's safety. Its interference to the operator during this process is minimized by limiting its effective horizon to the vehicle's immediate neighborhood and adopting a unique partition of proximate obstacles. In addition, it adopts a realistic representation of the geometrical shape of ground vehicles, which makes it less obtrusive and more robust in cluttered environments. Thanks to its assistive but unobtrusive nature, this algorithm can quietly share some control authority of a tele-operated vehicle with its operator and therefore makes tele-operation of ground vehicles in challenging environments and confined space significantly easier and safer. This algorithm has been successfully implemented in a shared-control system for a military-grade security robot, and its effectiveness and performance have been tested and assessed by professional operators of security robots in realistic environments.

10195-34, Session 11

Assessing autonomy vulnerabilities in military vehicles

Craig Lennon, Marshal Childers, U.S. Army Research Lab. (United States)

The Autonomous Ground Resupply (AGR) Program is a U.S. Army Tank Automotive Research Development and Engineering Center (TARDEC) effort to reduce the number of soldiers required for ground resupply. One objective of this program involves providing vehicles with the capability to operate unmanned in a variety of circumstances. Prior to fielding, this system is undergoing an assessment to identify possible vulnerabilities. We use this system to illustrate a general approach to the assessment of the autonomous decision making, describing a process which could be used to identify vulnerabilities in the autonomy of military systems without describing any actual vulnerabilities discovered in the AGR system.

10195-35, Session 11

The 25th Annual Intelligent Ground Vehicle Competition (IGVC): Building engineering students into roboticists

Andrew Kosinski, U.S. Army Tank Automotive Research, Development and Engineering Ctr. (United States); Gerald R. Lane, Great Lakes Systems & Technology, LLC (United States); Keim C. Cheok, Oakland Univ. (United States); Bernie L. Theisen, U.S. Army Tank Automotive Research, Development and Engineering Ctr. (United States); Jane Tarakhovsky, MOBIS Technical Ctr. of North America (United States)

The IGVC is a college level autonomous unmanned ground vehicle (UGV) competition that encompasses a wide variety of engineering professions – mechanical, electrical, computer engineering and computer science. It requires engineering students from these varied professions to collaborate in order to develop a truly integrated engineering product, a fully autonomous UGV.

There are three main competitions within IGVC 2017, the Design Competition, Auto-Nav Challenge and Interoperability Profile (IOP) Challenge. There will also be the addition of a preliminary new competition, the Spec 2 competition, which for the 2017 year will have a demonstration/meet format, to help drive a more formalized Spec 2 competition in 2018. The Design Competition challenges students to document their vehicle development by creating a design report, followed by an in-person presentation to the design judges during the actual IGVC 2017 event, including a vehicle examination by the judges. The Auto-Nav Challenge is the main challenge, which consists of an outdoor obstacle course that requires the UGVs to perform full autonomous operation/navigation throughout. The IOP Challenge encourages students to make their vehicles more interoperable, by requiring development of a Joint Architecture for Unmanned Systems (JAUS) compliant UGV, which is the architecture current military robots are being designed to. The new Spec 2 competition will be a freelance event, with performance based on performing actions such as lane keeping, lane switch, merging, avoiding crossing obstacles (simulated pedestrians/vehicles), taxi pickup of passengers, stop and crosswalk lines detection, right/left turn and intersection detection/logic, navigation to GPS waypoints and autonomous parking.

10195-36, Session 11

A class of polarized cavity orientation sensors

Harbans S. Dhadwal, Jahangir S. Rastegar, Philip Kwok, Carlos M. Pereira, Omnitek Partners, LLC (United States)

Angular orientation of both mobile and stationary objects continues to be an ongoing topic of interest for guidance and control as well as for non-GPS based solutions for geolocations of assets in any environment. 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 solution for many applications, particularly for gun-fired munitions and for all-weather and all environment scenarios. High accuracy angle measurements are needed, particularly for continuously rotating projectiles in flight. Most angle measurement systems in use today, suitable for all weather environments, essentially provide heading information, with an angular resolution of a few degrees.

A robust onboard full angular orientation sensor solution, based on a polarization scanning reference source and polarized geometrical cavity orientation sensors is presented. The sensor system provides a new non-GPS and non-inertial approach to angle measurements, with several key advantages over other methods, which include traditional phased-array antenna systems and the like. In this novel approach, the angular orientation information is coded into a time dependent pattern, which is insensitive to noise, while making the angle measurement independent of distance from the referencing source. The manuscript presents design and analysis of polarization cavity orientation sensors using finite element based numerical solutions and sensor validation is provided through both measurements in the outdoor environment and in an anechoic chamber.

10195-37, Session 11

Deep-belief trust estimation in multi-agent systems

Cristian Balas, U.S. Army Tank Automotive Research, Development and Engineering Ctr. (United States) and Univ. of Detroit Mercy (United States); Robert E. Karlsen, Paul L. Muench, Dariusz G. Mikulski, U.S. Army Tank Automotive Research, Development and Engineering Ctr. (United States); Nizar Al-Holou, Univ. of Detroit Mercy (United States)

In this paper we propose a trust algorithm, dubbed NeuroTrust, based on a multi-layered neural network. Previous work introduced trust as a performance estimation algorithm between team members in multi-agent systems, to allow for behavior optimization of the team. The trust model was developed based on an acceptance observation history (AOH) and confirmation and tolerance parameters to control trust growth and decay. Further work proposed certain improvements, in an autonomous vehicles convoy scenario, by considering agent diversity and a non-linear relationship between trust and vehicle control. In this work we show a further optimization using a deep recurrent neural network. This multi-layered neural network delivers trust as a probability function estimation with AOH as a sliding window batch input. The neural network is pre-trained using supervised learning, to emulate the previous trust model, as baseline. This pre-trained model is then exposed to future optimization using on-line reinforcement learning. The proposed trust model is adaptable to a variety of systems, external conditions, and agent diversity. One application example where such a biologically-inspired trust model is suitable would be for soldier-machine teaming. Furthermore, particularly in the autonomous convoy scenario, we can account for the trust-control relationship non-linearity in the trust domain, thus simplifying the control algorithm.

10195-38, Session 11

Fast reinforcement learning based distributed optimal flocking control and network co-design for uncertain networked multi-UAV system

Hao Xu, Luis Rodolfo Garcia Carrillo, Univ. of Nevada, Reno (United States)

Military applications require networked multi-UAV system to perform practically, optimally and reliably under changing mission requirements. Lacking the effective control and communication algorithms is impeding the development of multi-UAV systems significantly. Therefore, in this paper, distributed optimal flocking control and network co-design problem has been investigated for networked multi-UAV system in presence of uncertain harsh environment and unknown dynamics. Firstly, the mathematical relation between network imperfections (e.g. network-induced delays and packet dropouts) and practical mobile wireless mesh network protocol has been studied. Then, a novel networked multi-UAV system model has been represented that combining effects from control system and real-time wireless mesh network protocol effectively. Next, adopting the emerging neuro dynamics programming (NDP) technique, fast reinforcement learning algorithms and actor-critic-identifier (ACI) architecture, a novel fast reinforcement learning based finite horizon distributed optimal flocking control and network co-design has been proposed. The proposed scheme can learn the optimal co-design under uncertain harsh environment (e.g. earthquake, tornado areas etc.) effectively and rapidly, and also relax the requirement of networked multi-UAV dynamics. The Lyapunov Theorem is used to validate the effectiveness of proposed scheme. With the proper NN weight update law, proposed scheme can ensure all closed-loop signals and NN weights are uniformly ultimately bounded (UUB). Moreover, a novel multi-UAV testbed has been developed in Autonomous Systems Lab (ASL) at University of Nevada, Reno. The hardware-in-the-loop simulation results can further demonstrate the effectiveness of the proposed scheme.

10195-39, Session 11

Model-free adaptive controller for autonomous aerial transportation of suspended loads with unknown characteristics

Ricardo Antonio Barron Gomez, Luis Enrique Ramos Velasco, Univ. Autónoma del Estado de Hidalgo (Mexico); Eduardo Steed Espinoza Quesada, Univ. Politécnica de Pachuca (Mexico) and Univ. of Nevada, Reno (United States); Sesh Commuri, Univ. of Nevada, Reno (United States) and Nevada Advanced Autonomous Systems Innovation Ctr. (United States); Luis Rodolfo Garcia Carrillo, Univ. of Nevada, Reno (United States)

Due to the highly uncertain and dynamic nature of military conflict and planetary exploration missions, enabling UAS to gracefully adapt to mission and environmental changes is a very challenging task. In particular, the US Army, Air Force, Navy, and NASA have shown interest in the task of load transportation by means of UAS, which rely on the knowledge of both the UAS model and the load dynamics to function. Most of the currently available autopilot systems for UAS were built without suspended load transportation capabilities and are thus not appropriate, for example, to assist soldiers/planetary explorers in the tasks of carrying and deploying supplies, transporting injured people, or warfare. This research addresses the problem of autonomous suspended load transportation, attending national agencies expectations that UAS will perform effectively even in the challenging situation when loads of uncertain characteristics are transported and deployed, which heavily modify the UAS dynamic during the mission.

We present a novel model-free adaptive wavenet PID-based controller for enabling UAS to transport suspended loads of unknown characteristics. The designed controller enables the UAS to perform a trajectory tracking task, based solely on the knowledge of the UAS position. We propose a novel structure, which identifies inverse error dynamics using a radial-basis neural network with daughter Mexican hat wavelets activation function. A real-time load transportation mission consisting of a UAS carrying a cable suspended load validates the effectiveness of the trajectory tracking control strategy, even when the mathematical model of the UAS and load dynamics are unknown.

10196-1, Session 1

Detecting faint nearby companions to geostationary satellites with optical interferometry *(Invited Paper)*

Henrique R. Schmitt, Sergio R. Restaino, J. Thomas Armstrong, Ellyn K. Baines, U.S. Naval Research Lab. (United States)

One of the main problems faced by the Space Situational Awareness community is the detection and characterization of faint objects around geosats. Independent of the origin of these objects, whether they are debris or controlled spacecraft, they can potentially harm these assets and contaminate the geobelt environment. The challenge of detecting these companion objects comes from their proximity and brightness ratio relative to geosats. Here we present a novel interferometric fringe nulling technique, aimed at solving this issue. This technique takes advantage of the fact that the presence of companions introduces large phase fluctuations in the fringe phase observed by an interferometer, when the interferometer is observing a target at spatial frequencies where the fringe amplitude is near zero. We will present simulations of interferometric observations of satellites with companions using a range of satellite models, separations and brightness ratios. These simulations will be used to determine the limitations of the technique and as a guide to determine parameters of a future instrument.

10196-2, Session 1

Irradiation effect on back-gate graphene field-effect transistor

Xinlu Chen, Ashok Srivastava, Louisiana State Univ. (United States); Ashwani K. Sharma, Clay Mayberry, Air Force Research Lab. (United States)

Two-dimension graphene has emerged as one of the novel materials in electronics, nanoscience and technology field since its discovery in 2004 [1]. Because of large electron mobility and high cutoff frequency, graphene and graphene-based devices have attracted much attention. They are not only able to embody their advantages in usual irradiation-free environment but also suitable for application in high irradiation areas [2].

The effects of irradiation like gamma rays, x-rays and high energy electrons on MOSFET and bipolar junction transistor are well known [3-5]. Although the details of irradiation mechanisms in graphene and related devices are still unknown, there are many experimental reports about the irradiation effects [6-8]. In this work, we investigate irradiation mechanism based on a semi-empirical model for the graphene back-gated transistor and quantitatively analyze the irradiation influences on electrical properties of the device structure.

We have proposed a model including irradiation effects on the graphene back-gated device. This model is semi-empirical and shows the DC characteristics of back-gated graphene device. Based on this model, the influences of irradiation on graphene back-gated device is exhibited. The irradiation shifts the current which changes the region of device, degrades the mobility and raises the channel resistance which can increase the power dissipation. The main mechanisms caused by those degrades are oxide traps charges, interface traps charges near the SiO2/graphene interface and graphene layer traps charges. Extension of present work will include developing SPICE-compatible model of graphene transistor for gamma-ray radiation effect studies.

References:

[1] K.S. Novoselov, A.K. Geim, S.V. Morozov, et al., "Electric field effect in atomically thin carbon films," Science, 2004, 306(5695):666-669.

[2] F. Schwier, "Graphene transistors", Nat.Nanotechnol. 2010,5,487-496.

[3] T.R. Oldham, F.B. McLean, "Total ionizing dose effects in MOS oxides and devices," Nuclear Science, IEEE Transactions, 2003,50(3):483-499.

[4] D.M. Fleetwood, P.S. Winokur, "Effect of bias on the response of metal-oxide-semiconductor devices to low-energy x-ray and Coblt-60 irradiation," Applied Physics Letters, 1988,52(18):1514-1516

[5] S.C. Witczak, R.C. Lacoe, and M.R. Shaney, "Implications of radiation induced dopant deacti-vation for npn bipolar junction transistors," Nuclear Science, IEEE Transaction, 2000,47(6):2281-2288.

[6] M.Z. Iqbal, A.K. Singh and M.W. Iqbal, "Effect of e-beam irradiation on graphene layer grown by chemical vapor deposition," Journal of Applied Physics, 2012, 111(8):084307.

[7] I.S. Esqueda, C.D. Cress, and T.J.Anderson, "Modeling radiation-induced degradation in top-gated epitaxial graphene field-effect-transistors," Electronics, 2013,2(3):234-245.

[8] G. Imamura, K.Saiki, "Modification of Graphene /SiO2 interface by UV-irradiation: effect on electrical characteristics," ACS Applied Materials & Interfaces, 2015,7(4): 2439-2443.

10196-3, Session 1

The analysis of the defects of the view field of the UV image intensifier

Rongguo Fu, Nanjing Univ. of Science and Technology (China)

UV image intensifier is a kind of vacuum image device with Cs2Te (Cesium Tellurium). It receives the incident UV light through the optical lens ahead and converts it into electronic signal, then the electronic signal is converted into visible light on the phosphor screen.

The UV image intensifier includes four parts: photocathode, microchannel plate, phosphor screen and high voltage power.

During the imaging process, the image intensifier can produces defects in the field of view, these defects influence the observing effect. The resources of the defects come from three parts: the defects of the Cs2Te photocathode, the nonuniformity of the MCP, the phosphor screen.

The inspecting criterion of the defects is described according to the diameter of the screen. The defects are inspected with a specially designed system.

The UV light from the xenon lamp is collected by the integrated sphere and forms the uniform output light, with the optical filter glass and attenuator glass, a selected wave light incident on the UV image intensifier in the optical dark box. A CCD camera "coolsnap cf" with a pixel array of 1390?1040 observes the screen and get the picture of the screen and transfers to the computer, the picture is analyzed with a kind of edge detection algorithm based on the numeric differential coefficient near to the pixels of the images.

According to inspecting results, some advices are brought to decrease the defects including modifying working high voltage between photocathode and MCP, improving the uniform of MCP amplification, etc.

10196-4, Session 1

Study on the new type of multifunctional satellite system for orbital debris detection

Linghua Guo, China Academy of Space Technology (China)

With the rapid development of space exploration and utilization, orbital debris increase dramatically, leading to great threat to human space activities and spacecraft security. In this paper, a new type of multifunctional satellite system (MMS) for orbital debris detection was put forward, which shared main optical system and possessed functions of multidimensional information detection, polarized remote sensing and high rate transmission. Even the orbital debris which is 800km far away with the size less than 10cm can be detected by the MSS. At the same time, by the method of satellite orbital maneuver and attitude adjusting, the orbital debris information that is real-time, complex and refined, all-weather can be acquired and transmitted by the MSS. Such new type of multifunctional satellite system can provide important and effective technology for international orbital debris detection.

10196-5, Session 1

On-orbit degradation of recent space-based solar instruments and understanding of the degradation processes

Mustapha Meftah, LATMOS (France)

The space environment is considered hazardous to spacecraft, resulting in materials degradation. Understanding the degradation of space-based instruments is crucial in order to achieve the scientific objectives, which are derived from these instruments. This paper discusses the on-orbit performance degradation of recent space-based solar instruments. We will focus on the instruments of three space-based missions such as the Project for On Board Autonomy (PROBA 2) spacecraft, the Solar Monitoring Observatory (SOLAR) payload onboard the International Space Station (ISS), and the PICARD spacecraft. Finally, this paper intends to understand the degradation processes of these space-based solar instruments.

10196-6, Session 1

Big data for space situation awareness

Erik Blasch, Mark L. Pugh, Carolyn Sheaff, Joe Raquepas, Alex Aved, Peter Rocci, Air Force Research Lab. (United States)

Recent advances in big data have resulted in focused research on volume, velocity, veracity, and variety. Each of these developments have resulted in new trends in information management, visualization, machine learning, and information fusion that have potential implications for space situational awareness. In this paper, we explore some of these trends as applicable for SSA to develop new capabilities for enhancing the space operating picture. The big data developments could result in increases in measures of performance and measures of effectiveness for future management of the space environment to utilize weather protection, sensor management, and secure communications for situation space understanding.

10196-7, Session 2

Owning the program technical baseline for future space systems acquisition: program technical baseline tracking tool

Tien M. Nguyen, Andy T. Guillen, James J. Hant, Inki Min, The Aerospace Corp. (United States)

The U.S. Air Force has recognized a key contributing factor to space program failure is the lack of sufficient program and technical knowledge within the Air Force concerning the systems being acquired to ensure success. The Committee on Owning the Technical Baseline in the U.S. Air Force, appointed by the Air Force Studies Board of the National Academies' National Research Council (NRC), was formed in October 2014 under the auspices of the Air Force Studies Board to address this challenge. The committee planned and participated in a workshop and prepared a report to address the "Owning the Technical Baseline" challenge . In November 2014, SAF/AQRE defined "Owning the Technical Baseline" as "The Government Applies Technical Baseline Knowledge to be an Informed Decision Maker " and in December 2014, SAF/PAO approved "Owning the Technical Baseline" as part of overall DOD Acquisition Strategy . The key challenge in owning the technical baseline knowledge is to identify what technical baseline "artifacts" or technical baseline components that the government should "own."

During the SPIE conference in April 2015, the authors discussed "Owning the Program Technical Baseline" (OPTB) versus "Owning the Technical Baseline" (OTB) and concluded that "Program Baseline" is related to "Technical Baseline," and recommended the U.S. Airforce Space and Missile Systems Center (SMC) to own the PTB . The authors also provided a recipe for how PTB components can be generated from key program components 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 Architecture (OSA) process/tools, Risk Management process/tools, Critical Chain Program Management (CCPM), and Earned value Management System (EVMS) process/tools. They also provided a matrix that captured the required tools/processes with respect to technical features of a comprehensive reference U.S. DoD "owned" PTB and a Preliminary Check List for Government's and Contractor's Owned PTB Components.

The objective of this paper is three-fold, namely, (1) extend the previous matrices to include all required PTB components during the life of a space program including pre-award and post-award acquisition phases, (2) develop a PTB tracking model that can track these PTB components throughout the life of a space program, and (3) implement the PTB tracking model in The Aerospace Corporation's Portfolio Decision Support Tool (PDST).

The paper will describe the updated matrices with all key PTB components and their associated processes and tools, DOD/USAF/SMC guidelines/instructions to generate these components, and the PTB tracking models to capture these key PTB components at each pre-award acquisition gates and pre-/post-award milestones. The pre-award acquisition gates include Go-Ahead, Early Strategy and Issues Session (ESIS), Acquisition Strategy Review Board (ASRB), Acquisition Strategy Panel (ASP), Solicitation Review Boards (SRB), and Request for Proposal (RFP). Pre-award milestone includes Milestone A. The post-award milestones include Milestone B, Milestone C, Initial Operation Capability (IOC)-Production and Deployment, and Full Operation Capability (FOC)-Operation and Support. In addition, the paper also describes the implementation of the PTB tracking models in the Portfolio Decision Support Tool (PDST). PDST is a high level integration modeling environment that captures and displays multiple aspects of an architecture or enterprise, including descriptive, technical, programmatic and assessment (such as risk) data, as well as links to artifacts that provide traceability and rationale for the content. An illustration of the PTB-PDST tracking tool's ability to track the development state of the PTB components and display all major acquisition strategy and source selection events along with the required entrance criteria to meet each pre-award acquisition gate and post-award program milestone is provided.

1 Committee on Owning the Technical Baseline in the U.S. Air Force: A Workshop; Air Force Studies Board; Division on Engineering and Physical Sciences; National Research Council, A Workshop Report, ISBN: 978-0-309-37431-6, 2015.

2 Bud Boulter, SAF/AQRE, and David Crawford, MITRE, "OTB Implementation," presentation to the committee on November 4, 2014.

3 Lt Gen John Thompson, Commander, Air Force Life Cycle Management Center. Approved for release by SAF/PAO on December 18, 2014.

4 Tien M. Nguyen, Andy T. Guillen, Sumner S. Matsunaga, "A Resilient Program Technical Baseline Framework for Future Space Systems," Proceedings of SPIE Vol. 9469 946907-1, 2015.

5 Inki A. Min, James Hant, Gregory Furumoto, and Ryan Pfeiffer. "The Portfolio Decision Support Tool (PDST): A software tool for architecture integration and visualization", AIAA SPACE 2015 Conference and Exposition, SPACE Conferences and Exposition, (AIAA 2015-4420).

10196-8, Session 2

War-gaming application for future space systems acquisition: MATLAB implementation of war-gaming acquisition models and simulation results

Tien M. Nguyen, The Aerospace Corp. (United States); Heather Barcomb, SUNY Geneseo (United States); William A. Black, Lehigh Univ. (United States); Karel Marshall, Andrews Univ. (United States); Paul Vienhage, Emory Univ. (United States); Amanda Coons, Hien T. Tran, North Carolina State Univ. (United States); Andy T. Guillen, The Aerospace Corp. (United States)

In 2014, the federal government spent nearly half a trillion dollars on private contracts. The Department of Defense (DoD) is interested in developing an algorithm to optimize the acquisition of government contracts. Recently, The Aerospace Corporation developed an Unified Game-based Acquisition Framework- Advanced Game-based Mathematical Framework (UGAF-AGMF) that makes use of game theory, probability and statistics, non-linear programming and mathematical modeling components to model contract negotiations. Aerospace's proposed advanced mathematical war-gaming models and algorithms to define the Program and Technical Baseline (PTB) solution and generate corresponding optimum acquisition strategies will be presented in the upcoming SPIE 2017 conference.

Based on The Aerospace's developed war-gaming models and algorithms2,3, this paper describes a collaborative project between The Aerospace Corporation and North Carolina State University (NCSU) through the Research Experience for Undergraduates (REU) workshop that was funded by the National Science Foundation (NSF) during the summer of 2016. The objective of the REU project is three-fold: (1) Implement the Aerospace's war-gaming models in MATLAB (MathWorks) and enhance their computation speed, (2) Generate optimum Program and Technical Baseline (PTB) solution and its corresponding acquisition strategy, and (3) Provide simulation results for a notional space system acquisition. Similar to the Aerospace's acquisition and bidding war-gaming models3, the project focuses on the Fixed Price Seal Bid (FPSB)/Firm Fixed Price (FFP), Fixed-Price Incentive Firm (FPIF) and Cost Plus Incentive Firm (CPIF) contract types.

This paper describes the MATLAB programs that were developed during the REU workshop to implement the UGAF-AGMF with games that can be played from either the perspective of the DoD Acquisition Authority or of a contractor. An "optimum strategy" that combines low total ownership cost with innovative designs while meeting warfighter needs was developed and implemented in MATLAB. The paper also describes the Bayesian War-Gaming implementation approach using Monte Carlo simulations, which is a numerical analysis technique to account for uncertainty in decision-making and to simulate the acquisition process. A detailed procedure of the implementation and interactions between games will be provided.

The simulation results show that the acquisition strategy using the proposed Nash Equilibrium strategy converges to optimum contractor's bidding values, which simultaneously increases government savings and contractor profit in all bidding games

1. Tien M. Nguyen, Andy T. Guillen, "War-Gaming Application for Future Space Systems Acquisition," Sensors and Systems for Space Applications IX, edited by Khanh D. Pham, Genshe Chen, Proc. of SPIE, Vol. 9838, 983808, 2016.

2. Tien M. Nguyen Andy T. Guillen, "War-Gaming Application for Future Space Systems Acquisition: Program and Technical Baseline War-Gaming Models," to be submitted to SPIE 2017 Conference, Anaheim, CA.

3. Tien M. Nguyen Andy T. Guillen, "War-Gaming Application for Future Space Systems Acquisition: Acquisition and Bidding War-Gaming Models," to be submitted to SPIE 2017 Conference, Anaheim, CA.

10196-9, Session 2

War-gaming application for future space systems acquisition part 1: program and technical baseline war-gaming modeling approach

Tien M. Nguyen, Andy T. Guillen, The Aerospace Corp. (United States)

The U.S. Department of Defense (DoD) is seeking innovative strategies for modernizing1 existing space systems and development of new space systems in light of evolving threats and declining budgets. DoD and Congressional initiatives2, Defense Innovation Initiative3 (DII), and Better Buying Power 3.04 (BBP 3.0) initiatives intend to introduce innovation and improve acquisition efficiency; (i) making affordability a requirement, (ii) innovative solutions, (iii) increasing competition, and (iv) decreasing the time it takes to acquire a system. Similarly, Space Modernization Initiative (SMI) Strategy1 indicates that the modernization of existing space systems shall meet three strategic objectives1, namely, (i) design for low LCC/TOC5 for affordability, (ii) provide desired system capability to meet warfighter needs, and (iii) achieve resiliency to operate in contested environments. These strategic objectives and acquisition initiatives pose conflicting requirements and a real challenge for DOD Acquisition Authority (DAA) to acquire affordable future space systems.

Last year, during the 2016 SPIE conference, the authors presented an innovative approach employing Unified Game-based Acquisition Framework and Advanced Game-based Mathematical Framework (UGAF-AGMF)6 to help inform DAA decisions. The approach makes use of game theory, probability and statistics, non-linear programming and advanced mathematical modeling components to develop flexible and optimum Program and Technical Baseline (PTB) solutions and associated acquisition strategies. Our proposed frameworks address contract type, associated incentives, source selection criteria described in Sections L & M of a Request for Proposal (RFP).

Two levels of War-Gaming Engines (WGEs) are associated with UAGF-AGMF, namely, one representing the government's "acquisition" perspective, and another representing the contractor's "bidding" perspective. The multivariate optimization involves the government's objective to [maximize] performance and [minimize] cost for "affordability," and the contractors' objective to [maximize] performance and [maximize] profits. We establish government models (DAA-WGE), and contractor models (KTR-WGE). Each of these is further subdivided into PTB solution models and corresponding acquisition strategy models; government models are DAA-PWGE and DAA-AWGE, contractor models are KTR-PWGE and KTR-AWGE.

This paper focuses on the "performance" aspect of the PTB solution. The paper describes the analytical and simulation modeling approaches for developing the optimum government PTB solution (DAA-PWGE) and corresponding contractors' PTB solutions (KTR-PWGE); respectively. The approaches focus on static Bayesian game models with "Pure" and "Mixed" games depending on the outcomes of the market survey results.

The government PTB solutions generated from DAA-PWGE directly relate to the "Government Reference Architecture (GRA) solution." The paper will describe an approach to identify the Technology Enablers7 (TEs) from a set of required warfighter capabilities8, and effective market survey strategy to obtain required information for the identified TEs, including the format for data collection that can be used to conduct acquisition war-games. The paper will also describe and provide examples on how to generate a set Architectural Solutions9 (ARCS) from the identified TEs. In addition, the paper will describe the concept of Nash equilibrium strategy10 for PTB war-games, and how the PTB war-gaming models exercise the "Nash strategy" to select optimum architecture solutions from a specified ARCS set. The optimum PTB solutions are defined in terms of the Payoff-and-Cost Functions (PCFs) optimizations. For DAA-PWGE, the optimum solution is obtained from the PCF minimization, while for KTR-PWGE, the optimum solution is from the PCF maximization.

References

1 USAF, Report to Congressional Committees: Space Modernization Initiative (SMI) Strategy and Goals, April 2014.

2 Moshe Schwartz, "Defense Acquisitions: How DOD Acquires Weapon Systems and Recent Efforts to Reform the Process," May 23, 2014, Congressional Research Service, 7-5700, www.crs.gov, RL34026

3 Honorable Chuck Hagel, The Defense Innovation Initiative (DII), Secretary of Defense, 1000 Defense Pentagon, Washington D.C., 15 November 2014.

4 Honorable Frank Kendall, Better Buying Power 3.0 – White Paper, Office of the Under Secretary of Defense, Acquisition, Technology and Logistics, 19 September 2014.

5 LCC = Life Cycle Cost (LCC); TOC = Total Ownership Cost; SATCOM = Satellite Communications; SATOPS = Satellite Operations

6 Tien M. Nguyen, Andy T. Guillen, "War-Gaming Application for Future Space Systems Acquisition," Sensors and Systems for Space Applications IX, edited by Khanh D. Pham, Genshe Chen, Proc. of SPIE, Vol. 9838, 983808, 2016.

7 Technology Enabler (TE) is a specific technology solution that meets a "capability" alone or in combination with other technology enablers, e.g. a telemetry communications system

8 "Warfighter Capability" or "Capability" is a general need that should be fulfilled by a successful technological solution, e.g. the ability to manage satellite trajectories.

9 Architectural Solution (ARCS) is the solution set made up of different technology enablers (TEs) that meets all relevant "Capabilities"

10 Nash Equilibrium is a stable solution to game theoretic problem involving multiple players in which no individual player can improve their payoff by a unilateral change in behavior

10196-10, Session 2

War-gaming application for future space systems acquisition part 2: acquisition and bidding war-gaming modeling approaches

Tien M. Nguyen, Andy T. Guillen, The Aerospace Corp. (United States)

The U.S. Department of Defense (DoD) recently focused on modernizing1 existing space systems and development of new space systems using DoD and Congressional initiatives2, Defense Innovation Initiative3 (DII), and Better Buying Power 3.04 (BBP 3.0) initiatives to introduce innovation and improve acquisition efficiency. These initiatives impose four key requirements on the development of future space systems, including (i) making affordability a requirement, (ii) innovative solutions, (iii) increasing competition, and (iv) decreasing the time it takes to acquire a system. On the other hand, as the Space Modernization Initiative (SMI) Strategy1 indicates that the modernization of existing space systems shall meet three Strategic objectives1, namely, (i) design for low LCC/TOC5 for affordability, (ii) provide desired system capability to meet warfighter needs, and (iii) achieve resiliency to operate in contested environments.

These strategic objectives and acquisition initiatives pose conflicting requirements and a real challenge for DOD Acquisition Authority (DAA) to acquire affordable future space systems. Last year, during the 2016 SPIE conference, the authors have presented innovative acquisition frameworks employing Unified Game-based Acquisition Framework and Advanced Game-based Mathematical Framework (UGAF-AGMF)6 that make use of game theory, probability and statistics, non-linear programming and advanced mathematical modeling components to develop flexible and optimum Program and Technical Baseline (PTB) solutions and associated acquisition strategies. The frameworks address contract type, associated incentives, source selection criteria described in Sections L & M of a Request for Proposal (RFP).

There are two types of War-Gaming Engines (WGEs) associated with UGAF-AGMF, namely, Decision Acquisition Authority (DAA)-WGE that represents the government's "acquisition" perspective, and Contractor (KTR)-WGE represents the contractor's "bidding" perspective. The government's perspective is to optimize the cost for "affordability," and the contractors' perspective is to maximize their profits. For DAA-WGE, the DAA plays "games" to develop the optimum PTB solution and generate corresponding acquisition strategies. The DAA-WGE model that is used for developing the optimum government's PTB solution is abbreviated as DAA-PWGE; and the DAA-WGE model to generate corresponding government acquisition strategy is abbreviated as DAA-AWGE. Similarly, the KTR-WGE7 game model to generate contractor's PTB solution is abbreviated as KTR-PWGE; and the KTR-WGE model to generate corresponding optimum contractor bidding strategy is abbreviated as KTR-AWGE.

The objective of this paper is to describe the DAA-AWGE and KTR-AWGE analytical and simulation modeling approaches for the development of government's optimum acquisition strategies and corresponding contractors' bidding strategies, respectively. The approaches include a combination of both mathematical modeling and Monte Carlo simulation technique. For DAA-AWGE, the combined mathematical and simulation models generate optimum acquisition strategy corresponding to the government's PTB solution, which is derived from the DAA-PWGE . Likewise, for KTR-AWGE, the combined model generates optimum bidding strategy corresponding to the contractor's PTB solution, which is generated from the KTR-PWGE7. The paper discusses appropriate contract types and the use of incentive-type contracts depending on the market and technology risks associated with the selected PTB solution. It will be shown that the government's acquisition strategy is to be derived based on the contractor's bidding strategy to achieve "Increased-in-Competition" criterion8 for "affordability." The paper focuses on static Bayesian game models with complete and incomplete information9 for various contract types, including Firm Fixed Price (FFP), Fixed Price Seal Bid (FPSB), Cost Plus Incentive Fee (CPIF), and Fixed Price Incentive Firm (FPIF).

The paper will describe the selection of acquisition strategy based on the government's PTB risks and contractors' bidding strategies and contractors' PTB risks. The concept of "Nash Equilibrium" strategy for achieving optimum acquisition and bidding strategies will be described and incorporated into the combined AWGE models. The optimum acquisition and bidding strategies are derived from the Payoff-and-Cost Functions (PCFs) optimizations. For DAA-AWGE, the optimum solution is based on the PCF minimization, while for KTR-AWGE, the optimum solution is on PCF maximization. In addition, the paper will also address the non-Nash bidding strategies and discuss how these strategies can simultaneously increase government savings and contractor profit when converged with Nash strategy.

1 USAF, Report to Congressional Committees: Space Modernization Initiative (SMI) Strategy and Goals, April 2014.

2 Moshe Schwartz, "Defense Acquisitions: How DOD Acquires Weapon Systems and Recent Efforts to Reform the Process," May 23, 2014, Congressional Research Service, 7-5700, www.crs.gov, RL34026

3 Honorable Chuck Hagel, The Defense Innovation Initiative (DII), Secretary of Defense, 1000 Defense Pentagon, Washington D.C., 15 November 2014.

4 Honorable Frank Kendall, Better Buying Power 3.0 – White Paper, Office of the Under Secretary of Defense, Acquisition, Technology and Logistics, 19 September 2014.

5 LCC = Life Cycle Cost (LCC); TOC = Total Ownership Cost; SATCOM = Satellite Communications; SATOPS = Satellite Operations

6 Tien M. Nguyen, Andy T. Guillen, "War-Gaming Application for Future Space Systems Acquisition," Sensors and Systems for Space Applications IX, edited by Khanh D. Pham, Genshe Chen, Proc. of SPIE, Vol. 9838, 983808, 2016.

7 See paper titled "War-Gaming Application for Future Space Systems Acquisition: Program and Technical Baseline War-Gaming Models," to be submitted to this conference by the same authors.

8 "Increased-in-Competition" criterion is defined as there is at least two contractors bidding the government's PTB solutions.

9 Incomplete Information bidding game is assumed that each contractor is unaware of the bidding strategy of competitors.

10196-11, Session 3

Accelerated space object tracking via cloud computing

Bin Jia, Kui Liu, Intelligent Fusion Technology, Inc. (United States); Khanh Pham, Erik Blasch, Air Force Research Lab. (United States); Dan Shen, Genshe Chen, Intelligent Fusion Technology, Inc. (United States)

Space object tracking plays essential roles in communications, navigation, and surveillance. Many popular nonlinear filters have been used to estimate the positional state of a space object. There is a large number of space objects and the uncertainty of these space objects requires being propagated or updated. In this paper, we use the point-based Gaussian approximation filter due to its essential ability of being implemented in a parallel structure. With the development of the cloud computing technology, a large number of space objects can be simultaneously propagated or updated. Benefiting from this observation, we implement a cubature Kalman filter using the cloud computing platform. The space object tracking algorithm is specifically designed and embedded into the MapReduce framework. The simulation results reveal that cloud computing enabled space object tracking is highly scalable and more efficient than the traditional space object tracking.

10196-12, Session 3

An orbital emulator for pursuit-evasion game theoretic sensor management

Dan Shen, Tao Wang, Gang Wang, Bin Jia, Zhonghai Wang, Genshe Chen, Intelligent Fusion Technology, Inc. (United States); Khanh Pham, Erik Blasch, Air Force Research Lab. (United States)

This paper develops and evaluates an orbital emulator (OE) for space situational awareness (SSA). OE can emulate the 3D satellite orbit using the omni-wheeled robots and a robotic arm. The 3D motion of satellite is partitioned into the movements in the equatorial plane and the up-down motions in the vertical plane. The former actions are emulated by omni-wheeled robots while the up-down motions are performed by a stepped-motor-controlled-ball along a rod (robotic arm), which is attached to the robot. For multiple satellites, a fast map-merging algorithm is integrated into the robot operating system (ROS) and simultaneous localization and mapping (SLAM) to locate the multiple robots in the scene. The OE is used to demonstrate a pursuit-evasion (PE) game theoretic sensor management algorithm, which models conflicts between a space-based-visible (SBV) satellite (as pursuer) and a geosynchronous (GEO) satellite (as evader). The cost function of the PE game is based on the informational entropy of the SBV-tracking-GEO scenario. GEO is allowed to maneuver using a continuous and low thruster. The hard-in-loop space emulator visually illustrates the SSA problem solution based PE game.

10196-13, Session 3

Joint-sparsity based subspace heterogeneous data-level fusion for emitter detection and estimation

Ruixin Niu, Puxiao Han, Virginia Commonwealth Univ. (United States); Peter Zulch, Marcello Distasio, Erik Blasch, Air Force Research Lab. (United States); Zijian Mo, Genshe Chen, Intelligent Fusion Technology, Inc. (United States)

Typical surveillance systems employ decision- or feature-level fusion approaches to integrate heterogeneous sensor data, which are sub-optimal and incur information loss. In this paper, we investigate data-level heterogeneous sensor fusion. Since sensor data streams are reflections of the common targets of interest, whose states can be determined by only a few parameters, it is reasonable to assume that the measurement domain has a low intrinsic dimensionality. For heterogeneous linear sensor arrays, we develop a data-level fusion approach based on newly emerging dimensionality reduction techniques, including subspace tracking and joint sparsity based grid computation. For radio frequency (RF) sensors with Doppler shift, we develop another data-level fusion approach based on joint-sparse signal recovery techniques. These approaches are data-driven and do not assume the knowledge on the number of targets, denoted as K. Instead, it only requires a loose upper bound on the number of targets in the surveillance region. Furthermore, the joint-sparse data-level estimation and fusion (JDEF) approach only requires discretization in a single-target state space, instead of discretization in a K-target state space, as in the case of the maximum likelihood estimator.

Two numerical examples are provided. In the first example, data from an acoustic array and a RF array are fused for joint target detection and directional of arrival (DOA) estimation. In the second example, data from multiple RF Doppler sensors are fused for joint target detection and state estimation. Both approaches are computationally efficient and demonstrate excellent performance.

10196-14, Session 3

An adaptive software defined radio design based on a standard space telecommunication radio system API

Wenhao Xiong, Xin Tian, Genshe Chen, Intelligent Fusion Technology, Inc. (United States); Khanh Pham, Erik Blasch, Air Force Research Lab. (United States)

Software defined radio (SDR) has become popular tool for the implementation and testing for communications performance. The advantage of the SDR approach include: a reconfigurable design, adaptive response to changing conditions, efficient development, and highly versatile implementation. The development of a SDR system has drawn great attention from research facility like NASA Glenn research center (GRC). In order to understand the benefits of SDR, the space telecommunication radio system (STRS) was proposed by GRC along with the standard application program interface (API) structure. Each component of the system uses a well-defined API to communicate with other components. The benefit of standard API is to relax the platform limitation of each component for addition options. For example, the waveform generating process can placed in equipment like a field programmable gate array (FPGA), personal computer (PC), or an embedded system. As long as the API fits the requirements, the generated waveform selection will work with the complete system. In this paper, we demonstrate the design and development of adaptive SDR following the STRS and standard API protocol. We introduce step by step the SDR testbed system including the controlling graphic user interface (GUI), database, GNU radio hardware control, and USRP tranceiving front end. In addition, a performance evaluation in shown on the effectiveness of the SDR approach for space telecommunication.

10196-15, Session 3

Machine learning based channel estimation in wireless sensor networks

Zhihui Shu, Genshe Chen, Intelligent Fusion Technology, Inc. (United States); Erik Blasch, Air Force Research Lab. (United States)

Machine learning has many advantages when the application includes unknown models and parameters, the design supports applications in a

dynamic environment with different actor behaviors, and when there is a large possible set of data to process. In this paper, a machine learning based channel estimation scheme is investigated for a wireless sensor network. The advent of the internet of things (IoT) requires different approaches for the use a large amount of data for situation understanding. Multiple devices could communicate with a node in the network from a variety of data sources with different sensor spectrum allocations. A wireless sensor network model is considered in different fading channels. The imperfect information of channel estimation is obtained by spectrum sensing. Then, a machine learning based channel estimation (MaLCE) is proposed to improve channel estimation and prediction. The advantage of the proposed MaLCE scheme is that it can improve channel estimation accuracy once the behavior is learned. Furthermore, numerical results of the outage probability and channel capacity of the network model are presented. Our analysis brings insight into machine learning based channel estimation in wireless networks in different fading situations.

10196-16, Session 4

An update on the OpenOrbiter I Mission and its paradigm's benefits for the defense, homeland security and intelligence communities

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

The OpenOrbiter I spacecraft is the culmination of significant work on reducing the cost levels of a CubeSat-class spacecraft. By redesigning the spacecraft from the ground up, down to the component level, to use readily available electronic and physical components, the cost of CubeSat construction has been significantly reduced. A CubeSat can now be built with a parts cost (excluding payload) of about $1,200. Labor costs, including board-level testing (but not including the payload-included spacecraft/integration testing), may only add an additional several thousand dollars in cost to this. The result is a very low cost spacecraft that dramatically lowers mission risk levels and facilitates spacecraft level redundancy (as opposed to subsystem – or lower – level redundancy on the spacecraft). When fully operating, a comparable cost constellation can collect and transmit significantly more data and, as it suffers eventual failures, it may degrade to having the capability of a single (more resilient / subsystem redundant) spacecraft at the beginning of its mission.

This paper provides an overview of the OpenOrbiter I mission, to date. It then focuses on the benefits that can be provided by the lower-cost, low-risk spacecraft, with particular focus on the ability to use these spacecraft as secondary payloads to increase mission return on investment (and/or provide a particular additional capability) at very low incremental cost. The paper discusses the prospective utility of this mission paradigm for the defense, homeland security and intelligence communities. It concludes with a discussion of next steps for the OpenOrbiter I mission and beyond.

10196-17, Session 4

Consideration of materials for creating 3D printed space sensors and systems

Jacob Reimers, Jeremy Straub, North Dakota State Univ. (United States)

Three-dimensional printing (also known as additive manufacturing) in space is a very practical solution to reducing the mass and volume required for bringing materials into orbit and beyond. Materials can be launched in their raw form and transformed (by printing) into the requisite parts and structures, as needed. This provides flexibility in terms of delaying the decision as to how materials will be used. Structures can be designed to support only microgravity and sensing systems can be configured (and reconfigured) based on needs identified during the mission. In-space printing also removes the need containerized part storage systems for printable parts.

This paper presents work undertaken to identify materials that are well-suited to in-space 3D printing. Materials commonly used for aerospace hardware were examined to determine if they could be used for Fused Filament Fabrication (FFF) 3D printing. The ideal goal is to enable printing aluminum; however, other materials such as carbon fiber and Ultem were considered, as well.

For each material multiple qualities were considered including the material's melting point, radiation tolerance and shielding, density, tensile strength, and thermal conductivity. Some materials are problematic for FFF as they do not have a material state conducive to deposition, which is needed for FFF printing. Without this state, printing these materials would be akin to trying to mold water.

Apart from just looking at pure metals, alloys and substrates were also examined to identify candidate materials with desirable properties and which could be deposited in formation through FFF printing.

10196-19, Session 5

Electrical design for origami solar panels and a small spacecraft test mission

James Drewelow, Jeremy Straub, North Dakota State Univ. (United States)

Efficient power generation is crucial to the design of any type of spacecraft. Mass, volume and other limitations prevent the use of traditional spacecraft support structures from being suitable for the size of solar array required for some missions. One potential solution to this problem is the use of foldable origami-style solar panels or panel arrays. A set of foldable solar panels can be initially stored in a very compact orientation to conserve volume onboard the spacecraft. They are then deployed to expose their full surface area for power generation once in orbit.

Folding solar panel / panel array systems, however, present a number of design challenges. One of the key challenges is the deployment of the panels. To maximize efficiency, the panels should be able to be deployed with as few actuators and as little power as possible. Another problem that arises with the deployment of the panels is physical limitations of the electrical connections. At the very low temperatures of space, some wires or other electrical conducts can become brittle and possibly crack or break when bent.

This paper considers the electrical design of an origami / foldable system. Specifically, it considers how to provide low impedance, durable channels for the generated power to flow through. Also considered are the electrical aspects of the deployment system and procedure. The ability to dynamically reconfigure the electrical configuration of the solar cells is discussed. Finally a small satellite test mission to demonstrate the technology is proposed, before concluding.

10196-20, Session 5

Low cost satellite mechanical design and construction

Nathaniel Boisjolie Gair, Jeremy Straub, North Dakota State Univ. (United States)

When designing and constructing the mechanical structure for a spacecraft there are a number of constraints that must be taken into consideration such as time, materials, machine availability and cost. When operating on a small budget, it can prove to be difficult to complete the project with a shortage of any one resource. This paper presents a discussion of techniques for low-cost design and construction of a CubeSat mechanical structure that can serve as a basis for other academic programs as well as a starting point for government, military and commercial large-scale sensing networks, where the cost of each node must be minimized to facilitate system affordability and lower the cost and associated risk of the loss of any one node.

Spacecraft Design plays a large role in manufacturability. An intentionally

simplified mechanical design is presented which reduces machining costs, as compared to more intricate designs that were considered.

Several fabrication approaches are evaluated relative to the low-cost goal. The first was to use a local commercial CNC router. The procedure for this is simple: export the 3-D model, convert it to g-code and send this code to the CNC router. The use of a low-cost CNC router was also considered; however, while usable for university programs, this was seen as a solution that wouldn't scale easily to other uses. Outsourcing was also considered and was seen as a very scalable solution. This however, imposed design limitations, based on vendor capabilities, that were not applicable to the other two approaches.

10196-21, Session 5

Efficiency in design and cost of a CubeSat: designing a low cost/weight satellite without compromising structural stability and quality

August Rockeman, Jeremy Straub, North Dakota State Univ. (United States)

This paper considers how design efficiency impacts the cost, schedule and quality of a small spacecraft suitable for sensing and other space missions. CubeSats have several physical parameter requirements. One requirement is the incorporation rails that are used for deploying the satellite from the launcher into space. Others requirements include electromechanical inhibit devices and overall form-factor mass, volume and other restrictions.

Design choices can significantly alter the mass and volume available for other uses within the satellite. For example, hollow tubing could be used instead of solid rails. This reduces material cost in this area by 50% and reduces mass consumption from 40% of the allowable mass to only 20%.

Irrespective of the materials used, the satellite needs to be stable enough to withstand the vibrations, acceleration forces, and temperature changes of launch. A key focus of this paper will be on optimizing durability, weight and cost. The goal is to ensure the longevity of the craft from launch through to final decay, while maximizing the mass and volume available within the craft for electrical and mechanical components.

The cost and quality of manufacturing are also relevant to consider. The use of high-end CNC machine to produce the mechanical parts will result in low dimension error. Manual production, particularly in the context of an academic project, can dramatically reduce cost, but may result in unacceptable levels of dimension error. The use of testing to validate the performance and suitability of the produced parts and overall spacecraft will also be discussed.

10196-22, Session 5

CubeSat mechanical design: creating low mass and durable structures

Gilbert Fiedler, Jeremy Straub, North Dakota State Univ. (United States)

This paper considers the mechanical design of a low-mass, low-cost spacecraft for use in a multi-satellite sensing constellation. For a multi-spacecraft mission, even small mass and cost reductions can have significant impact, in aggregate. This type of project illustrates the importance of material reduction and its impact on mass and durability.

One approach to mass reduction is to make cuts (such as holes and slots) into the structure, removing material. Stress analysis must be used to determine the level of cross-sectional area needed for different members of a structure. Once the level of cross-sectional area needed for each element is known, potential reduction strategies can be identified.

Focus areas for this paper include determining areas to make cuts to ensure that a strong shape remains, while considering the comparative cost and skill level of each type of cut. This is an especially important consideration for members that may be subjected to bending moment – with the right shape, the member can withstand more bending with less material.

The North Dakota State University Cubesat project will be using this type of design. In this case, a small satellite will be launched to the International Space Station and deployed into orbit. The paper presents both the real-world results of this analysis for the NDSU CubeSat as well as more general principles and analysis that can be universally applicable. Using stress analysis and other principles, the satellite will be made as light as possible while still being durable enough to survive the trip.

10196-23, Session 5

Evolution of the mechanical design and development for a university CubeSat program

Jay Goebel, Jeremy Straub, North Dakota State Univ. (United States)

This paper focuses on the mechanical design and development of a type of small satellite known as a CubeSat. CubeSats are used for collecting data, conducting experiments, and educational purposes. Several ways of launching CubeSats exist. Many are brought to the International Space Station (ISS) on a resupply mission, and then released into orbit. These satellites will eventually burn up in the atmosphere and must transmit all of the data they've collected prior to re-entry.

The team working on the CubeSat project at North Dakota State University was started in the early Fall of 2016, and has worked closely with the previously established group at the University of North Dakota to build a CubeSat. The main function of this first CubeSat was to test the concept of 3-D printing in microgravity and orbital pressure and temperature levels. This work sought to determine what issues would be encountered and would pose a challenge. After the initial proof of concept, both teams collaboratively developed a second CubeSat that contained a functional 3-axis 3-D printer installed in the unit.

The goal of this project is to establish a baseline for future 3-D printers operating in space, and to prove that CubeSats can be built at a significantly lower cost than traditional designs. If successful, it will open an opportunity for other schools and groups to enter the domain of space exploration and hopefully inspire interest in the science of space.

Tuesday - Wednesday 11–12 April 2017

Part of Proceedings of SPIE Vol. 10197 Degraded Environments: Sensing, Processing, and Display 2017

10197-1, Session 1

Color vision in the twilight zone: an unsolved problem

Leonard Temme, U.S. Army Aeromedical Research Lab. (United States); Paul St. Onge, U.S. Army Aeromedical Research Lab. (United States) and Laulima Government Solutions (United States)

The human visual system functions over more than 10 log units of luminance. This immense range of useful vision is due primarily to the presence of two classes of retinal photoreceptors, rods and cones, with rods supporting nighttime and cones daytime vision. These two photoreceptor classes have a number of differences that form the basis of the duplicity theory of vision, which has been elaborated and refined over the 150 years since Max Schultze first suggested it. For most of this time, rods and cones have been considered essentially independent and separable, with much research characterizing each class in isolation. Even though rods and cones are clearly differentiable, there is a 3 to 4 log unit luminance range over which both are simultaneously active. This overlapping luminance range defines mesopic vision (MV), typical of twilight. There is an increased appreciation that the assumption of rod-cone independence ignores the complex interactions occurring between these systems in MV. These complexities come from several factors, including the relative distribution of the two photoreceptor types across the retina, their differential metabolic demand and vulnerability to hypoxia, the separation of color from luminance information, and the extraordinary convergence from about 100 million rods and 6 million cones to about 1 million ganglion cells. The present paper describes rod-cone interaction in MV, emphasizing rod effects on color perception. This is particularly important since cone color standards are inappropriate for MV while appropriate mesopic color standards remain a matter of active investigation.

10197-2, Session 1

Human variability in facility of dark adaptation

Morris R. Lattimore, Thomas H. Harding, U.S. Army Aeromedical Research Lab. (United States)

Army-centered visual performance standards are primarily concerned with photopic vision. Yet, a significant number of investigators have deemed photopic standards to be inappropriate references, when considering individual visual performance under dimly-lit conditions. This represents a major visual performance classification gap for our military! Data from 24 subjects (who had participated in a project on "Facilitating the transition from bright to dim environments") have been re-assessed with regard to their individual response variability. A reduced 'bleaching' stimulus of 376 Trolands, lasting only 5 minutes, often elicited a rod-cone break in a matter of seconds. The time required for each subject to subsequently detect and identify as many of the 10 reduced light sources was measured. The lighted targets ranged from 0.250 to 0.0005 foot Lamberts. The mean dark adaptation time to visual sensitivity of the 0.002 foot Lambert target for the clear spectacle lens condition was 66.76 +/- 43.82 seconds. The mean time to sensitivity of the same target under the control condition was 60.81 +/- 26.9 seconds. Grouped data analysis indicated the lack of a significant difference between the two grouped means by t-test. Yet, there is a clear difference in the degree of response variability by both groups, as well as by individual. Anatomical and neurological processes isolated to the retina govern dark adaptation. Neural processes within the visual cortex (i.e., visual resolution) exhibit very similar individual variability under dimly lit conditions. These data variability indices suggest a cross-interaction between these processes under dimly lit conditions.

10197-3, Session 1

Optical characterization of the Sandia fog facility

Jeremy B. Wright, John D. van der Laan, Shanalyn A. Kemme, David A. Scrymgeour, Sandia National Labs. (United States)

Degraded visual environments are a serious concern for modern sensing and surveillance systems. In particular fog is of interest due to the frequency of its formation along our coastlines disrupting border security and surveillance. Fog presents hurdles in intelligence and reconnaissance by preventing data collection with optical systems for extended periods. We will present recent results from our work in operating optical systems in our controlled fog experimental chamber. This facility is a 200 foot long, 10 foot wide, and 10 foot tall structure that has over 60 spray nozzles to achieve uniform aerosol coverage with various particle size, distributions, and densities. We will discuss the physical formation of fog in nature and how our generated fog compares. In addition we will discuss fog distributions and characterization techniques. In particular we will investigate the biases of different methods and discuss the different techniques that are appropriate for realistic environments. Finally, we will compare the data obtained from our characterization studies against accepted models (e.g., MODTRAN) and validate the usage of this unique capability as a controlled experimental realization of natural fog formations. By proving the capability we will enable the testing and validation of future fog penetrating optical systems and providing a platform for performing optical propagation experimentation in a known, stable, and controlled environment.

10197-4, Session 1

Particle distribution variation on linear and circular polarization persistence in fog environments

John D. van der Laan, Jeremy B. Wright, David A. Scrymgeour, Shanalyn A. Kemme, Sandia National Labs. (United States)

Scattering environment conditions, such as fog, pose a challenge for many detection and surveillance active sensing operations in both ground and air platforms. For example, current autonomous vehicles rely on a range of optical sensors that are affected by degraded visual environments. Real-world fog conditions can vary widely depending on the location and environmental conditions during its creation. In our previous work we have shown benefits for increasing signal and range through scattering environments such as fog utilizing polarized light, specifically circular polarization. In this work we investigate the effect of changing fog particle sizes and distributions on polarization persistence for both circularly and linearly polarized light via simulation. We present polarization tracking Monte Carlo results for a range of realistic monodisperse particle sizes as well as varying particle size distributions as a model of scattering environments. We systematically vary the monodisperse particle size, mean particle size of a distribution, particle size distribution width, and number of distribution lobes (bi-modal, tri-model), as they affect polarized light transmission through a scattering environment. We show that circular polarization signal persists better than linear polarization signal for most variations of the particle distribution parameters.

10197-6, Session 1

Nano-patterned spectrally selective particles

Mathew J. Zablocki, Timothy A. Creazzo, Lenin Zaman, Ahmed S. Sharkawy, Lumilant, Inc. (United States)

As infrared (IR) electo-optical sensors improve in both availability and quality, a need exists to provide an innovative measure to spectrally obscure such sensors. Conventional approaches have relied heavily on conductive particles with high aspect ratios, providing an increased scattering cross-section. Often the scattering and absorption to obscure a scene via particles is broad, relying on bulk material properties and the electrical resonances that are excited by the incident IR radiation. This ability to obscure a scene can be further enhanced by employing spectrally selective surfaces at the particulate scale, to create stronger resonances within particles, thereby increasing the particulate's scattering and absorption properties. Additionally, through the use of a spectrally selective particle, it is possible to engineer a transparency window within the scattering and absorption spectrum. A transparency window can be specifically targeted to provide a broad obscuration of a scene while still providing select critical systems to operate. Lumilant has made great progress in the design and fabrication of such particles, exhibiting high-rejection of IR signals with and without transparency windows, utilizing nano-patterning techniques and thin-film depositions. Designs span the IR spectrum from SWIR to LWIR wavelengths, for multi-spectral scene obscuration.

10197-8, Session 2

Present and future of vision systems technologies in commercial flight operations *(Invited Paper)*

Randall E. Bailey, NASA Langley Research Ctr. (United States)

No Abstract Available

10197-9, Session 2

Synthetic vision display with integral sonic boom predictions

Laura Smith-Velazquez, Rockwell Collins, Inc. (United States); Erik Theunissen, Informatie Systemen Delft (Netherlands); Timothy J. Etherington, Rockwell Collins, Inc. (United States)

Synthetic vision systems are becoming commonplace in the business jet community. The perspective display of terrain and runway information provides a display of complex information in a visual manner that pilots are accustomed to. Research and flight testing is currently underway to allow low noise supersonic business jet operations. Widespread acceptance will require regulatory changes as well as the ability for pilots to predict and manage where the sonic boom from aircraft operations will impact people on the ground. The display will be used for inflight as well as flight planning. This paper details the CONOPS, algorithm development, and human machine considerations of a synthetic vision display design that incorporates a sonic boom carpet. Using a NASA developed algorithm, sonic boom prediction, Mach cut-off, and sound pressure levels are calculated for current flight plan and flight plan changes. The algorithm information is transformed into georeferenced objects that can be presented on navigation and guidance displays. Using the navigation display, the pilot can determine whether the current flightplan avoids the generation of sonic booms in noise-sensitive areas. In case the pilot maneuvers away from the flightplan, a dynamically computed predicted boom carpet is presented onto the guidance and navigation displays. Instead of using the flightplan, the boom prediction algorithm is now fed with an extrapolation of the current flightpath. This results in the depiction of a sonic boom footprint which changes location as the aircraft maneuvers. By using a certain look-ahead time for the prediction, the pilot has the possibility to shift the location where boom intensity will be at a maximum. Additional considerations of allowable sound levels for various locations on the ground are incorporated into the synthetic vision display for comparison of the real-time and predicted sonic boom. Results from structured pilot interviews are detailed from both past Concorde operations and future predicted business jet operations on the display design. CONOPS are detailed for international operations, current envisioned American and European operations, and American and European operations after regulatory changes that may allow sonic boom over land masses and even populated areas.

10197-10, Session 3

Best practices for cross-platform virtual reality development

Jonathan Schlueter, Iowa State Univ. (United States); Holly Baiotto, Vijay Kalivarapu, Gabriel Evans, Eliot Winer, Iowa State Univ. of Science and Technology (United States)

With virtual reality's (VR) return to mainstream attention, interest in immersive VR development has increased exponentially. To meet this demand, game engines such as Unity3d and the Unreal Engine have made substantial efforts to support various forms of VR, including the HTC Vive, smartphone-enabled devices like the GearVR, and with appropriate plugins, even fully-immersive CAVE(TM) systems. Coupled with a plethora of features, these modern game engines have become an attractive choice for developers wanting to quickly create immersive VR experiences for a wide range of devices and platforms. The challenge however, is to maintain a consistent experience across these platforms. As an example, consider that a smartphone-enabled GearVR requires a paired Bluetooth controller to provide navigation controls. With the same application on a PC-hosted Oculus Rift, a wired or RF controller can be used, or even a keyboard and mouse. With current game engines, the disparity between controls is left entirely to the developer to handle, creating many mapping complexities with creation and content interaction. The Virtual Reality Applications Center (VRAC) developed a VR football gameday experience application that was deployed to an Oculus Rift, a mobile phone, and the C6, a 4K-resolution six-sided immersive stereoscopic VR CAVE(TM) environment. Through creating this application, many lessons were learned, and best practices were identified in cross-platform development. While there is no unique approach to achieve consistency across VR systems, the authors hope to disseminate these best practices in cross-platform VR development in this paper, using the football application as a guiding example.

10197-11, Session 3

Safely enhanced low visibility taxi

Matthew Carrico, Felix Turcios, Patrick McCusker, Rockwell Collins, Inc. (United States)

This paper describes operational concepts, certification considerations, and initial user evaluations for using an avionics system for low visibility taxi operations. The ability to taxi to / from the runway safely and efficiently in low visibility conditions is becoming increasingly important as airplanes and aircrews become equipped and approved for low visibility landing and takeoff.

Typically in the United States, any surface operations below 1200 ft Runway Visual Range (RVR) generally encourage the airport authority to have an approved Low Visibility Operations / Surface Movement Guidance and Control System (LVO / SMGCS) plan which specifies certain markings, signs, lighting, and controls in the airport movement area. Operations below 600 ft RVR (or 500 ft RVR under FAA Order 8000.94 enablement) require additional infrastructure in movement and non-movement areas and may

also require Airport Surface Detection Equipment (ASDE or ASDE-X) or a suitable substitute (ref. FAA Order 8400.94) to allow the ground controllers to adequately monitor surface traffic. Surface operations below 300 ft RVR are generally precluded (or need extra controls such as the use of a follow-me truck).

The operational concepts described in this paper show how using on-board systems based on synthetic and enhanced vision systems may substitute for or augment an airport's existing infrastructure. These on-board systems along with proper additional mitigations under the LVO/SMGCS concept of Protected Low Visibility Taxi Routes (PLOVTR) would enable an appropriately equipped aircraft and qualified crew to safely taxi in low visibility conditions.

10197-12, Session 3

Simulation test of a head-worn display with ambient vision display for unusual attitude recovery

Jarvis (Trey) J. Arthur III, Stephanie N. Nicholas, Kevin J. Shelton, Lawerence J. Prinzel III, Kyle E. Ellis, Randall E. Bailey, Stephen P. Williams, NASA Langley Research Ctr. (United States)

Research, development, test, and evaluation of flight deck interface technologies is being conducted by the National Aeronautics and Space Administration (NASA) to proactively identify, develop, and mature tools, methods, and technologies for improving overall aircraft safety of new and legacy vehicles operating in the Next Generation Air Transportation System (NextGen). One specific area of research is the use of a Head-Worn Display (HWD) to serve as a possible equivalent to a Head-Up Display (HUD). A simulation experiment was conducted to evaluate whether the HWD can provide an equivalent level of performance to a HUD in terms of unusual attitude recovery. The HWD was outfitted with ambient vision displays which were varied (on/off) as an independent variable in the experiment to examine the effects of large-horizontal field-of-view HWD for attitude awareness. The simulation experiment was conducted in two parts: 1) several short unusual attitude recovery scenarios where the aircraft is placed in an unusual attitude and a single-pilot crew recovered the aircraft; and 2) a two-pilot crew operating in a realistic flight environment with "off-nominal" events to induce unusual attitudes (e.g. a wake vortex encounter). Analysis of HWD performance and pilot comments will be discussed.

10197-13, Session 4

A mmW video-based algorithm on wire recognition for DVE applications

Darren S. Goshi, Honeywell International Inc. (United States); Haoming Chen, Ming-Ting Sun, Univ. of Washington (United States); John C. Kirk Jr., Goleta Star, LLC (United States)

To address the numerous challenges for rotorcraft operation in degraded visual environments, multi-sensor solutions with advanced fusion and display capabilities are being developed to provide high fidelity situational feedback to an operator. While the active mmW sensor image lacks the optical resolution and perspective of an IR or LIDAR sensor, it currently presents the only true see-through mitigation under the heaviest of dust and fog conditions. Additionally, the mmW sensor produces a high-resolution, radar map that has proven to be highly interpretable, especially to a familiar operator. In this work, we present a mmW video-based algorithm for wire recognition and classification, and some initial results on its automatic wire detection capability. The current algorithm is not only trained on, but evaluated against mmW imagery collected from a live flight test in a relevant environment. The foundation of our approach is based on image processing and machine learning techniques due to the nature of the featured image, but also leverages the utilization of radar-based signal properties and sensor and platform information for added robustness – i.e. Bragg pattern signatures, helicopter motion, etc. Lastly, we focus some discussion on some of the practical challenges in any wire detection algorithm, its implications to the current approach, and offer proposed paths for continued development and evaluation.

10197-14, Session 4

Visibility enhancement of multi-waveband infrared images from degraded visual environment

Qin Jiang, Yuri Owechko, HRL Labs., LLC (United States); Brendan Blanton, The Boeing Co. (United States)

Multi-waveband infrared (IR) sensors capture more spectral information of atmospheric particles and may provide better penetration thru dust under dynamically changing conditions. Therefore, enhancing the visibility of multi-waveband infrared images obtained in degraded visual environment (DVE) is an important way to improve the perception of the environment under DVE conditions. In this paper, we present a system to enhance visibility of multi-waveband IR images from DVE conditions by modifying the wavelet coefficients of the multi-waveband IR images. In the proposed system, input multi-waveband IR images are transferred into the wavelet domain using an integer lifting wavelet transformation. The low-frequency wavelet coefficients in each waveband are independently modified by an adaptive histogram equalization technique for improving the contrast of the images. To process high-frequency wavelet coefficients, a joint edge-mapping filter is applied to the multi-waveband high-frequency wavelet coefficients to find an edge map for each subband wavelet coefficients; then a nonlinear filter is used to remove noise and enhance edge coefficients for enhancing image edges. Finally, inverse lifting wavelet transformation is applied to the modified multi-waveband wavelet coefficients to obtain enhanced multi-waveband IR images. We tested the proposed system with degraded multi-waveband IR images obtained from a helicopter landing in brownout conditions. Our experimental results show that the proposed system is effective for enhancing the visibility of multi-waveband IR images under DVE conditions.

10197-15, Session 4

Image quality metrics for degraded visual environments

Brendan Blanton, The Boeing Co. (United States)

With the development of a myriad of imaging sensors and associated image processing algorithms to address the DVE problem relative performance evaluations have becoming increasingly important. In this paper we present a comprehensive image quality metric which has been developed for DVE evaluations. This quality metric is based on the human visual system and considers factors such as induced processing noise, information content, and preserved image detail. These measures are shown to be important both for the evaluation of sensors and processing as well as for the tuning of specific DVE local area processing algorithms. Results of the application of these metrics will be shown based on dust trials of several cameras and local area processing algorithms. In addition, we will discuss considerations for DVE range setup and target characteristics and configuration to ensure adequate image content to apply these image quality measures.

10197-16, Session 4

A description of the Met Office's tactical decision aids (NEON and MONIM)

Stephan Havemann, Jean-Claude Thelen, Gerald J. Wong, Warren J. Lewis, Met Office (United Kingdom)

The Havemann-Taylor Fast Radiative Transfer Code (HT-FRTC) is a component of the Met Office NEON Tactical Decision Aid (TDA). Within NEON, the HT-FRTC has been used operationally to predict the apparent thermal contrasts between different surface types as observed by an airborne sensor. The HT-FRTC is given the inherent temperatures and spectral properties of ground targets and surrounding backgrounds to achieve this.

The HT-FRTC has the ability to ingest detailed atmospheric properties provided by Numerical Weather Prediction (NWP) forecasts. While water vapour and ozone are generally the most important gases, additional trace gases have been incorporated into the HT-FRTC. The HT-FRTC also includes an exact treatment of scattering based on spherical harmonics, allowing the treatment of several different aerosol species and of liquid or ice clouds. The HT-FRTC works in Principal Component space and is trained with numerous atmospheric and surface conditions, significantly reducing the computational requirements with one clear-sky simulation taking approximately one millisecond.

Recent developments allow the training to be sensor independent and can also account for precipitation or falling snow. This is significant as the user can add new sensors and new surfaces/targets by supplying extra files which contain their (possibly classified) spectral properties. The HT-FRTC has been extended to cover the spectral range of Photopic and NVG sensors to give guidance on the expected, directionally resolved sky brightness, especially at night, again taking the actual or forecast atmospheric conditions into account. These latest developments include light level predictions during the period of twilight.

10197-17, Session 4

Block match denoising for the integrated digital vision system (IDVS)

Mokhtar M. Sadok, John S. Alexander, Andrew LeVake, Rockwell Collins, Inc. (United States)

There is a need to develop fast vision systems capable of supporting real time operations that require split-second decision making. To perform at high speed, these vision systems are subject to stringent latency requirements thus hindering their light sensing elements to collect a meaningful number of photons with an acceptable Signal to Noise Ratio (SNR). As a result, high amplifier gains end up amplifying large amounts of noise along with image content. Rockwell Collins developed an all-digital vision system, dubbed Integrated Digital Vision System (IDVS) with very low latency capable of operating real time in conditions ranging from complete darkness to daylight.

This paper presents an algorithmic approach to denoise IDVS frames based on state of the art image denoising algorithms including Block Matching 3D (BM3D) and Non Local Mean (NLM) algorithms that are modified to meet IDVS hardware restrictions.

10197-18, Session 4

Semantic image segmentation for information presentation in enhanced vision

Oleg V. Vygolov, Vladimir S. Gorbatsevich, Nikita A. Kostromov, Maxim A. Lebedev, Yury V. Vizilter, Vladimir A. Knyaz, Sergey Y. Zheltov, State Research Institute of Aviation Systems (Russian Federation)

Enhanced Vision (EV) concept for aircraft operations in poor visibility conditions is evolving from the first generation “sensor to display” systems, which have directly provided the pilot with a sensor-derived infrared or millimeter wave radar image, toward more complex systems with multispectral image fusion and combined vision features, and further to partly autonomous systems. The significant advance in Computer Vision owing to the emergence of deep learning technology is opening up possibilities in delivering to the pilot a new level of situational awareness using image processing algorithms for understanding the external environment.

The paper proposes a new approach for information presentation in EV applications based on semantic image segmentation with deep convolutional neural networks. The segmented image contains regions that outline objects and have labels in accordance with the object type. This segmented image is overlaid onto the multispectral EV image to form a kind of augment reality image but without the need of high precision synthetic and sensor data matching.

The original architectures of the fully convolutional network for image segmentation are presented in purpose of one channel and multispectral EV systems. The learning dataset includes real images from flight experiments along with synthetic images generated by realistic 3D simulation.

The examples of information presentation based on developed semantic image segmentation are shown both on simulated and real images for different visibility conditions.

10197-19, Session 5

Pilot cueing synergies for degraded visual environments

Aaron McAtee, Kathryn S. Feltman, Donald Swanberg, Deborah Russell, Jonathan Statz, John Rammiccio, Thomas H. Harding, U.S. Army Aeromedical Research Lab. (United States)

Operating in degraded visual environments (DVE) poses a significant risk to helicopter operations. DVE can be caused by partial or total loss of visibility from airborne dust, sand, or snow being stirred up by the helicopter’s rotor downwash. DVE cause a loss of spatial orientation and situational awareness, which has on several occasions led to controlled flight into terrain, ground obstacle collisions, and the loss of aircraft and personnel. DVE have driven the development of new display technologies, which in turn present new challenges, including the integration of scene imagery, visual symbology, as well as tactile and aural cueing. In a full-motion DVE simulation study with seven test pilots, we evaluated aural and tactile cueing along with sensor imagery displayed on either a helmet or panel-mounted display. The symbology and FLIR imagery were presented on a UH-60M panel mounted display or a SA Photonics high definition, wide field-of-view, binocular helmet mounted display. Additionally, the synergistic effects of aural and tactile cues were assessed. Tactile cues were presented via belt, shoulder harness, and seat cushion using electromechanical tactors. Aural cues were presented via an HGU-56/P rotary-wing aircrew helmet. The compatibility and effectiveness of each combination of FLIR sensor imagery, selected display, and aural and tactile cueing set were evaluated with quantitative measures of flight performance, pilot’s subjective reports, and pilot psychophysiological measures.

10197-20, Session 5

Integrating DVE, cueing technologies, and pilot performance metrics into a research grade helicopter simulator

Donald E. Swanberg, John Ramiccio, U.S. Army Aeromedical Research Lab. (United States); Deborah Russell, Federal Express (United States); Katie S. Feltman, Aaron M. McAtee, U.S. Army Aeromedical Research Lab. (United States); Rolf Beutler, AECOM (United States); Angus H. Rupert, Ian Curry, Michael Wilson, Thomas H. Harding, U.S. Army Aeromedical Research Lab. (United States)

The U.S. Army Aeromedical Research Laboratory has transformed its NUH-60 Blackhawk simulator into a degraded visual environment (DVE) test bed capable of assessing integrated cueing technologies and their impact on flight performance. It is a unique simulator with the Lift Simulator Modernization Program database and is equipped with an enhanced brownout/whiteout model that replicates typical DVE conditions. The simulator is equipped with environmental temperature control and is a full-visual and full-motion simulator with six degrees of freedom. The flight simulator consists of a simulator compartment containing a cockpit, instructor/operator station, and observer station and a six-degree-of-freedom motion system. It is equipped with eight Dell XIG visual image generator systems that simulate natural helicopter environments for day, dusk, night, and NVG with blowing sand or snow. The visual scenes data bases are created using satellite imagery of real-world database locations. New sensor imaging capabilities produce realistic visuals that allow testing of DVE countermeasures. The simulator is equipped with USAARL's Tactile Situation Awareness System (TSAS), which stimulates the pilot through belt worn and seat cushion "tactors" that vibrate to transmit specific aircraft flight parameters such as drift, direction, and altitude through the sense of touch. In addition, a glass cockpit façade allow Mike model functionality. The system is now being used as part of the Research, Development, and Engineering Command's DVE mitigation program.

10197-22, Session 6

Multi-aperture approach to digital color night vision

Eric M. Gallo, Jessica Lindle, Michael A. Strauss, William P. Parker, Creative Microsystems Corp. (United States)

Digital color night vision is a high priority goal for the defense and commercial communities. Many manufacturers produce high quality, low-light sensors using improved silicon technologies, sometimes coupling them to image intensifiers. These approaches usually require expensive sensors and large optics while not even exceeding the performance of traditional image intensifiers. In addition, there is a trade-off between dynamic range and sensitivity, leaving most systems severely lacking in quality imagery in high dynamic range scenes.

Creative Microsystems Corporation (CMC) has developed a multi-aperture, computational vision approach to night vision that uses commercially available, reduced-size image sensors and commercial off-the-shelf mobile processing to reduce the cost and size while achieving high sensitivity. By acquiring simultaneous multiple images, our system provides enhanced vision through computed vision processes. Coupled to this, using refined post-processing methods, we have achieved color night vision in moonless night conditions. Operational performance can be achieved at 60 Hz rates on commercially available processors, enabling real-time color night vision. The multi-aperture approach also provides depth information and foveated enhancement possibilities. Creative Microsystems will report on the multi-aperture approach using multiple configurations and compare results to existing night vision systems.

10197-23, Session 6

Simple low cost DVE solutions for rotorcraft applications

Brendan Blanton, The Boeing Co. (United States)

The solution space to the DVE sensor problem can be considered to be a continuum where the goal is to minimize Size, Weight, Power, Cost (SWaP-C), and complexity while simultaneously maximizing performance. Performance is often achieved at the expense of SWAP-C and complexity. The core DVE sensor system technologies can be grouped into three broad areas: (1) sensors (e.g., LiDAR, RADAR, or IR imaging) and (2) data processing such as data fusion, or image processing, and (3) synthetic vision, and symbology. Much of the body of DVE sensor research has focused on advancing the current state of the art in one or more of these particular areas, such as advanced sensing and/or data processing technologies. However, often the difficulties of integrating such a DVE technology into an aircraft, or certification of flight are not considered, both of which are adversely impacted by increases in SWaP and complexity. In this paper we examine the solution space to the DVE sensor problem and consider the advantages and disadvantages of simple, low cost DVE system solutions.

10197-24, Session 6

Usage of lidar in a brownout pilotage system: flight test results on a single ship and chalk 2 scenarios

Thomas R. Münsterer, Airbus Defence and Space (Germany); Paul Rannik, Airbus DS Electronics and Border Security (United States); Matthias Wegner, Airbus Defence and Space (Germany); Peter Tanin, Airbus DS Electronics and Border Security (Germany); Christian Samuelis, Airbus Defence and Space (Germany)

The paper discusses recent results of flight tests performed with the Airbus LiDAR system in brownout. The SferiSense® LiDAR system was mounted on a Mi-2 test platform as part of a complete DVE system to undergo the tests. To optimize brownout capabilities minor modifications were performed on the sensor firmware over the SferiSense® serial LiDAR system which is in operational use on the NH90 transport helicopter. Also dust echoes were filtered out by a real-time filtering algorithm. Numerous approaches into own ship generated dust (light to heavy) as well as fan generated dust clouds (chalk 2 scenarios) were performed. The paper discusses the results and shows under which conditions the LiDAR can still look through the dust cloud. Also the contribution of high resolution real-time 3D LiDAR data to the DVE system usage is discussed.

10197-25, Session 6

Evaluation of a steerable 3D laser scanner using a double Risley prisms pair

Philip M. Church, Justin Matheson, Xiaoying Cao, Neptec Technologies Corp. (Canada); Gilles Roy, Defence Research and Development Canada (Canada)

Laser scanners using Risley prism pair technology offer several advantages, including a multitude of scan pattern generation, non-overlapping patterns, and a conical field-of-view (FOV) that offers a high data density around the center. The geometry and material properties of the prisms define the conical FOV of the sensor, which can be typically set between 30° to 120°. However, once the prisms are defined, the FOV cannot be changed. Neptec Technologies in collaboration with Defence Research and Development Canada has developed a unique scanner prototype using two pairs of Risley prisms. The first pair defines a small 30° FOV which is then steered into a larger 90° field-of-regard (FOR) by using the second pair of prisms. This presents the advantages of a high-resolution scan pattern footprint that can be moved quickly and randomly into a larger area, eliminating the need for mechanical steering equipment such as a turret. The Double Risley Prisms (DRP) prototype was recently evaluated at Yuma Proving Ground with the scanner positioned atop a tower, overlooking various types of targets while dust was generated by a helicopter. Results will be presented in clear and dusty conditions, showing examples of moving a high resolution FOV within the FOR.

10197-26, Session 6

How much is enough? The human factors of field of view in head-mounted displays

Jim E. Melzer, Thales Visionix, Inc. (United States)

Originally developed for military applications, head-mounted displays (HMD) are becoming very popular in the commercial world for both virtual and augmented reality applications. The question is how large the field of view needs to be as this requirement drives the size, weight and cost of the HMD, so it should be as small as possible to accomplish the intended task. This paper will address some of the visual human factors that govern field of view.

10197-38, Session 6

Fusion for DVE pilotage

Jason Seely, James T. Murray, Jeffrey J. Plath, William L. Ryder, Eric Lindquist, Samson Chu, Neil R. Van Lieu, Arete Associates (United States)

No Abstract Available

10197-27, Session 7

HMD daylight symbology: color choice and luminance considerations

Thomas H. Harding, Michael K. Smolek, Leonard A. Temme, U.S. Army Aeromedical Research Lab. (United States); Jeff K. Hovis, Univ. of Waterloo (Canada); Morris R. Lattimore, Clarence E. Rash, U.S. Army Aeromedical Research Lab. (United States)

As the military increases its reliance upon and continues to develop Helmet Mounted Displays (HMD), it is paramount that HMDs are developed that meet the operational needs of the Warfighter. During the development cycle, questions always arise concerning the operational requirements of the HMD. These include questions concerning luminance, contrast, color, resolution, and so on. When color is implemented in HMDs, which are eyes-out, see-through displays, visual perception issues become an increased concern. A major confound with HMDs is their inherent see-through (transparent) property. The result is color in the displayed image combines with color from the outside world, possibly producing a false perception of either or both images. Last year at this meeting, we discussed the daylight luminance requirements for symbology. Here we evaluate possible color choices and the effect that these choices have on perception and situational awareness. Special emphasis will be placed on the evaluation of hues in the 1976 CIE u'v' color space and their relative display luminances as well as perceptual issues concerning normal versus color deficient observers. In addition, choices are evaluated in terms of acquisition specifications, manufacturing standards, and information content.

10197-28, Session 7

Review of colored conformal symbology in head-worn displays

David L. da Silva Rosa, Niklas Peinecke, Johannes M. Ernst, Deutsches Zentrum für Luft- und Raumfahrt e.V. (Germany)

The usage of conformal symbology in color head-worn displays (HWDs) opens up a range of new possibilities on modern flight decks. The capability of color augmentation seems especially useful for low flights in degraded visual environments. Helicopter flights in these conditions, including brownout by swirling dust or sand particles, can often lead to spatial disorientation (SD) and result in a significant amount of controlled flight into terrain (CFIT). While first generation color-capable conformal displays are deployed, practical guidelines for the use of color in these see-through interfaces are yet to be established. A literature survey is carried out to analyze available knowledge of color use in conformal displays and to identify established methodologies for human-factors experimentation in this domain. Firstly the key human factors involved in color HWDs are outlined, including hardware design aspects as well as perceptual and attentional aspects. Secondly research on color perception is mapped out, focusing on investigations of luminance contrast requirements, modeling of color space blending and development of color correction solutions. Thirdly application-based research of colored conformal symbology is reviewed, including several simulations and flight experiments. Analysis shows that established luminance contrast requirements need to be validated and that performance effects of colored HWD symbology need more objective measurements. Finally practical recommendations are made for further research. This literature study has thus established a theoretical framework for future experimental efforts in colored conformal symbology. The German Aerospace Center (DLR) is currently conducting experiments within this framework.

10197-29, Session 7

HMD distortion characterization and alignment toolset for precision-critical applications

Mitchell Bauer, Logan Williams, USAF School of Aerospace Medicine (United States); Georges Nehmetallah, The Catholic Univ. of America (United States); Alexander Van Atta, KBRwyle (United States); James Gaska, Marc Winterbottom, Steven C. Hadley, USAF School of Aerospace Medicine (United States)

Head Mounted Displays (HMDs) generally exhibit significant image distortion which must be reduced/eliminated prior to effective use. Additionally, bi-ocular near-eye displays must be carefully aligned to enable overlapping 2D or 3D image synthesis without causing eye strain, fatigue, or performance loss. Typically, HMDs include distortion correction maps supplied by the manufacturer which are often generated by theoretical calculations that do not precisely match the as-built optical system or account for manufacturing variance. However, HMD users often assert that manufacturer supplied distortion maps are not accurate enough for some alignment-critical applications. In this work we present the design and validation of a relatively low cost alignment and distortion characterization toolset (hardware & software) for characterization of both virtual reality (opaque) and augmented reality (see-through) bi-ocular HMDs. This toolset is able to replicate the ocular alignment of most human observers by emulating a user's ocular position to examine both on- and off-axis distortion and alignment over a wide range of viewing angles and eye positions. This enables accurate characterization of distortion changes experienced as a user's eyes move to view different regions of the display (e.g. viewing off-boresight symbols in a well-aligned HMD or viewing a new alignment after an HMD has "slipped" to a slightly different position). The toolset characterizes distortion through image registration of distorted patterns displayed in the HMD to undistorted reference patterns. This work is intended to be of interest to HMD manufacturers, vision scientists, and operators of bi-ocular HMDs for use in precision-critical applications.

10197-30, Session 8

Display optimization via simulated viewing distance as predicted by the TTP metric

Kimberly E. Kolb, Jeffrey T. Olson, Bradley L. Preece, Joseph P. Reynolds, U.S. Army RDECOM CERCEC NVESD (United States)

In the pursuit of fully-automated display optimization, the US Army RDECOM CERDEC Night Vision and Electronic Sensors Directorate (NVESD) is evaluating a variety of approaches, including the effects of viewing distance on target acquisition performance. One such approach is the Targeting Task Performance (TTP) metric, which NVESD has developed to model target acquisition performance in a wide range of conditions. While NVESD has previously evaluated the TTP metric for predicting the peak-performance viewing distance as a function of blur, no such study has been done for noise-limited conditions. In this paper, the authors present a study of human task performance for images with noise versus viewing distance. Results are compared to predictions based on the TTP metric using the Night Vision Integrated Performance Model (NV-IPM). The potential impact of the results on the development of automated display optimization are discussed.

10197-31, Session 8

Holographic Imageguide display for situational awareness

William Parker, Julie Parker, Creative Microsystems Corp. (United States)

Augmented and virtual reality technology continue to drive the need for high resolution, see-through display technologies. Commercially available devices, such as the Microsoft Hololens, have demonstrated the possibilities for this technology but still possess some drawbacks. Military applications require displays with wide field of view, sunlight readability, light weight, and durability--something that commercial devices have yet to provide.

Creative Microsystems Corporation is developing the Holographic Imageguide Display, a light-weight, sunlight-readable, high-resolution see-through display for augmented reality and increased situational awareness. The display excels in situations where a user must maintain their normal sight (such as shooting a weapon), or size and weight are a primary consideration (such as behind a night vision device). The display uses holographic technology to display projected images through an imageguide directly to the user's eye. The system connects to standard image signal inputs and has a small form factor for support electronics. The results are a full-color, low-cost display that can superimpose images onto a user's field of view. Creative Micosystems has integrated the display into several data and video systems, including geo-located symbology, head trackers, image fusion and augmented reality for simulations. The existing display performance and current applications to situational awareness will be reported.

10197-32, Session 8

Developing an augmented reality application to evaluate the Microsoft HoloLens

Mariangely Iglesias Pena, Jack Miller, Gabriel Evans, Anastacia MacAllister, Eliot Winer, Iowa State Univ. of Science and Technology (United States)

Industry and academia have repeatedly demonstrated the transformative potential of augmented reality (AR) guided assembly instructions. In the past,?however,?computing hardware limitations often dictated that these systems were deployed on tablets or other cumbersome devices. Often, these systems impeded worker progress by?diverting?the user's hands and forcing workers to alternate between the instructions and the assembly. With the rapid release of?affordable, easy to obtain commodity?head mounted display (HMD) devices, notably Microsoft's HoloLens, an opportunity?has been?provided to explore AR applications that?free?a user's hands?to?focus?on the assembly. Because the HoloLens is a new commodity device, there?exists?minimal academic research that?points out?specific or possible issues when?creating an assembly application for the system. Furthermore, while there are previous academic publications on how AR interfaces should look, it is not certain how they will translate onto the HoloLens?or other new commodity HMD devices.?In order to assess the HoloLens' potential for delivering AR assembly instructions, a proof of concept application for a small table top assembly was developed using Unity 3D, a cross-platform game engine tool.?Within this application three major components were focused upon: user interfaces, 3D virtual models, and spatially registered object location.?The research uncovered how adequate integration of 3D user interface practices for an AR HMD, the generation of 3D virtual models through sufficient opacity and occlusion, and the implementation of a marker based tracking, Vuforia v6, to supplement the HoloLens spatial mapping system, helped generate a functional assembly application.

10197-33, Session 9

VR and AR environments for virtual cockpit enhancements

Niklas Peinecke, Johannes M. Ernst, Deutsches Zentrum für Luft- und Raumfahrt e.V. (Germany)

The recent evolution of cockpit design has moved from the established glass cockpits into new directions. Amongst them is the virtual enhancement of cockpits by augmented reality (AR) and virtual reality (VR) displays. Well known in aviation are helmet mounted see-through displays, but opaque VR displays are of increasing interest also. This technology enables the pilot to use virtual instrumentation as an add-on to the real cockpit. Even a totally virtualized instrumentation is possible. Furthermore, VR technology allows the fast prototyping and pilot training in cockpit environments that are still in development before even a single real instrument is built.

We show how commercial off-the-shelf VR hardware can be used to build a prototyping environment. We demonstrate advantages and challenges when using software engines usually built for the games industry. We detail our own integration concept that aims to re-use as much of in-house developed software and allows an integration with minimal parallel developments.

In detail, the following systems will be discussed:

1. Integration of generic OpenGL displays in the Oculus Rift SDK,
2. Integration of OpenSceneGraph displays in the Oculus Rift SDK,
3. Integration of generic OpenGL displays in the Unity game engine,
4. Integration of OpenSceneGraph displays in the Unity game engine.

All of these integration scenarios pose different technical and legal issues that will be discussed briefly.

10197-34, Session 9

Advanced architectures for high bandwidth video transport

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

Modern Aircraft video systems are not limited to displays. Modern systems are starting to include a wide variety of sensors and camera systems for applications such as night vision, degraded vision, and other sensors. Systems that require multiple coordinated sensors (including sensor fusion) used for ISR, navigation in degraded environments, or infrared

countermeasures are constantly trying to increase throughput to carry higher resolution images and video in real-time. The need for ever higher throughput challenges system designers on every level, including the physical interface. Simply moving video efficiently from point to point or within a network in itself is a challenge. ARINC 818, the Avionics Digital Video Bus continues to expand into high-speed sensor applications because of its low latency, robustness, and high throughput capabilities. This paper explores architectures based on both high speed coax and fiber optic ARINC 818 links, which include: time multiplexing multiple sensors onto single links, high speed regions of interest, channel bonding of video signals, bi-directional communication over a single link, and ultra-high speed (56Gbps) interfaces. Results will be presented from prototype implementations that enable all of the above technical objectives.

10197-35, Session 9

Sensor driven guidance for rotorcraft landing in DVE

Joe Minor, Zachariah Morford, Walter Harrington, Zoltan P. Szoboszlay, U.S. Army (United States)

While a great deal of focus has been placed on the resolution provided by sensors in degraded visual environment's for rotorcraft. Research has shown that even with 20/20 visual acuity the resulting handling qualities are level 2 or level 3 and detecting obstacles can be extremely challenging. One way to mitigate these issues with panel mounted images is to utilize a sensor to drive two dimensional (2D) pilot cueing to guide the pilot to a desired landing point or hover point. The output of the sensor package needs to provide a 3D world map that can be utilized by guidance algorithms to provide useable cues for a pilot to maneuver over or around obstacles.

Initial flight test efforts into sensor driven guidance by the RDECOM DVE-Mitigation program have used mature cueing sets that feature traditional "2D" elements like a velocity vector, acceleration ball and vertical velocity, as well as "3D" elements like a conformal landing pad. This symbology set has been paired with landing guidance to provide horizontal and vertical navigation solution from approach entry to the desired landing or hover point while providing a trajectory solution based upon the topographical, foliage and cultural features of the environment using a sensor provided three-dimensional representation. The initial iteration of landing guidance utilizes a height map of the objective area which focuses sensor assets at the area most critical to the approach by building a layered "GeoGrid" height map with increasing data resolution near the landing or hover point.

10197-36, Session 9

Designing a virtual cockpit for helicopter offshore operations

Johannes M. Ernst, Sven Schmerwitz, Thomas Lueken, Lars Ebrecht, Deutsches Zentrum für Luft- und Raumfahrt e.V. (Germany)

In recent years the number of offshore wind farms is rapidly increasing. Especially coastal European countries are building numerous offshore wind turbines in the Baltic, the North, and the Irish Sea. During both construction and operation of these wind farms, many specially-equipped helicopters are on duty. Due to their flexibility, their hover capability, and their higher speed compared to ships, these aircraft perform important tasks like helicopter emergency medical services (HEMS) as well as passenger and freight transfer flights. The missions often include specific challenges like ship landings or hoist operations to drop off workers onto wind turbines.

However, adverse weather conditions frequently limit offshore helicopter operations. In such scenarios, the adoption of aircraft-mounted sensors and obstacle databases together with helmet-mounted displays (HMD) seems to offer great potential to improve the operational capabilities of the helicopters used. By displaying environmental information in a visual conformal manner, these systems mitigate the loss of visual reference to the environment. This helps the pilots to maintain proper situational awareness.

This paper presents how our previously introduced concept of an HMD-based virtual flight deck can enhance offshore helicopter missions. The advantages of this system – for instance its "see-through the airframe"-capability and its highly-flexible cockpit instrument setup – enable us to design entirely novel pilot assistance systems. The work analyzes the specific requirements on our virtual cockpit so as to assist the helicopter crew in offshore-specific tasks. The gained knowledge is used to propose and evaluate concepts for a virtual cockpit that is tailor-made for helicopter offshore maneuvers.

10197-37, Session 9

Integrating data and sensor based obstacle information in a conformal landing display for helicopter

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

The task to land a helicopter in a degraded visual environment poses a high risk to helicopter and crew. Even if the approach itself can be under best weather conditions a brownout or whiteout can occlude all visual references the pilot needs to stabilize and land the helicopter safely. Presenting a virtual and conformal landing zone display on a head-mounted display to the pilot can provide enough spatial awareness to control the helicopter. At a well-known landing site this might be sufficient but additional data based information about nearby obstacles would further enhance the pilot's situational awareness. This more complete picture allows to preplan tactical alternatives if needed. In case the landing site is unknown, data base information alone will be insufficient and additional sensor data is needed. This data can be acquired from a combination of sensors like infrared cameras, ladar sensors or millimeter wave radars. The different characteristics of these sensors pose a challenge in order to fuse the information, including the data based information available, and display it to the pilot. This paper will compare different methods of fusion and introduce the experimental research symbol set in use. The task at hand is to optimize the display's see-through capability, there again allow best obstacle recognition. All of that is accomplished without hindering the pilot to safely fly the helicopter to the ground by using the conformal landing zone symbol set.

Conference 10198: Algorithms and Technologies for Multispectral, Hyperspectral, and Ultraspectral Imagery XXIII

SPIE. DCS DEFENSE+ SECURITY

Tuesday - Thursday 11–13 April 2017

Part of Proceedings of SPIE Vol. 10198 Algorithms and Technologies for Multispectral, Hyperspectral, and Ultraspectral Imagery XXIII

10198-1, Session 1

Absolute radiance and reflectance calibration of the crime scene imaging camera

Jie Yang, David W. Messinger, Rochester Institute of Technology (United States)

Filtered multispectral imaging technique might be a potential method for crime scene documentation and evidence detection due to its abundant spectral information as well as non-contact and non-destructive nature. While material signatures are usually measured and stored as reflectance spectra, it is crucial for crime scene imaging cameras to generate images recording absolute field reflectance so that target detection methods can be applied to imaging cubes. The absolute calibrated reflectance images are also comparable for different lighting and geometry conditions thus improving the system robustness and portability. A radiometric calibration relating raw image digital numbers to scene radiance values with an integrating sphere is made to correct dark current noise, flat fielding and lens falloff for a high resolution CMOS monochrome sensor. A reflectance calibration mapping scene reflectance to image pixel radiance is made afterwards based on precisely known reflectance spectrum materials and constant lighting and scene-camera geometry. As Interference Filters (IFs) being used in the imaging system, IF transmission spectra are calibrated ahead of time and will be utilized during camera calibration. This absolute radiance and reflectance calibration is a foundation for the crime scene imaging system and the following crime evidence target detection algorithm analysis.

10198-2, Session 1

Designing manufacturable filters for a 16-band plenoptic camera using differential evolution

Timothy J. Doster, Colin C. Olson, Erin F. Fleet, Michael K. Yetzbacher, Andrey V. Kanaev, Paul Lebow, Robert A. Leathers, U.S. Naval Research Lab. (United States)

A 16-band plenoptic camera allows for the rapid exchange of filter sets via a 4x4 filter array on the lens's front aperture. This ability to change out filters allows for an operator to quickly adapt to different locales or threat intelligence. Typically, such a system incorporates a set of 16 equally spaced flat topped filters. Knowing the operating theater or the likely targets of interest it becomes advantageous to tune the filters. We propose a Differential Evolution (DE) algorithm to do such a task and realize the filters as modified beta functions. This allows us to jointly optimize the width, taper and center of each filter in the set over a number of evolutionary steps. Further by constraining the function parameters we can develop solutions which are not just theoretical but manufacturable. We examine two independent tasks: general spectral sensing and target detection. In the general spectral sensing case we utilize the theory of compressive sensing (CS) and find filters that generate codings which minimize the CS reconstruction error based on a fixed spectral dictionary of endmembers. For a set of known targets we train the filters to optimize the separation of the background and target signature for the smashed ACE detector. We compare our results to the baseline 16 flat top filter set utilizing previously taken hyperspectral data.

10198-3, Session 1

Fresnel zone plate light field spectral imaging simulation

Francis Hallada, Anthony L. Franz, Michael R. Hawks, Air Force Institute of Technology (United States)

Through numerical simulation, we have demonstrated a novel "snapshot" spectral imaging concept using binary diffractive optics. Binary diffractive optics, such as Fresnel zone plates (FZP) or photon sieves, can be used as the single optical element in a spectral imager that conducts both imaging and dispersion. In previous demonstrations of spectral imaging with diffractive optics, the detector array was physically translated along the optic axis to measure different image formation planes. In this new concept the wavelength-dependent images are constructed synthetically, by using integral photography concepts commonly applied to light field cameras. Light field cameras use computational digital refocusing after image capture to make images at different object distances. Our concept "refocuses" to make images at different wavelengths instead of different object distances. The simulations in this study demonstrate this concept for an imager designed with a FZP. Monochromatic light from planar sources is propagated through the system to a measurement plane using wave optics in the Fresnel approximation. Simple images, placed at optical infinity, are illuminated by monochromatic sources and then digitally refocused to show different spectral bins. We show the formation of distinct images from different source objects, illuminated by monochromatic sources in the VIS/NIR spectrum. Additionally, this concept could easily be applied to imaging in the MWIR and LWIR ranges. In conclusion, this new type of imager offers a rugged and simple optical design for "snapshot" spectral imaging and warrants further development.

10198-4, Session 1

Three-dimensional hyperspectral imaging technique

Ingmar G. Renhorn, Renhorn IR Consultant AB (Sweden); Jörgen Ahlberg, Linköping Univ. (Sweden); David Bergström, FOI-Swedish Defence Research Agency (Sweden); Tomas R. Chevalier, Scienvisic AB (Sweden); Joakim Rydell, FOI-Swedish Defence Research Agency (Sweden); Martin Svensson, Spotscale AB (Sweden)

Hyperspectral remote sensing based on unmanned airborne vehicles is a field increasing in importance. Although mobile mapping to generate three-dimensional terrain has been demonstrated, the combined functionality of simultaneous hyperspectral and geometric modeling is less developed. A configuration has been developed that ensures that all information required to reconstruct the hyperspectral three-dimensional environment is available. Data is acquired using an octocopter moving along buildings in an urban context. The hyperspectral camera is based on a linear variable filter measuring reflectance in the spectral region 450-900 nm. The high frame rate camera is recording highly correlated images due to the small changes between frames. Structural information is therefore not lost due to the spectral variation which results in robust point matching. This allows the information to be combined into a single and complete 3D hyperspectral model.

10198-5, Session 1

Spectrally resolved longitudinal coherence interferometry for passive standoff imaging

Ethan R. Woodard, Michael W. Kudenov, North Carolina State Univ. (United States)

We present a one-dimensional imaging technique using spectrally resolved interferometry to encode a scene's spatial information onto the source's power spectrum. Fourier transformation of the spectrally resolved channeled spectrum output yields a measurement of the incident scene's angular spectrum. Theory for two distinct methods is presented to exhibit analogies with conventional Fourier transform spectroscopy. The first method leverages the principles of longitudinal spatial coherence interferometry using a Fabry-Perot etalon to generate a channeled spectrum. Spatial modulation of the incident scene's angular spectrum with a sinusoidal carrier is used to heterodyne the channeled spectrum's regions of coherence to visible wavelengths. The second method relies on the dispersion characteristics of glass for coherence heterodyning. By implementing a Mach-Zehnder interferometer with dispersion, a nonlinear channeled spectrum encoded with the scene's angular information is produced at the output. Experimental proof of concept validation of both techniques is presented using angularly dependent interferometer-based optical systems for the reconstruction of one-dimensional sinusoidal and randomly generated scenes.

10198-6, Session 1

Real-time hyperspectral image processing for UAV applications, using Hyspex Mjolnir-1024

Pesal Koirala, Trond Løke, Ivar Baarstad, Andrei Fridman, Julio Hernandez, Norsk Elektro Optikk AS (Norway)

The HySpex Mjolnir-1024 hyperspectral camera provides a unique combination of small form factor and low mass combined with high performance and scientific grade data quality. Top level specifications include a spatial resolution of 1024 pixels, a spectral resolution of 200 bands within 400 nm to 1000 nm range and high light throughput (F1.8). A rugged design with good thermal and mechanical stability makes this camera an excellent option for a wide range of scientific applications for UAV operations and field applications. The optical architecture is based on the high-end ODIN-1024 system [1] and features a total FOV of 20 degrees with approx. 0.1pixel residual keystone after resampling [2].

With a total mass of less than 4kg including hyperspectral camera, data acquisition unit, battery, IMU and GPS, the system is suitable for even small UAVs. The system is generic and can be deployed on a wide range of UAVs with various downlink capabilities. The ground station software enables full control of the sensor settings and also has the capability to show in real time where the UAV is located, plot the track of the UAV and display a georeferenced waterfall preview image in order to give instant feedback on spatial coverage. The system can be triggered automatically by the UAV's flight management system, but can also be controlled manually.

Mjolnir-1024 housing contains both the camera hardware and a high performance onboard computer. The computer enables advanced processing capabilities such as real time georeferencing based on the data streams from the camera and INS. The system is also capable of performing real time image analysis such as anomaly detection [3,4], NDVI and SAM. The data products can be overlaid on top of various background maps and images in real time. The real time processing results can also be downlinked and displayed directly on the monitor of the ground station.

In this article we will present the general data quality parameters of the Hyspex Mjolnir camera system along with real time georeferencing and real time hyperspectral data analysis capabilities.

References:

1. S Blaaberg, T Løke, I Baarstad, A Fridman, P Koirala, "HySpex ODIN-1024: a new high-resolution airborne HSI system", SPIE Defense+ Security, 90700L-90700L-11 2. Andrei Fridman, Gudrun Høye, Trond Løke, "Resampling in hyperspectral cameras as an alternative to correcting keystone in hardware, with focus on benefits for optical design and data quality". Opt. Eng. 53(5), 053107 (May 07, 2014)

3. José M. Molero, Ester M. Garzón, Inmaculada García and Antonio Plazac, "Anomaly detection based on a parallel kernel RX algorithm for multicore platforms", Journal of Applied Remote Sensing 6(1):061503 · May 2012 DOI: 10.1117/1.JRS.6.061503

4. Trym V. Haavardsholm, Amela Kavara, Ingebjørg Kåsen, Torbjørn Skauli, "Improving anomaly detection with multinormal mixture models in shadow", IEEE International Symposium on Geoscience and Remote Sensing 2012, 5478-5481

10198-7, Session 2

Intelligent detection algorithm of hazardous gases for FTIR-based hyperspectral imaging system using SVM classifier

Hyeong-Geun Yu, Jai-Hoon Lee, Yong-Chan Kim, Dong-Jo Park, KAIST (Korea, Republic of)

A hyperspectral imaging system (HIS) using the Fourier transform infrared (FTIR) spectrometer is an excellent method for detection and identification of gaseous fumes. There are various detection algorithms which remove background spectra from measured spectra and find spectral similarity between the extracted signature and the reference signature of each target compound. However, because of interference signatures caused by FTIR instruments, it is impossible to extract the spectral signatures of target gases perfectly. Those interference signatures degrade a detection performance. In this paper, a detection algorithm of the gaseous fumes using the support vector machine (SVM) classifier is proposed. The algorithm is composed of two steps: a training step and a test step. In the training step, the spectral signatures are extracted from measured spectra which are labeled. Then, hyperplanes which classifies the gas spectra is trained and SVM classifier are calculated using the hyperplanes. In the test step, spectral signatures extracted from unknown measured spectra are substituted to the SVM classifier. Then we obtain detection result. This SVM classifier is robust to the performance degradation caused by the unremoved interference signatures because the SVM classifier trains not only gaseous signatures but also those interference signatures. The experimental results verify that the algorithm can effectively detect hazardous clouds.

10198-8, Session 2

Characterizing sensitivity of longwave infrared hyperspectral target detection with respect to atmospheric and temperature estimates

Joseph Meola, Air Force Research Lab. (United States)

Hyperspectral target detection typically relies upon libraries of material reflectance and emissivity signatures. Application to real-world, airborne data requires estimation of atmospheric properties in order to convert reflectance/emissivity signatures to sensor data domain. In the longwave infrared, an additional nuisance parameter of surface temperature exists that further complicates the signature conversion process. A significant amount of work has been done in atmospheric compensation and temperature-emissivity-separation techniques. This work examines the sensitivity

of target detection performance for various materials with respect to atmospheric and temperature estimates using real-world airborne longwave infrared hyperspectral imagery.

10198-9, Session 2

Total electron count variability and stratospheric ozone effects on solar backscatter and LWIR emissions

John Ross, Steven T. Fiorino, Air Force Institute of Technology (United States)

The development of an accurate ionospheric Total Electron Count (TEC) model is of critical importance to high frequency (HF) radio propagation and satellite communications. However, the TEC is highly variable and is continually influenced by geomagnetic storms, extreme UV radiation, and planetary waves. Being able to capture this variability is essential to improve current TEC models. The growing body of data involving ionospheric fluctuations and stratospheric variations has revealed a correlation. In particular, there is a marked and persistent association between increases in stratospheric ozone and variability of the TEC. The spectral properties of ozone show that it is a greenhouse gas that alters long wave emissions from Earth and interacts with the UV spectrum coming from the sun. This study uses the Laser Environment Effects Definition and Reference (LEEDR) radiative transfer and atmospheric characterization code to model the effects of changes in stratospheric ozone on solar backscatter and longwave (LWIR) terrestrial emissions and infer TEC and TEC variability.

10198-10, Session 2

Improved atmospheric characterization for hyperspectral exploitation

Nathan P. Wurst, Air Force Institute of Technology (United States) and Air Force Research Lab. (United States); Steven T. Fiorino, Air Force Institute of Technology (United States); Joseph Meola, Air Force Research Lab. (United States)

Hyperspectral imagers (HSI) are often used in an airborne platform and have shown utility in material detection and identification. Recent interest in longwave infrared (LWIR) HSI systems operating in the 7-14 micron range has developed due to strong spectral features of minerals, chemicals, and gaseous effluents. LWIR HSI has the advantage over other spectral bands by operating in day or night scenarios because emitted/reflected thermal radiation rather than reflected sunlight is measured. This research seeks to determine the most effective methods to perform model-based atmospheric compensation of LWIR HSI data using two existing atmospheric radiative transfer (RT) models, MODTRAN and LEEDR. These RT models are used to generate downwelling radiance and path transmission data at different sky zenith angles and compared to real world data. For certain scenarios, directional downwelling radiance data may improve exploitation performance. The number and angle of zenith sky downwelling radiance data sets required to accurately perform atmospheric compensation is analyzed. MODTRAN and LEEDR are then compared in their ability to generate downwelling radiance and path transmittance data for atmospheric compensation of LWIR HSI data taken in a nadir looking geometry. MODTRAN is the more established RT model, but it lacks LEEDR's robust capability to generate realistic atmospheric profiles from probabilistic climatology or observations and forecasts from numerical weather prediction (NWP) models. Thus one of the central research questions is "does starting with an accurate assessment of the atmospheric profile improve and/or expedite the atmospheric compensation process for LWIR HSI?"

10198-11, Session 3

Mid-infrared hyperspectral simulator for laser-based detection of trace chemicals on surfaces *(Invited Paper)*

Travis R. Myers, Anish K. Goyal, David B. Kelley, Petros Kotidis, Block Engineering, Inc. (United States); Gil M. Raz, Cara P. Murphy, Chelsea Georgan, Systems & Technology Research (United States); Derek Wood, Block Engineering, Inc. (United States)

Laser-based, mid-infrared (MIR) hyperspectral imaging (HSI) has the potential to detect a wide range of trace chemicals on surfaces at standoff distances of many 10's of meters. This is due to the fact that MIR absorption spectra are unique for a given chemical and their absorption cross-section can be very large. This enables chemical classification with both high sensitivity and high specificity. The major challenge of MIR reflection spectroscopy is that the reflection signatures for surface chemicals can be quite complex and exhibit significant spectral variability. Reflection spectra often deviate considerably from absorption spectra obtained under laboratory conditions because they depend on a wide range of parameters including chemical concentration, particle size distribution (for solids), substrate material, substrate roughness, viewing angle, etc. Furthermore, the reflection signatures often include speckle which adds considerable noise. In order to realize the potential of MIR reflection spectroscopy for this application, it is imperative that reflectance models for contaminated surfaces be developed including the factors that affect signature variability. In this talk, we describe a MIR Hyperspectral Simulator that has been developed to model the reflectance signatures from surfaces. The simulator includes the effects of detector noise and speckle at each pixel of the HgCdTe focal-plane array when the target is illuminated by a wavelength tunable laser. Simulated hypercubes will be compared with experiments. Detection results using a classification algorithm will also be shown that compare detection results from both simulated and experimental data.

10198-12, Session 3

Novel trace chemical detection algorithms: a comparative study *(Invited Paper)*

Gil M. Raz, Cara P. Murphy, Chelsea Georgan, Ross Greenwood, Ravi K. Prasanth, Systems & Technology Research (United States); Travis R. Myers, Anish K. Goyal, David B. Kelley, Petros Kotidis, Block Engineering, Inc. (United States)

Standoff detection of trace chemicals on surfaces using active (long-wave and mid-wave) IR hyperspectral imaging in the presence of unknown interferent contaminants and degraded by speckle poses significant challenges.

The proposed paper compares the performance of four algorithmic approaches with differing strengths and weaknesses that depend on: signal to interference and noise ratio (SINR), speckle as it relates to surface roughness, and the abundances of target and interferent chemicals. The algorithms include: sparse methods; Bayesian estimation; and machine learning. These are compared against the industry standard – ACE (adaptive cosine estimator). We compare detection and abundance estimation performance and computational complexity for a variety of solid particles and liquid films on multiple substrates using simulated and measured hyperspectral images.

ACE detection assumes known target and background spectral responses with residual Gaussian error. We show that ACE is suboptimal for liquid targets in low SNR regime and fails entirely when background estimates are degraded by large spatial variability due to interferents or speckle. Even at high SNR, ACE necessitates a comparison of all possible trace chemicals to determine the specific target, resulting in high computational complexity.

Sparse methods overcome some shortcomings of ACE for high SINR when few chemicals are present. Bayesian methods allow arbitrary spatial variability and non-Gaussian errors. They require accurate models that translate abundances into intensity hypercubes. Machine learning has similar benefits to Bayesian approaches but requires significant training.

In the full paper we provide details of all approaches and a comparative discussion of their utility under various conditions.

10198-13, Session 3

Deep learning over diurnal and other environmental effects *(Invited Paper)*

Dalton S. Rosario, Patrick J. Rauss, U.S. Army Research Lab. (United States)

Environmental effects severely impact detection and material identification algorithm performance. This is especially true with hyperspectral (HS) imagery. There is very little work quantifying the impact of diurnal, seasonal, and weather effects on HS algorithm performance. However careful construction of the training set for a learning algorithm can expand the performance envelope. We discuss current results of an ongoing effort to characterize the performance of a deep learning algorithm to environmental effects. The U.S. Army Research Laboratory and the U.S. Army's Armament Research, Development, and Engineering Center collaborated on the "Spectral and Polarimetric Imagery Collection Experiment" (SPICE). SPICE produced a large scale longwave IR hyperspectral data set of the same area over time that can be used to characterize the effects of time, weather, and other environmental factors have on spectral signatures. We discuss the performance envelope of a deep learning network trained with the SPICE LWIR HS data, the means to mitigate some of the environmental effects and improve algorithm performance. Performance is evaluated on spectral samples extracted from HS cubes throughout the diurnal cycle, as well as cubes collected on different days and with various weather conditions. Beginning with training sets from narrow time windows (for example 10:00 to 14:00 hrs. or 03:00 to 06:00 hrs.), the effect of the diurnal cycle on ROC curve performance are discussed. The goal is to learn how best to train an algorithm that can deal with many environmental effects and maintain high performance levels.

10198-14, Session 3

Experiments with Simplex ACE: dealing with highly variable targets *(Invited Paper)*

Amanda K. Ziemann, James P. Theiler, Los Alamos National Lab. (United States)

In hyperspectral target detection, one must contend with variability in both target materials and background clutter. Most algorithms focus on the clutter, but for some materials there is substantial variability in the spectral signatures of the target. This is especially true for solid target materials, whose signatures depend on morphological properties (particle size, particle shape, packing density, etc.) that are rarely known a priori. When multiple target signatures can be used to describe a material, subspace detectors are typically the detection method of choice. However, as the variability in the target spectra increases, so does the size of the target subspace spanned by these spectra; so much so, in fact, that the number of false alarms (i.e., pixels that are improperly considered "target-like") quickly becomes intractable. We recently proposed a modification to this approach, wherein the target subspace is instead a constrained basis, or simplex. The most common subspace-based detector is the subspace adaptive cosine estimator (ss-ACE), and accordingly we refer to our technique as simplex adaptive cosine estimator (simplex-ACE). In this paper, we present new results using simplex-ACE for highly variable targets, and compare the performance against traditional subspace detectors. Results will be shown on hyperspectral images using implanted targets as both full and mixed pixels.

10198-15, Session 3

Crop classification using temporal stacks of multispectral satellite imagery (Rising Researcher Presentation) *(Invited Paper)*

Daniela I. Moody, Michael S. Warren, Nathan Longbotham, Steven P. Brumby, Samuel W. Skillman, Rick Chartrand, Ryan Keisler, Descartes Labs, Inc. (United States)

The increase in performance, availability, and coverage of multispectral satellite sensor constellations has led to a drastic increase in data volume and data rate. Multi-decadal remote sensing datasets at the petabyte scale are now available in commercial clouds, with new satellite constellations generating petabytes/year of daily high-resolution global coverage imagery. The data analysis capability, however, has lagged behind storage and compute developments, and has traditionally focused on individual scene processing. We present results from an ongoing effort to develop satellite imagery analysis tools that aggregate temporal, spatial, and spectral information and can scale with the high-rate and dimensionality of imagery being collected. We investigate and compare the performance of pixel-level crop identification using tree-based classifiers and its dependence on both temporal and spectral features. Classification performance is assessed using as ground-truth Cropland Data Layer (CDL) crop masks generated by the US Department of Agriculture (USDA). The CDL maps contain 30 m resolution, pixel-level labels for up to 255 categories of land cover, but are however only available post-growing season. The analysis focuses on McCook county in South Dakota and shows crop classification using a temporal stack of Landsat 8 (L8) imagery over the growing season, from April through October. Specifically, we consider the temporal L8 stack depth, as well as different normalized band difference indices, and evaluate their contribution to crop identification.

10198-16, Session 3

Invariance concepts in spectral analysis *(Invited Paper)*

Alan P. Schaum, U.S. Naval Research Lab. (United States)

Uncontrollable environmental and operational factors in remote sensing applications can complicate the analysis of multi- and hyperspectral imagery. Material detection and dis-crimination algorithms should be invariant to such epistemic unknowns, which should be distinguished from pixel-to-pixel variations that must be modeled stochastically. The spectral radiance measured at any pixel is usually sensed under unknown values of illu-mination, bi-directional reflectance angles, target age and morphology, and of column densities of water vapor, carbon dioxide, and aerosols. These all modify the amplitude and shape of spectra from what is measured in the laboratory. However, the form of sta-tistical models for describing such data often depends on the values of all epistemic fac-tors. Here we describe several methods for insuring robust discrimination performance invariant to epistemic uncertainties and contrast them with naïve data transformations that can remove unknown factors, but at the cost of hindering the performance of detec-tion algorithms. We also describe the mathematically precise formulation of invariance, along with new methods of: (1) predicting which statistical models admit uniformly most powerful invariant (UMPI) detection algorithms, and (2) deriving them when they exist. Finally, we describe generalized methods of invariant multi-dimensional visualization.

10198-17, Session 4

Spectral and spatial variability of undisturbed and disturbed grass under different view and illumination directions *(Invited Paper)*

Christoph C. Borel-Donohue, U.S. Army Research Lab. (United States); Sarah W. Shivers, Univ. of California, Santa Barbara (United States); Damon M. Conover, U.S. Army Research Lab. (United States)

It is well known that disturbed grass covered surfaces show variability with view and illumination conditions. A good example is a grass field in a soccer stadium that shows stripes indicating in which direction the grass was mowed. These spatial variations are due to a complex interplay of spectral characteristics of grass blades, density, length and their orientations. Viewing a grass surface from nadir or near horizontal directions results in observing different components. Views from a vertical direction show more variations due to reflections from the randomly oriented grass blades and their shadows. Views from near horizontal show a mixture of reflected and transmitted light from grass blades. An experiment was performed on a mowed grass surface which had paths of simulated heavy foot traffic laid down in different directions. High spatial resolution hyperspectral data cubes were taken by an imaging spectrometer covering the visible through near infrared over a period of time covering several hours. Ground truth grass reflectance spectra with a handheld spectrometer were obtained of undisturbed and disturbed areas. Close range images were taken of selected areas with a handheld camera which are then used to reconstruct the 3D geometry of the grass using structure-from-motion algorithms. Using spectral bidirectional reflectance distribution (BRDF) vegetation models such as PROSAIL we compare predicted to measured spectra. Computer graphics rendering using raytracing of reconstructed and procedurally created grass surfaces are used to compute BRDF models. In this paper we discuss differences between observed and simulated spectral and spatial variability. Based on the measurements and/or simulations we derive simple spectral index methods to detect spatial disturbances and apply scattering models.

10198-18, Session 4

Measurement of optical constants for spectral modeling: n and k values for ammonium sulfate via single-angle and ellipsometric methods *(Invited Paper)*

Thomas A. Blake, Carolyn S. Brauer, Molly Rose Kelly-Gorham, Sarah D. Burton, Mary Bliss, Timothy J. Johnson, Pacific Northwest National Lab. (United States)

The complex index of refraction, n? = n + ik, has the two constants n(nu) and k(nu), both a function of frequency nu. For the optical constants n is the real part (the dispersion), and k is the complex component (proportional to the absorption). The constants, n and k, can be used to model infrared spectra, including refraction, absorption, reflectance, and emissivity, but obtaining reliable values for solid materials (pure or otherwise) presents a challenge: In the past, the best results for n and k have been obtained from bulk, homogeneous materials, free of defects. That is, materials where the Fresnel equations are operant since there is no light scattering. Since it is often not possible to obtain a pure macroscopic (crystalline) material, it may be possible to press the material into a (uniform, void-free) disk. We have recently demonstrated this with ammonium sulfate powder and then measured the n and k values via two independent methods: 1) Ellipsometry - which measures the changes in amplitude and phase of light reflected from the material of interest as a function of wavelength and angle of incidence, and 2) Single angle specular reflectance with an FT spectrometer using a specular reflectance device within an FT instrument which measures the change in amplitude of light reflected from the material of interest as a function of wavelength and angle of incidence over a wide wavelength range. [The Kramers-Kronig relationship is then used to obtain the optical constants.] The quality of the n and k values derived from the pellet via the two methods was tested by comparing the n and k literature values where reflectance and transmission measurements were made of a single crystal [Toon et al., Journal of Geophysical Research, 81, Oceans and Atmospheres, 5733–5748, (1976)]. The comparison to the literature values showed good accuracy and good agreement, indicating promise to measure other materials by such methods.

10198-19, Session 4

Characterizing the temporal and spatial variability of longwave infrared spectral images of targets and backgrounds *(Invited Paper)*

Nirmalan Jeganathan, John P. Kerekes, Rochester Institute of Technology (United States); Dalton S. Rosario, US Army Research Lab. (United States)

The key principle of target detection is the distinguishability between an object and the background. Any radiance data collected in the longwave infrared (LWIR) region will be dependent on the object, the atmospheric composition, the time of day and meteorological conditions. The sensor-reaching radiance will vary for both the object in question (man-made) and the environment (vegetation). However, in a perfect world, the emissivity of the object will be consistent, while the emissivity of the environment will vary due to its composition. Exploring this theory, the LWIR hyperspectral data subset of the Spectral and Polarimetric Imagery Collection Experiment (SPICE) dataset collected by the United States Army Research Lab (US ARL) in 2012 was used to obtain the vegetation (background) and man-made object (target) spectral emissivities. Several methods are used to calculate the emissivity from sensor-reaching radiance and brightness temperature. The variability in background emissivity and the constancy of man-made object's emissivity are studied for several continuous 24-hr periods with data obtained approximately every five minutes. Comparisons between the background and target emissivities are analyzed, and categorized against time of day, air temperature, surface temperature and sensor-reaching radiance. The emissivity characteristics are being used to study the separability of the targets and backgrounds. Results of this study will be used to develop robust algorithms for a range of longwave spectral imagery.

10198-20, Session 4

Spatial-spectral signature modeling for solid targets in hyperspectral imagery *(Invited Paper)*

Jason R. Kaufman, Univ. of Dayton Research Institute (United States); Joseph Meola, Air Force Research Lab. (United States)

Spatial-spectral feature extraction algorithms – such as those based on spatial descriptors applied to selected spectral bands within a hyperspectral image – can provide additional discrimination capability beyond traditional spectral-only approaches. However, when attempting to detect a target with such algorithms, an exemplar target signature is often manually derived from the hyperspectral image's representation in the spatial-spectral feature space. This requires a reference image in which the target's location is known. Additionally, the scene-based signature captures only the representation of the target under certain collection conditions from a specific sensor, namely, illumination level and atmospheric composition, look angle, and target pose against a specific background. A detection algorithm utilizing this spatial-spectral signature (or the spatial descriptor itself) that is sensitive to changes in these collection conditions could suffer a loss

in performance should the new conditions significantly deviate from the exemplar's case. To begin to overcome these limitations, we formulate and evaluate the effectiveness of modeling techniques for synthesizing exemplar spatial-spectral signatures for solid targets, particularly when the spatial structure of the target of interest varies due to pose or obscuration by the background, and when applicable, the target temperature varies. We assess the impact of these changes on a group of spatial descriptors' responses to guide the modeling process for a set of two-dimensional targets specifically designed for this study. The sources of variability that most affect each descriptor are captured in target subspaces, which then form the basis of new spatial-spectral target detection algorithms.

10198-21, Session 4

Contaminant mass estimation of powder contaminated surfaces *(Invited Paper)*

Timothy Gibbs, David W. Messinger, Rochester Institute of Technology (United States)

How can we determine the physical characteristics of a mixture of multiple materials within a single pixel? Intimately mixed pixels are a result of nonlinear interactions between particles having different physical properties. Powder contaminated surfaces have unique spectral signatures in the longwave infrared region. The Nonconventional Exploitation Factors Data System (NEFDS) Contamination Model can make longwave hyperspectral mixture signatures, but only for a small subset of their database. In addition, the model uses percent coverage as its only physical property input despite it not being informative to the contminants physical properties. A parameter inversion model derived from the inverted NEFDS Contamination Model was created to estimate the amount of contaminant material present as well as other properties. Outdoor emissivity measurements of varying contaminant amount were made using a Designs and Prototypes fourier transform infrared spectrometer and input into the parameter inversion model. Estimated parameters will be used to recreate spectral emissivity signatures and compared to empirically measured data. The estimated areal coverage density is used to derive a total deposited mass on the surface based on the area of contaminated surface. This is compared to the known amount deposited that was measured during the experimental campaign. This paper presents some results of those measurements and model estimates.

10198-22, Session 4

Improvements to an earth observing statistical performance model *(Invited Paper)*

Runchen Zhao, Emmett J. Ientilucci, Rochester Institute of Technology (United States)

Hyperspectral remote sensing systems typically provide data composed of hundreds of narrow spectral channels both in the visible and long wave infrared. The ultimate goal of our work is to examine emissivity signature variability in an application such at material detection. A model currently used at RIT, the Forecasting and Analysis of Spectroradiometric System Performance (FASSP) model, can handle most of the statistical model variation in the LWIR. However, this model only examines LWIR variation in the radiance domain. For the visible portion of the EM spectrum, atmospheric compensation is performed so as to examine surface reflectance, for example. What is missing is a temperature-emissivity separation (TES) routine such that transformations are performed on the statistics generated from such an algorithm. FASSP transfers user defined input statistical characteristics of targets and backgrounds through the imaging chain, implements an atmospheric compensation, and performs detection analysis in the form of receiver operating characteristic (ROC) curves. This paper illustrates the implementation and statistical evaluation of an LWIR compensation routine in FASSP along with results in the form of ROC curves.

10198-52, Session PSTue

A new sampling strategy based on CGM for LAI measurements over non-uniform surface

Xiaohua Zhu, Lingling Ma, Yongguang Zhao, Academy of Opto-Electronics, CAS (China)

Currently, the remotely sensed product compared by measurements of field reference targets is still the basic means for validation. Limited by the representativeness of point sampling, all of the field measurements covering the whole region should be collected, which is impossible. Taking the cost of field measurement into account, more representative points with minimum number should be selected during remotely sensed product validation. There are several sampling strategies are used for remotely sensed product validation, including simple random sampling strategy, spatial uniform sampling strategy, Prior knowledge-based sampling strategy and so on. However, without fully considering the influence of the surface spatial heterogeneity, those sampling strategies often reduce the reliability of products validation. In this paper, a new sampling strategy based on Taylor expansion method (TEM) and computational geometry model (CGM) is proposed for leaf area index (LAI) ground measurement over non-uniform surface. Firstly, a correlation index (CI) is calculated based on TEM using high-resolution LAI image to choose the points of field measurement. Secondly, based on the first selected field measurements, the CGM model is used for simulating low-resolution LAI. Thirdly, the points of field measurement are decided according to the gaps between the simulated LAI and the aggregated LAI from high resolution. If the gap is accepted, the sampling strategy is finally established for field measurement. Otherwise, the field measurements should be re-selected and analyzed until the gap is accepted.

10198-53, Session PSTue

A new method for LAI retrieval from hyperspectral data

Xiaohua Zhu, Key Lab. of Quantitative Remote Sensing Information Technology, CAS (China) and Academy of Opto-Electronics, CAS (China)

Traditional methods for leaf area index (LAI) retrieval from hyperspectral data have some drawbacks, including hard making full use of spectral information, ill-posedness of inversion process. In this paper, we proposed a new method for LAI inversion based on spatial and spectral information of HIS (instruments boarded on China HJ-1A satellite) hyperspectral data. Firstly, HSI data (100 meter) is upscaled to 500 meters and 1000 meters for establishing a multi-scale data series. Secondly, a multiple scale inversion frame is constructed to update the prior knowledge and introduce spatial information. Thirdly, a multiple stages strategy is carried out in each scale inversion based on an uncertainty and sensibility matrix to introduce spectral information step by step, with which the most uncertainty parameters will be retrieved from the most sensibility spectral information. The spatial and spectral information of HIS data are both fully used in the inversion process. The experiment results indicate that the methodology proposed in this paper has achieved improved accuracy in LAI estimation.

10198-54, Session PSTue

Image denoising and deblurring using multispectral data

Evgeny A. Semenishchev, Vyacheslav V. Voronin, Don State Technical Univ. (Russian Federation)

Currently decision-making systems get widespread. These systems are based on the analysis video sequences and also additional data. They are

volume, change size, the behavior of one or a group of objects, temperature gradient, the presence of local areas with strong differences, and others. Security and control system are main areas of application. A noise on the images strongly influences the subsequent processing and decision making. This paper considers the problem of primary signal processing for solving the tasks of image denoising and deblurring of multispectral data. The additional information from multispectral channels can improve the efficiency of object classification. In this paper we use method of combining information about the objects obtained by the cameras in different frequency bands. We apply modified BM3D method to denoising and restoring the blur on the edges. In case of loss of the information will be applied an approach based on the interpolation of data taken from the analysis of objects located in other areas and information obtained from multispectral camera. The effectiveness of the proposed approach is shown in a set of test images.

10198-55, Session PSTue

Superpixel segmentation for dimensionality reduction in hyperspectral unmixing

Jiarui Yi, Miguel Velez-Reyes, The Univ. of Texas at El Paso (United States)

Superpixels have been widely used as a pre-processing stage in image processing to reduce the dimensionality of subsequent image processing tasks. Image processing operations are applied to the superpixels instead of the full set of pixels from the image. The superpixel representation reduces the redundancy present in the image and increases processing efficiency of the next processing task. SLIC superpixel segmentation is a popular method for superpixel extraction. This paper presents an approach to reduce dimensionality for hyperspectral unmixing using superpixel segmentation. The dimensionality reduction is achieved by over-segmenting the hyperspectral image to obtain local spectrally homogeneous regions (or superpixels) that can be used as representatives of the full hyperspectral image. The average pixel is used as the representative spectral signature for the superpixel segment. Once the average signature is extracted for each superpixel, endmember extraction methods are applied to the reduced data set of spectral signatures with clear computational advantages. The proposed method is illustrated on the AVIRIS image captured over Fort AP Hill, Virginia. A comparison of the method with standard unmixing techniques is also included.

10198-56, Session PSTue

Ensemble learning and model averaging for material identification in hyperspectral imagery

William Basener, Rochester Institute of Technology (United States) and Spectral Solutions (United States) and Univ. of Virginia (United States)

Over recent decades, much attention has been placed on building more effective target detection algorithms for hyperspectral imagery. Much of this work is based on signal processing methods, locating a known spectra out of a background image derived as detection of a known signal from Gaussian noise. While target detections are very effective at detecting targets, these methods also output high scores for both target objects and correlated confusers.

In this paper we develop a method for material identification based on ensemble machine learning using model averaging. Not only does this enable identification of a target from confusers, it enables an accurate assessment of the level of specificity that is achievable from the data. Model averaging is particularly well suited for this task because it enables averaging over multiple spectra and outputs results that can more readily be interpreted in a probabilistic framework for decision making.

10198-59, Session PSTue

Clouds removal of hyperspectral remotely sensed images using SREM

Xuejian Sun, Lifu Zhang, Yi Cen, Mingyue Zhang, Institute of Remote Sensing and Digital Earth (China)

Hyperspectral remote sensing has been playing an important role in a wide variety of fields. However, its widely progress has been constrained due to the different shape thick opaque cloud obscure. Thus, the reconstruction of missing information on hyperspectral remote sensing images has been focused, aiming to restore the image details. Consider the background that GF-5 which equipped with hyperspectral sensor is going to launch on the end of 2016 in China, this method can be a specialized algorithm for the images that acquired. In this study, we put a algorithm which is a multispectral image guided while hyperspectral image spectral reconstruction method (SREM) to remove the cloud, the SREM was a fusion algorithm to expand the swath of hyperspectral images. Firstly, the hyperspectral image with cloud and the multispectral image of the same area are needed. Secondly, the approach makes use of the linear relationships between multi and hyper-spectral of specific materials to generate a set of transformation matrices. Then, a spectral angle weighted minimum distance (SAWMD) matching method is used to select a suitable matrix to create hyperspectral image vectors from the original multispectral image, pixel by pixel. The final result image has the same spectral resolution as the original hyperspectral image that used while without cloud. This approach was test with two image datasets, and the result were compared by visual interpretation, statistical analysis to evaluate the performance. The result showing good performance as we expected.

10198-23, Session 5

Piecewise flat embeddings for hyperspectral image analysis (Rising Researcher Presentation)

Tyler L. Hayes, Renee T. Meinhold, John F. Hamilton Jr., Nathan D. Cahill, Rochester Institute of Technology (United States)

Graph-based dimensionality reduction techniques have been used in a variety of hyperspectral image analysis applications. Nonlinear algorithms such as Laplacian Eigenmaps (LE) and Schrödinger Eigenmaps (SE) yield powerful low-dimensional representations of image data for use in segmentation, classification, and target detection of hyperspectral imagery. These low-dimensional representations of the data, known as embeddings, are intrinsically smooth, which preserves structure of the original data but makes classification an ambiguous task. Piecewise Flat Embeddings (PFE) were recently introduced into the computer vision community as a means to generate a data representation through the constrained optimization of a weighted ?1-norm error term, as opposed to the weighted ?2-norm error term used by LE. Unlike the smooth embeddings generated by LE, the embeddings from PFE are piecewise constant, making subsequent clustering or classification much less ambiguous.

In this paper, we show how the LE and SE techniques that have been applied to hyperspectral image classification and target detection can be reposed using PFE, yielding a new family of graph-based algorithms for hyperspectral image analysis. These algorithms enable spatial-spectral fusion when desired, and they allow expert-provided pairwise constraints to be incorporated when available. We then show how to use iterative procedures to approximate solutions to the resulting constrained ?1-minimization problems. Finally, using publicly available hyperspectral imagery, we carry out a series of experiments to assess the trade-offs between PFE and LE/SE with respect to classification/target detection accuracy and computation time.

10198-24, Session 5

Dimensionality estimation for manifold-based classification of airborne spectral data acquired over terrestrial regions

Ron Fick, Paul D. Gader, Univ. of Florida (United States)

The goal of the research described in this paper is on robustly classifying entities derived from hyperspectral imagery. These entities include sub-pixels, pixels, and regions. For this work, robustness is defined in terms of the ability of a classifier to identify patterns that are unlikely to be from the training and testing distributions. This is a more difficult problem than one might think. For example, it can be shown that most neural network models used in deep learning are not robust because they can map multi-dimensional spaces to a single value.

It is well known that the information contained in hyperspectral data is of much lower dimensionality than the number of wavelengths that are sampled, referred to here as the original space. It is also evident in many cases that the data do not lie on a linear subspace of the original space but are generally continuous, and can therefore be considered as samples from topological manifolds. They are often not convex however. For example, the mean of the data may not be close to a data point. In addition, multiple regions in the spatial area imaged can have different materials present and mixing. They therefore form different manifolds. Thus, the problem becomes one of characterizing distributions over multiple, nonlinear, non-convex manifolds. The manifolds are the domains of the classifiers, considered as functions. Therefore, we can considered this problem as one of domain learning or domain characterization as well.

This paper focuses on estimating the dimensionality of these manifolds. As manifolds, they are locally-Euclidean. Hence, a hypothesis considered is that local methods that consider unique characteristics of hyperspectral data are better for characterizing domains of classifiers in the sense that they produce more robust classifiers. Results are shown on synthetic data and real data obtained from multiple sensors, including a CASI VisNIR with 72 spectral bands and the National Science Foundations NEON VisNIR / SWIR system with 426 spectral bands.

10198-25, Session 5

Supervised non-negative tensor factorization for automatic hyperspectral feature extraction and target discrimination

Dylan Anderson, Joshua Coon, Aleksander B. Bapst, Aaron J. Pung, Sandia National Labs. (United States); Michael W. Kudenov, North Carolina State Univ. (United States)

Hyperspectral imaging provides a highly discriminative and powerful signature for target detection and discrimination. Recent literature has shown that considering additional target characteristics, such as spatial or temporal profiles, simultaneously with spectral content can greatly increase classifier performance. Considering these additional characteristics in a traditional discriminative algorithm requires a feature extraction step be performed first. An example of such a pipeline is computing a filter bank response to extract spatial features followed by a support vector machine (SVM) to discriminate between targets. This decoupling between feature extraction and target discrimination yields features that are suboptimal for discrimination, reducing performance. This performance reduction is especially pronounced when the number of features or available data is limited. In this paper, we propose the use of Supervised Nonnegative Tensor Factorization (SNTF) to jointly perform feature extraction and target discrimination over hyperspectral data products. SNTF learns a tensor factorization and a classification boundary from labeled training data simultaneously. This ensures that the features learned via tensor factorization are optimal for both summarizing the input data and separating the targets of interest. Practical considerations for applying SNTF to hyperspectral data are presented, and results from this framework are compared to decoupled feature extraction/target discrimination pipelines.

10198-26, Session 5

Band selection for hyperspectral image classification using extreme learning machine

Benjamin Kingsdorf, Qian Du, Mississippi State Univ. (United States)

Extreme learning machine (ELM) is a feedforward neural network with one hidden layer, which is similar to a multilayer perceptron (MLP). To reduce the complexity in the training process of MLP using the traditional backpropagation algorithm, the weights in ELM between input and hidden layers are random variables. The output layer in the ELM is linear, as in a radial basis function neural network (RBFNN), so the output weights can be easily estimated with a least squares solution. It has been demonstrated in our previous work that the computational cost of ELM is much lower than the standard support vector machine (SVM), and a kernel version of ELM can offer comparable performance as SVM.

In our previous work, we also investigate the impact of the number of hidden neurons to the performance of ELM. Basically, more hidden neurons are needed if the number of training samples and data dimensionality are large, which results in a very large matrix inversion problem. To avoid handling such a large matrix, we propose to conduct band selection to reduce data dimensionality (i.e., the number of input neurons), thereby reducing the number of hidden neurons. Experimental results show that band selection can yield a simplified ELM offering similar or even better classification accuracy.

10198-27, Session 5

A comparison of column subset selection methods for hyperspectral band subset selection

Maher Aldeghlawi, Miguel Velez-Reyes, The Univ. of Texas at El Paso (United States)

Observations from hyperspectral imaging sensors lead to high dimensional data sets from hundreds of images taken at closely spaced narrow spectral bands. High storage and transmission requirements, computational complexity, and statistical modeling problems combined with physical insight motivate the idea of hyperspectral dimensionality reduction using band subset selection. Many algorithms are described in the literature to solve supervised and unsupervised band subset selection problems. This paper explores the use of unsupervised band subset selection methods using column subset selection (CSS). Column subset selection is the problem (CSSP) of selecting the most independent columns of a matrix. A recent variant of this problem is the positive column subset selection problem (pCSSP) which restricts column subset selection to only consider positive linear combinations. Many algorithms have been proposed in the literature for the solution of the CSSP. However, the pCSSP is less studied. This paper will present a comparison of different algorithms to solve the CSSP and the pCSSP for band subset selection. The performance of classifiers using the algorithms as a dimensionality reduction stage will be used to evaluate the usefulness of these algorithms in hyperspectral image exploitation.

10198-28, Session 5

Band selection for change detection from hyperspectral images

Sicong Liu, Tongji Univ. (China); Qian Du, Mississippi State Univ. (United States); Xiaohua Tong, Tongji Univ. (China)

Change detection is one of the most important applications of remote sensing. Change detection from multitemporal hyperspectral images is more challenging than from multispectral images, because its high dimensionality may imply many possibilities of potential changes. Finding the changes of interest from trivial background changes incurred by sensing environment variations is also very challenging. Change detection can be conducted in a supervised or unsupervised fashion. Due to the difficulty of having training samples in an unknown environment, unsupervised change detection is often preferred.

In our previous work, we have conducted unsupervised band selection to reduce data dimensionality, and using a subset of distinctive and informative bands can offer even better classification accuracy than using all the original bands. In this paper, we propose to apply unsupervised band selection to improve the performance of change detection. Radiometric normalization is conducted to remove background changes due to seasonal and diurnal changes that are trivial, and a difference image for change vector analysis is generated. By reducing data dimensionality through finding the most distinctive and informative bands in the difference image, foreground changes may be better detected. Experimental results using simulated and real hyperspectral images demonstrate performance improvement from using the proposed method.

10198-29, Session 6

Method for sensitivity analysis of anomaly detection in hyperspectral images

Adam Messer, Kenneth W. Bauer Jr., Air Force Institute of Technology (United States)

Anomaly detection within hyperspectral images, among other applications areas, relies on the critical step of thresholding to declare the specific pixels based on their anomaly scores. When the detector is built upon sound statistical assumptions, this threshold is often probabilistically based, such as the RX detector and the chi-squared threshold. However, when either the detector lacking statistical framework or the background pixels of the image violate the required assumptions, the approach to thresholding is complicated and can resolve into performance instability. We present a method to test the sensitivity thresholding to small changes in the characteristics of the anomalies based on their Mahalanobis distance to the background class. In doing so, we highlight issues in detector's thresholding techniques comparing statistical approaches against heuristic methods of thresholding.

10198-30, Session 6

Local background estimation and the replacement target model *(Invited Paper)*

James P. Theiler, Amanda K. Ziemann, Los Alamos National Lab. (United States)

To detect weak or rare signals in a cluttered background, a key first step is to model that background. The classic choice -- seemingly naive, but popular, and often quite effective -- is a simple multivariate Gaussian distribution, with a single global mean and a single global covariance. Both additive target detectors (such as adaptive matched filter [AMF] or adaptive coherence estimator [ACE]) and replacment target detectors (such as mixture-tuned matched filter [MTMF] or finite target matched filter [FTMF]) have been developed for the global Gaussian background, though the additive models are more commonly used. In part this is because they are easier to compute, but also because they provide reasonable target detection performance even for targets that are more physically well-represented by the replacement model.

Another background model, widely adopted for anomaly detection, but only recently employed for target detection, is a local background estimator, in which the background is individually estimated at each pixel with a mean (or some other function) of the pixels in an annulus surrounding the pixel of interest. Subtracting this estimated background from the observed image yields a "residual" image that can be used for target detection. Since more of the background will have been subtracted, one might presume that target detection perfomance would be improved. We discovered, however, that for replacement-model targets, this subtraction of the background can be deleterious.

We investigate approaches for improving replacement-model target detection when the background is estimated locally.

10198-31, Session 6

A method for automatically extraction of typical disaster-bearing targets from LiDAR point cloud in coastal zone

Zheng Wei, Ping Wang, Yuchao Sun, Jisheng Zeng, Fan Yang, South China Sea Institute of Planning and Environment (China)

It is essential to study the fast and accurate methods of automatic recognition and dynamic monitoring for the coastal disaster-bearing body. Airborne LiDAR provides powerful technical support for fast, efficient and direct access to the 3D information of the coastal disaster bearing targets. Aiming at the typical hazard bearing targets such as buildings and trees, this paper presents a method of automatic extraction of disaster bearing targets from coastal LiDAR data, based on georeferenced feature image of the point clouds. Firstly, LiDAR point cloud data of coastal zone are pretreated by elevation histogram, including point cloud noise elimination and water surface point cloud automatic elimination. Secondly, by analyzing the spatial distribution characteristics of point cloud (plane distance, elevation difference, point cloud density, etc.), a georeferenced feature image of the point clouds is generated. In this way, the airborne LiDAR point cloud data is transformed into the two-dimensional image space, and the object classification of the hazard-bearing objects is carried out by the image processing method. Finally, the hazard-bearing objects is automatically extracted according to the correspondence between the 3D point cloud and the two-dimensional feature image. In this paper, the LiDAR cloud data of Haidian Island, Haikou, Hainan Province, which was acquired by ALS70, is used as experimental data to verify the feasibility and practicability of this method. The experimental results show that the method proposed in this paper can well extract the typical hazard bearing targets in the LiDAR point clouds over a large range of coastal zones.

10198-32, Session 6

A study of anomaly detection performance as a function of relative spectral abundances for graph- and statistics-based detection algorithms

Colin C. Olson, U.S. Naval Research Lab. (United States); Michelle Coyle, Claflin Univ. (United States); Timothy J. Doster, U.S. Naval Research Lab. (United States)

We investigate an anomaly detection framework that uses manifold-learning techniques to learn a model of the non-anomalous data. The algorithm begins by uniformly sampling a small subset of the data under the assumption that anomalous data is, by definition, relatively rare. A manifold is then constructed from the adjacency matrix constructed solely from the subsampled data. The algorithm proceeds by using out-of-sample extension methods (e.g., the Nystrom extension) to project the remaining data into the manifold space. The projection error of each point is approximated and the selected measure is then thresholded under the assumption that background data will project close to the manifold while anomalous data will not.

The operating assumption of this framework is that the ratio of anomalous to non-anomalous data in the subset is small and therefore the few anomalous data represented in the sampled subset will have little effect on the learned background model. Closer consideration reveals that there is interplay between the abundance of the anomalous class and the least-abundant background class. A good subsampling will fail to sample much of the anomalous class while simultaneously sampling a sufficient percentage of the least-abundant background class such that said class is well-represented by the learned background model. We employ a statistical bootstrapping method to build synthetic data from field collects such that we may vary the relative spectral abundances of the anomalous and background classes and investigate the effect on detection performance. Comparisons are drawn between our method and other graph- and statistics-based detection algorithms.

10198-33, Session 6

Optimization of feature identification and surface target detection using DIRSIG and Caffe Berkeley

Cassandra Post, Kenneth Hopkinson, Bryan J. Steward, Air Force Institute of Technology (United States)

The possibility of using low-fidelity sensors of satellites in a constellation for accurate surface target detection has the potential to lower costs while increasing flexibility, replacement time, and fault tolerance. This article investigates the possibility of utilizing an array of satellites with a heterogeneous mix of sensor types to optimize the validation process of surface target detection. Remote sensing allows the possibility to generate various synthetic scenes of interest through optical feature extraction. Features of interest are generated from varying resolutions, representing different sensor types using RIT's DIRSIG platform. Synthetic images are jittered to varying degrees to represent the performance of low-fidelity sensors. Image fusion is utilized to combine synthetically jittered images of varying degrees to render high fidelity sensor data. These synthetic images are utilized to train an artificial intelligence platform to automatically detect targets of interest on the earth's surface. Validation of obscured targets of interest is made possible through the image fusion of jittered target images. The Berkeley Caffe Convolution-Based Deep Learning open source platform is trained and employed to automatically detect features of interest. Berkeley Caffe is fast, powerful, and well-supported with deployed projects by major corporations including Pinterest, Google, and others, which makes it particularly valuable for our experiments. Through these experiments, we demonstrate that remote sensing platforms can provide features of interest to an artificial intelligence platform to increase overall feature identification effectiveness. This is useful for the verification and validation for targets of interest in various mission types.

10198-34, Session 6

Transformation for target detection in hyperspectral imaging

Edisanter Lo, Susquehanna Univ. (United States); Emmett J. Ientilucci, Rochester Institute of Technology (United States)

Conventional algorithms for target detection in hyperspectral imaging usually require multivariate normal distributions for the background and target pixels. Significant deviation from the assumed distributions can lead to poor detection. It is possible to make the non-normal pixels into more normal-looking pixels by transforming the pixels into different units. A multivariate transformation on the pixels is proposed in this paper to improve target detection in hyperspectral imaging. Experimental results will be presented.

10198-35, Session 7

Terrestrial hyperspectral image shadow restoration through fusion with terrestrial lidar

Preston J. Hartzell, Craig L. Glennie, Univ. of Houston (United States); David C. Finnegan, Cold Regions Research and Engineering Lab., U.S. Army Corps of Engineers (United States); Darren L. Hauser, Univ. of Houston (United States)

Recent advances in remote sensing technology have expanded the acquisition and fusion of active lidar and passive hyperspectral imagery (HSI) from exclusively airborne observations to include terrestrial modalities. In contrast to airborne collection geometry, hyperspectral imagery captured from terrestrial cameras is prone to extensive solar shadowing on vertical surfaces leading to reductions in pixel classification accuracies or outright removal of shadowed areas from subsequent analysis tasks. We demonstrate the use of lidar spatial information for sub-pixel HSI shadow detection and the restoration of shadowed pixel spectra via empirical methods that utilize sunlit and shadowed pixels of similar material composition. We examine the effectiveness of radiometrically calibrated lidar intensity in identifying these similar materials in sun and shade conditions and further evaluate a restoration technique that leverages ratios derived from the overlapping lidar laser and HSI wavelengths. Simulations of multiple lidar wavelengths, i.e., multi-spectral lidar, indicate the potential for robust HSI spectral restoration that is independent of the complexity and costs associated with rigorous radiometric transfer models, which have yet to be developed for horizontal-viewing terrestrial HSI sensors. The spectral restoration performance of shadowed HSI pixels is quantified for imagery of a geologic outcrop through improvements in spectral shape, spectral scale, HSI band correlation, and classification consistency between sunlit and shadowed pixels of similar materials.

10198-36, Session 7

Mutual Information registration method for WorldView-3 multi-spectral bands

Grzegorz Miecznik, William M. Baugh, Seth Malitz, Jeff Shafer, Fabio Pacifici, DigitalGlobe, Inc. (United States)

WorldView-03 (WV-3) is a DigitalGlobe commercial, high resolution, push-broom imaging satellite with three instruments: Panchromatic (0.3m nadir GSD) plus visible and near-infrared VNIR (1.2m), short-wave infrared SWIR (3.7m), and multi-spectral CAVIS (30m). Applications based on VNIR/SWIR spectra, such as object classification and material identification, require accurate co-registration between bands. WV-3 geometric calibration and ortho-rectification of VNIR and SWIR results in co-registration accurate to within about 1 SWIR pixel (3.7m), whereas inter-SWIR band to band registration is within about 0.3 SWIR pixels. More precise registration can be achieved by utilizing image processing algorithms, such as Mutual Information (MI). In comparison with other registration methods, MI has been proven in medical and remote sensing applications to provide the best registration for images with different modalities. Although highly accurate, automatic implementation of MI-based algorithms can be challenging. One challenge is how to compute bin widths of intensity histograms, which are fundamental building blocks of MI algorithms. We solve this problem by making the bin widths proportional to instrument shot noise. For hazy scenes and scenes with high aerosol loading, MI accuracy can be further augmented by using surface reflectance as opposed to top-of-atmosphere reflectance. Using Neural Networks to synthesize geometrically aligned VNIR and SWIR spectra, we demonstrate that as long as the digital elevation model does not deform images, and clouds and water are masked out, global VNIR to SWIR registration can be achieved to within 1/4th of a SWIR pixel.

10198-37, Session 7

A reconstruction algorithm for three-dimensional object-space data using spatial-spectral multiplexing

Zhejun Wu, Michael W. Kudenov, North Carolina State Univ. (United States)

In this paper, we present a reconstruction algorithm for Spatial-Spectral Multiplexing (SSM) optical system. The goal of this algorithm is to recover the three-dimensional spatial and spectral information of a scene, given that a one-dimensional spectrometer array is used to sample the pupil of the spatial-spectral modulator and a measurement matrix using SSM techniques. The challenge of the reconstruction is that the non-parametric representation of the three-dimensional spatial and spectral object requires a large number of variables, thus leading to an underdetermined linear system that is hard to uniquely recover. We propose to reparameterize the spectrum using B-spline functions to reduce the number of unknown variables. Our reconstruction algorithm then solves the improved linear system via a least-square optimization of such B-spline coefficients with additional spatial smoothness regularization. The ground truth object and the optical model for the measurement matrix are simulated with both spatial and spectral assumptions according to a realistic field of view. In order to test the robustness of the algorithm, we add poisson noise to the measurement and test on both two-dimensional and three-dimensional spatial and spectral scenes. Our analysis shows that the mean square error of the recovered results can be achieved within 0.2%.

10198-38, Session 7

Target-driven selection of lossy hyperspectral image compression ratios

Jason R. Kaufman, Christopher D. McGuinness, Univ. of Dayton Research Institute (United States)

A common problem in applying lossy compression to a hyperspectral image is predicting its effect on spectral target detection performance. Recent work has shown that light amounts of lossy compression can remove noise in hyperspectral imagery that would otherwise bias a covariance-based spectral target detection algorithm's background-normalized response to target samples. However, the detection performance of such an algorithm is a function of both the specific target of interest as well as the background, among other factors, and therefore sometimes lossy compression operating at a particular compression ratio (CR) will not negatively affect the detection of one target, while it will negatively affect the detection of another. To account for the variability in this behavior, we have developed a target-centric metric that guides the selection of a lossy compression algorithm's CR without knowledge of whether or not the targets of interest are present in an image. Further, we show that this metric is correlated with the adaptive coherence estimator's (ACE's) signal to clutter ratio when targets are present in an image.

10198-39, Session 7

On the creation of high spatial resolution imaging spectroscopy data from multi-temporal low spatial resolution imagery

Wei Yao, Jan A. N. van Aardt, David W. Messinger, Rochester Institute of Technology (United States)

The Hyperspectral Infrared Imager (HyspIRI) mission aims to provide global imaging spectroscopy data to especially benefit ecosystem studies. The on board spectrometer will collect radiance spectra from the visible to short wave infrared (VSWIR) regions (400-2500 nm). The mission calls for fine spectral resolution (10 nm band width) and as such will enable scientists to perform material characterization, species classification, and even sub-pixel mapping. However, the global coverage requirement results in a relatively low spatial resolution (GSD 30m), which restricts the applications to objects of similar scales. We therefore have focused on assessment of sub-pixel vegetation structure from the spectroscopy data in past studies. In this study, we investigate the development or reconstruction of higher spatial resolution imaging spectroscopy data via fusion of multi-temporal data sets to address the drawbacks implicit in low spatial resolution imagery.

The projected temporal resolution of the HyspIRI VSWIR instrument is 15 days, which implies that we have access to up to six data sets for an area in a given season. Previous studies have shown that select vegetation structural parameters, e.g., leaf area index (LAI) and gross ecosystem production (GEP), are relatively constant in summer and winter for temperate forests; we therefore consider the data sets collected in summer to be from a similar, stable forest structure. The first step, prior to fusion, then involves registration and normalization (to the same scale) of the multi-temporal data. A data fusion algorithm then could be applied to the pre-processed data sets. The approach hinges on an algorithm that has been widely applied to fuse RGB images: Ideally, if we have four images of a scene which meet the following requirements i) they are captured with the same camera configurations; ii) the pixel size of each image is x; and iii) the four images are aligned on a grid of x/2, then a high-resolution image, with a pixel size of x/2, can be reconstructed from the multi-temporal set.

The algorithm was applied to data from NASA's Airborne Visible and Infrared Imaging Spectrometer (AVIRIS; GSD 18m), collected between 2013-2016 (summer) over our study area (NEON's Southwest Pacific Domain; Fresno, CA) to generate higher spatial resolution imagery (GSD 9m). The reconstructed data set was validated via comparison to NEON's imaging spectrometer (NIS) data (GSD 1m). The early results showed that algorithm worked well with the AVIRIS data and could be applied to the HyspIRI data. The detailed data sets and results will be presented at the conference.

10198-40, Session 7

Versatile and efficient data compression for ground, maritime, and aerospace applications

Jordi Portell de Mora, Institut d'Estudis Espacials de Catalunya (Spain) and Institut de Ciències del Cosmos, Univ. de Barcelona (Spain) and DAPCOM Data Services (Spain); Riccardo Iudica, DAPCOM Data Services (Spain); Alberto G. Villafranca, STAR-Dundee Ltd. (United Kingdom); Enrique García-Berro, Institut d'Estudis Espacials de Catalunya (Spain) and Univ. Politècnica de Catalunya (Spain); Marcial Clotet, Institut d'Estudis Espacials de Catalunya (Spain) and Institut de Ciències del Cosmos, Univ. de Barcelona (Spain) and DAPCOM Data Services (Spain); Gabriel Artigues, Institut d'Estudis Espacials de Catalunya (Spain) and DAPCOM Data Services (Spain); David Amblas, Scott Polar Research Institute, Univ. of Cambridge (United Kingdom)

FAPEC is a fast entropy coding algorithm offering good ratios even on data severely affected by noise and outliers. On top of it we have created the FAPEC Archiver, a high-performance data compression framework providing several pre-processing stages. These include lossless and lossy hyperspectral image compression based on prediction, DWT or our HPA algorithm, which achieves excellent image sharpness even at low quality levels. Sample sizes of 8 to 24 bits are supported. The multi-thread framework is flexible enough to allow easy integration of new algorithms such as for genomics, marine echosounders and point cloud data in general. Its ANSI C implementation makes it portable, from cubesats to supercomputers, either as a standalone program running on files or invoked on memory buffers through its API. 256-bit AES encryption and error detection and correction are embedded. The coding core is available in VHDL, successfully tested in several FPGA platforms with excellent results. In this work we present the basic concepts of our entropy coder and the main pre-processing stages. We elaborate on the FAPEC framework and the strategies followed to achieve a high-performance despite of this versatility. Finally, we show some use cases, both in software and hardware, and the performance obtained on these, including the first cubesat using FAPEC in flight.

10198-41, Session 8

Globally scalable generation of high-resolution land cover from multispectral imagery

Craig Stutts, Benjamin L. Raskob, Eric J. Wenger, Applied Research Associates, Inc. (United States)

We present an automated method of generating high resolution (~ 2 meter) land cover using a pattern recognition neural network trained on spatial and spectral features obtained from over 9000 WorldView multispectral images in six distinct world regions. At this resolution, the network can classify small-scale objects such as individual buildings, roads, and irrigation ponds. This paper focuses on three key areas. First, we describe our land cover generation process, which involves the co-registration and aggregation of multiple spatially overlapping MSI, post-aggregation processing, and the registration of land cover to Open Street Map road vectors using rigorous feature correspondence. Second, we discuss the generation of land cover derivative products and their impact in the areas of region reduction and object detection. Finally, we discuss the process of globally scaling our land cover generation using cloud computing via Amazon Web Services.

10198-42, Session 8

A genetic algorithm for flood detection and evacuation route planning

Rahul Gomes, Jeremy Straub, North Dakota State Univ. (United States)

This paper covers the development of a genetic-type algorithm that uses geospatial data to determine the most probable path to safety for individuals in a disaster area. A traditional routing system is not appropriate for disaster scenarios. The proposed algorithm uses geological features and disaster information to determine the shortest safe path. It predicts how a flood can change a landform over time and use this data to predict alternate routes. It also predicts safe routes in rural places where GPS/map based routing data is unavailable or inaccurate.

Satellite multi-spectral imagery will be used to deduce trends in hydrological events in a specific area over time. GRACE provides detailed measurements of the Earth's gravitational field. MODIS and LANDSAT provide multi-spectral images in several bands. These images are used to create a system than can accurately predict probable flood inflicted areas for a particular time interval. Supervised classification is performed to segregate similar pixel values which can identify possible evacuation roads or buildings. The reflectance of relevant features is used by the supervised classification algorithm, which determines other pixel values within the image. Multiple polygons are created for each class from similar spectral signatures. The algorithm generally classifies the pixels into two categories, hard and soft classifiers. Hard classifiers assign each pixel with discrete value based on the training data. Soft classifiers are based on a probability of maximum likelihood of the spectral signatures being assigned to particular class. The output is compared with the Reserved Flood Potential Index and PCR-GLOBWB.

10198-43, Session 8

Neural network applying for reflectance spectrum classification

Gefei Yang, Michael G. Gartley, Rochester Institute of Technology (United States)

Traditional Reflectance spectrum classification algorithms are based on comparing spectrum in bands. These methods should consider measurement and analyze reflectance pixel by pixel. Inspired from high performance by convolution neural networks in image classification, we apply neural network to analyze BRDF pattern images. By using The bidirectional reflectance distribution function (BRDF) data, we can reshape angles and reflectance into 3-dimension which will present some special patterns. BRDF 4-dimension function with azimuth angle and zenith angle of incident and reflected rays. Once we express them into angles maps which is in format as lighting orientation x camera orientation x channels. Lighting orientation is incident ray and camera orientation is reflected ray. Both of them presented azimuth and zenith angles as angles maps. Meanwhile, utilizing RIT micro-DIRSIG to simulate more training samples for improving the robustness of neural networks training.

Unlike traditional classification by using hand-designed feature extraction with a trainable classifier, neural networks create several layers to learn a feature hierarchy from pixels to classifier and all layers are trained jointly. Hence the angles features are different to traditional methods'. Training process cost large computation, however, simple classifiers work well when using neural networks generated features.

Currently, most popular neural networks such as VGG, GoogLeNet and AlexNet are trained based on RGB image scene. Our approaching is aim to build reflectance spectrum based neural network to help us to understand from another perspective.

At the end of this paper, we compared the difference among several classifiers and analyzed the tradeoff between neural networks parameters and numbers of layers.

10198-44, Session 8

Subsurface classification of objects under turbid waters by means of regularization techniques applied to real hyperspectral data

Emmanuel Carpena, Luis O. Jimenez-Rodriguez, Emmanuel Arzuaga, Ernesto Reyes, Sujeily Fonseca, Juan Figueroa, Univ. de Puerto Rico Mayagüez (United States)

Improved benthic habitat mapping is needed to monitor coral reefs around the world and to assist coastal zones management programs. A fundamental challenge to remotely sensed mapping of coastal shallow waters is due to the significant disparity in the optical properties of the water column caused by the interaction between the coast and the sea. The objects to be classified have weak signals that interact with turbid waters that include sediments. In real scenarios the absorption and backscattering coefficients are unknown with different sources of variability (river discharges and coastal interactions). Under normal circumstances, another unknown variable is the depth of shallow waters. This paper presents the development of algorithms for retrieving information and its application to the classification and mapping of objects under coastal shallow waters

with different unknown concentrations of sediments. A mathematical model that simplifies the radiative transfer equation was used to quantify the interaction between the object of interest, the medium and the sensor. The retrieval of information requires the development of mathematical models and processing tools in the area of inversion, image reconstruction and classification of hyperspectral data. The algorithms developed were applied to one set of real hyperspectral imagery taken in a tank filled with water and TiO2 that emulates turbid coastal shallow waters. Tikhonov method of regularization was used in the inversion process to estimate the bottom albedo of the water tank using a priori information in the form of stored spectral signatures, previously measured, of objects of interest.

10198-47, Session 8

Improving the detection of cocoa bean fermentation-related changes using image fusion

Daniel Ochoa, Ronald Criollo, Escuela Superior Politécnica del Litoral (Ecuador); Wenzhi Liao, Univ. Gent (Belgium); Rodrigo Castro, Oswaldo Bayona, Juan Cevallos, Escuela Superior Politécnica del Litoral (Ecuador)

Complex chemical processes occur in during fermentation of cocoa beans. Enzyme activity, oxidation and the breakdown of proteins determine the chocolate color and flavour. To select well-fermented beans, experts take a sample of beans, cut them in half and visually check its colour. Very often farmers mix high and low-quality cocoa beans which make difficult to control the chocolate flavour. In this paper, we explore how close-range hyperspectral data can be used to characterize the fermentation process of two types of cocoa beans nacional and CCN-51. Our aim is to find spectral differences that allow bean class classification. The proposed approach is based on close range hyperspectral imaging. Cocoa bean images from a hyperspectral camera are calibrated using a commercial spectrometer. The main issue for this kind of analysis is to extract reliable spectral data because the surface of cocoa bean halves is not flat. Cracks, resulting from the loss of water during fermentation, can cover up to 40% of the bean surface. Since, hyperspectral data has low spatial resolution, we exploit hyperspectral pansharpening techniques used in remote sensing to increase the spatial resolution of hyperspectral images and filter out uneven surface regions. In particular, the guided filter PCA approach which has proved to work well using RGB images as input. Our preliminary results show that this pre-processing step improves the separability of classes corresponding to each fermentation stage compared to using the average spectrum of the bean surface.

10198-48, Session 9

A pigment analysis tool for hyperspectral images of cultural heritage artifacts

Di Bai, David W. Messinger, Rochester Institute of Technology (United States); David F. Howell, Univ. of Oxford (United Kingdom)

The Gough Map, a mid-fourteenth century map of Britain is the earliest surviving map of the island in geographically recognizable form. Previous research revealed that this map was extensively revised over 13th and 14th century. Image analysis tools used to analyze the Gough Map can help historians understand its timeline and methodology of creation. The availability of a hyperspectral image of the map coupled with the use of different hyperspectral imaging analysis tools provides the opportunity for a new look at the Gough Map. Attention in this article is directed to produce a pigment analysis tool to analyze the similarities and differences shown in the areas that have common pigments "visually" on the map. The hyperspectral image of the Gough Map was taken from the Bodleian Library, Oxford University, with 334 bands over the Vis-NIR. In this research, we started from using a supervised classification tool, for example, the Mahalanobis Distance classification tool, to extract pixels at common visual "color" of the Gough Map. Then, Principal Component Analysis (PCA), Laplacian Eigenmap (LE) and unsupervised classification tools were used to analyze the similarity and differences between those pixels. Finally, we mapped the results back to the original image space for visual interpretation. Results showed that buildings, text and Hadrian's Wall on the Gough Map were created by different red pigments. This research provides evidence for historical geographers and cartographic historians on the methodology and timeline of creation of the Gough Map.

10198-49, Session 9

LAI retrieval and scale effect analysis of multiple crops from UAV-based hyperspectral data

Xiaohua Zhu, Lingling Ma, Yongguang Zhao, Key Lab. of Quantitative Remote Sensing Information Technology, CAS (China) and Academy of Opto-Electronics, CAS (China)

Leaf Area Index (LAI) is a key structural characteristic of crops and plays a significant role in precision agricultural management and farmland ecosystem modeling. However, LAI retrieved from different resolution data contain a scaling bias due to the spatial heterogeneity and model non-linearity, that is, there is scale effect during multi-scale LAI estimate. In this article, the typical farmland of Baotou test site in Inner Mongolia is taken as the study area, based on the combination of PROSPECT model and SAIL model, a multiple dimensional Look-Up-Table (LUT) is generated for multiple crops LAI estimation from unmanned aerial vehicle hyperspectral data. Based on Taylor expansion method and computational geometry model, a scale transfer model considering both difference between inter- and intra-class is constructed for scale effect analysis of LAI inversion over inhomogeneous surface. The results indicate that, 1) the LUT method based on classification and parameter sensitive analysis is useful for LAI retrieval of corn, potato, sunflower and melon on Baotou test site, with correlation coefficient R2 of 0.82 and root mean square error RMSE of 0.43m2/m-2. 2) The scale effect of LAI is becoming obvious with the decrease of resolution, and scale difference between inter-classes is higher than that of intra-class. which can be corrected efficiently by the scale transfer model established based Taylor expansion and Computational geometry.

10198-50, Session 9

The extraction of hazard bearing body of UAV image in coastal area based on minimum spanning tree

Wang Ping, Yang Fan, Wei Zheng, Zeng Jisheng, South China Sea Institute of Planning and Environment (China)

This paper proposes a multi-level image segmentation method based on the minimum spanning tree to identify the target of a specific rule object in order to extract the information of the hazard bearing bodies such as ships, fish rafts and hanging net in the coastal areas. The segmentation method is based on the statistical learning theory to define the optimal criterion of edge weight, and the scale control parameter is used to control the segmentation scale. The identification and extraction of different types of hazard bearing bodies can be realized by combining the characteristics of the texture, shape and regional spectrum of the hazard bearing bodies with the multi-level character description information provided by the multi-scale segmentation results. Based on the image of high resolution unmanned aerial vehicle (UAV) in the coastal areas, the method is applied to identify and extract the hazard bearing bodies such as ships, rafts and hanging nets. Experiments show that the multi-level image segmentation method based on the minimum spanning tree can effectively segment the texture area and get good regional boundaries. On the basis of the trained object model, the automatic recognition and accurate extraction of the target of hazard bearing bodies are realized.

10198-51, Session 9

Ultraspectral airborne measurements in support of satellite validation and Earth science applications

Allen M. Larar, Daniel K. Zhou, Xu Liu, NASA Langley Research Ctr. (United States); William L. Smith Sr., Univ. of Wisconsin-Madison (United States) and SSAI/LaRC (United States)

Measurement system validation is critical for advanced satellite sensors to achieve their full potential of improving observations of the Earth's atmosphere, clouds, and surface for enabling enhancements in weather prediction, climate monitoring capability, and environmental change detection. Field campaigns focusing on satellite under-flights with validation sensors aboard high-altitude aircraft are an essential part for satisfying the satellite measurement system validation task. The NASA Langley Research Center National Airborne Sensor Testbed – Interferometer (NAST-I) is a cross-track scanning Fourier Transform Spectrometer system that is frequently deployed aboard NASA aircraft as a key payload in validation and airborne science field campaigns. This presentation addresses benefits achieved from such airborne field campaigns with a specific focus on NAST-I results from recently conducted experiments in support of validation of the Cross-track Infrared Sounder (CrIS) aboard the Suomi NPP satellite.

Conference 10199: Geospatial Informatics, Motion Imagery, and Network Analytics VII

SPIE. DCS DEFENSE+ SECURITY

Wednesday 12–12 April 2017

Part of Proceedings of SPIE Vol. 10199 Geospatial Informatics, Fusion, and Motion Video Analytics VII

10199-1, Session 1

Background modeling with improved robustness to video compression artifacts

Larry Pearlstein, The College of New Jersey (United States); Alexander J. Aved, Air Force Research Lab. (United States)

One challenge in a video surveillance system is the data rate required to represent digital video. The raw data rate for a single stream of video is typically several Gbits/sec – far too high for carriage on most wireless links and even challenging for powerful cloud computing networks. Accordingly, the use of lossy video compression at a compression ratio of 100:1, or higher, is an essential part of any distributed live video system. Although very high compression ratios are frequently necessitated by system limitations, their use can introduce significant picture distortion.

Moving object detection is a key tool used in automated processing and enhancement of surveillance videos. Moving object detection is closely related to the problem of background modeling, which remains a challenging problem, where no single dominant solution currently exists.

In a recent paper we demonstrated how sophisticated methods for background modeling can be severely impacted by even small amounts of non-stationary distortion, which can be introduced by video compression. In this work we examine the root causes of the problem, and propose a robust algorithm for background modeling that outperforms currently available methods under a wide range of video compression artifacts. We focus particular attention on the application of moving object detection in surveillance videos, and we consider compression scenarios that are most applicable to the surveillance environment.

10199-3, Session 1

Pilot study on real-time motion detection in UAS video data by human observer and image exploitation algorithm

Jutta E. Hild, Wolfgang Krüger, Stefan Brüstle, Patrick Trantelle, Gabriel Unmüssig, Norbert Heinze, Michael Voit, Elisabeth Peinsipp-Byma, Fraunhofer-Institut für Optronik, Systemtechnik und Bildauswertung (Germany); Jürgen Beyerer, Fraunhofer-Institut für Optronik, Systemtechnik und Bildauswertung (Germany) and Karlsruher Institut für Technologie (Germany)

Real-time motion video analysis is a challenging and exhausting task for the human observer, particularly in safety and security critical domains. Hence, customized video analysis systems providing system functions for analysis subtasks like motion detection or target tracking are welcome. While such automated algorithms relieve the human operators from performing basic subtasks, they impose additional interaction duties on them. Prior work shows that, e.g., for interaction with target tracking algorithms, a gaze-enhanced user interface is beneficial [1, 2].

In this contribution, we present an investigation on interaction with a motion detection algorithm [3]. Besides identifying an appropriate interaction technique for the user interface – again, we compare gaze-based and traditional mouse-based interaction – we focus on the aspect of the presentation of motion detection results. This is an essential issue as, in state-of-the-art motion detection algorithms, there is a trade-off between correct detections and false positive detections. Hence, the visualized motion detection results might cause information overload or might be misleading for the human operator.

Our methodology is as follows. In a pilot study, we expose the subjects to the task of motion detection in UAS video data twice, once performing with automatic support, once performing without it. We compare the two conditions considering performance in terms of effectiveness and efficiency in finding relevant motion, and report perceived workload (measured using the NASA-TLX questionnaire) and user satisfaction.

[1] Hild, J., Krüger, W., Brüstle, S., Trantelle, P., Unmüßig, G., Heinze, N., Peinsipp-Byma, E., & Beyerer, J. (2015, May). Collaborative real-time motion video analysis by human observer and image exploitation algorithms. In SPIE Defense+ Security(pp. 94630C-94630C). International Society for Optics and Photonics.

[2] Hild, J., Krüger, W., Heinze, N., Peinsipp-Byma, E., & Beyerer, J. (2016, May). Interacting with target tracking algorithms in a gaze-enhanced motion video analysis system. In SPIE Defense+ Security (pp. 98410K-98410K). International Society for Optics and Photonics.

[3] 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.

10199-4, Session 1

Data transpositioning for content-based image retrieval

Michael Manno, Air Force Research Lab. (United States); Daqing Hou, Clarkson Univ. (United States); Erik Blasch, Air Force Research Lab. (United States)

Data Transpositioning is a search methodology that leverages the context of a previous manual search process, to formulate a new automated search. As a result, the data collection process for one situation, can quickly be applied to another situation, but with less user effort. Thus, a set of new results can quickly be constructed without the user manually revisiting each of the originating sources. Currently, when data is collected, it is usually collected for a specific need or situation. This includes text and image data. When a new need or situation arises, the data collection process repeats, often without referencing the original data collected for previous situations. In the case of Context-Based Image Retrieval, when attempting to identify an individual using facial recognition, it would be desirable to not only identify the images where the subject appears, but also to include additional searches to obtain other information about the subject as well, such as name, employment, and criminal record. Each data element may reside in a different database, webpage, or document. Therefore, for each subject, all of these searches can be performed to enhance the metadata that can be indexed with the image. Data Transpositioning attempts to use the original result set constructed from the original manual search, for future queries, by using an automated process that changes the search parameters for each source from the original result set, and producing a new data set without revisiting each of the originating sources.

10199-5, Session 1

An analysis of optical flow on real and simulated data with degradations

Joshua D. Harguess, Christopher M. Barngrover, Amin Rahimi, SPAWAR Systems Ctr. Pacific (United States); Peng Zhang, Space and Naval Warfare Systems Ctr. Pacific (United States)

Estimating the motion of moving targets from a moving platform is an extremely challenging problem in unmanned systems research. One common and often successful approach is to use optical flow for motion estimation to account for ego-motion of the platform and to then track the motion of surrounding objects. However, in the presence of video degradation such as noise, compression artifacts, and reduced frame rates, the performance of state-of-the-art optical flow algorithms greatly diminishes. We consider the effects of video degradation on two well-known optical flow datasets as well as on a real-world data collected from an unmanned system. To highlight the need for robust optical flow algorithms in the presence of real-world conditions, we present both qualitative and quantitative results on these datasets.

10199-6, Session 1

Geopositioning with a quadcopter: extracted feature locations and predicted accuracy without a priori sensor attitude information

John T. Dolloff, Bryant Hottel, David Edwards, Henry J. Theiss, Aaron Braun, Integrity Applications, Inc. (United States); Peter J. Doucette, U.S. Geological Survey (United States)

This paper presents an overview of the Full Motion Video Geopositioning Test Bed (FMV-GTB) developed to investigate algorithm performance and issues related to the registration of motion imagery and subsequent extraction of feature locations along with predicted accuracy. A case study is included corresponding to a video taken from a quadcopter. Registration of the corresponding video frames is performed without the benefit of a priori sensor attitude (pointing) information. In particular, tie points are automatically measured between adjacent frames using standard optical flow matching techniques from computer vision, an a priori estimate of sensor attitude is then computed based on supplied GPS sensor positions contained in the video metadata and a photogrammetric/search-based structure from motion algorithm, and then a Weighted Least Squares adjustment of all a priori metadata across the frames is performed. Extraction of absolute 3D feature locations, including their predicted accuracy based on the principles of rigorous error propagation, is then performed using a subset of the registered frames. Results are compared to known locations (check points) over a test site. Throughout this entire process, no external control information (e.g. surveyed points) is used other than for evaluation of solution errors and corresponding accuracy.

10199-7, Session 2

Using image quality metrics to identify adversarial imagery for deep learning networks

Joshua D. Harguess, SPAWAR Systems Ctr. Pacific (United States); Jeremy Miclat, Univ. of California, San Diego (United States); Julian Raheema, Space and Naval Warfare Systems Ctr. Pacific (United States)

Deep learning has continued to gain momentum in applications across many critical areas of research in computer vision and machine learning. In particular, deep learning networks have had much success in image classification, especially when training data is abundantly available, as is the case with the ImageNet project. However, several researchers have exposed potential vulnerabilities of these networks to carefully crafted adversarial imagery. Additionally, researchers have shown the sensitivity of these networks to some types of noise and distortion. In this paper, we investigate the use of no-reference image quality metrics to identify adversarial imagery and images of poor quality that could potentially fool a deep learning network or dramatically reduce its accuracy. Results are shown on several adversarial image databases with comparisons to popular image classification databases.

10199-8, Session 2

Methods for the specification and validation of geolocation accuracy and predicted accuracy

John T. Dolloff, Jacqueline S. Carr, Integrity Applications, Inc. (United States)

This paper presents recommended methods for the specification and validation of accuracy and predicted accuracy for a general geolocation system. Both accuracy and predicted accuracy are defined as probabilistic-based and relative to the error in a solution or extraction of an object's 3x1 geolocation, including the solution's a posterior 3x3 error covariance matrix if predicted accuracy. Accuracy is specified as a required upper bound for the XXth percentile of vertical, horizontal, and/or (3d) radial error, also termed Linear Error (LE_XX), Circular Error (CE_XX), and Spherical Error (SE_XX), respectively, with XX nominally equal to 90%. The validation of accuracy requirements is based on order statistics using independent samples of geolocation (radial) errors relative to a reference or "ground truth". No assumptions regarding the errors' underlying probability distribution is required or used, making the technique particularly robust. Predicted accuracy is specified as required bounds regarding the magnitude of independent samples of geolocation errors normalized by predicted radials at different probability levels, where the predicted radials are computed from the solution's error covariance matrix, and an approximate multi-variate Gaussian probability distribution is assumed. Validation of predicted accuracy consists of computing the percentage of normalized error samples meeting the bound requirements. The methods presented are practical yet theoretically rigorous. The effects of the number of error samples, with recommendations for their minimum, are included. The corresponding data used for the extractions are typically measurements of the object in commercial satellite imagery, although the recommended methods are applicable to most other sensor data as well.

10199-9, Session 2

Three dimensional scene construction from a two dimensional image

Franz Parkins, Eddie L. Jacobs, The Univ. of Memphis (United States)

We propose a method of constructing a three dimensional scene from a two dimensional image. The method is useful for the purpose of developing and augmenting world models or maps for autonomous navigation. Our solution to this ill posed problem is the construction of a 3D scene from its 2D projected image. It is an inverse problem of the mapping from a 2D plane of pixels into a 3D space of voxels requiring prior knowledge in order to infer about the voxel states. Three main approaches can be taken in addressing this problem, surface based, model based, and volumetric based. Our approach is volumetric and encompasses object recognition, segmentation, 3D pose estimation, and 3D scene construction. It is an adaptation of the Rother-Sapiro general framework which partitions 3D space into voxels and uses maximum likelihood estimation to infer about the pose of the object. More specifically, the crux of our method produces a probability that an individual voxel is occupied by a specified object. In this proposal we extend the Rother-Sapiro framework on a scene of 3D objects and implement it on embeddable hardware. The computations required by these methods are processor intensive but are parallelizable enough to implement on GPU hardware approaching the performance of a real time system. One of the main objectives of this research is to utilize the 3D scene construction in an imbedded environment where it may be used for navigation. The final solution will be deployed on the NVIDIA Tegra.

10199-10, Session 2

Correlation-agnostic fusion for improved uncertainty estimation in multi-view geo-location from UAVs

Clark N. Taylor, Air Force Research Lab. (United States); Paul Sundlie, Univ. of Dayton Research Institute (United States)

When geo-locating ground objects from a UAV, multiple views of the same object can lead to improved geo-location accuracy. Of equal import to the location estimate, however, is the uncertainty estimate associated with that location. Standard methods for estimating uncertainty from multiple views generally assume that each view represents an independent measurement of the geo-location.

Unfortunately, this assumption is often violated due to correlation between the location estimates. This correlation may occur due to the measurements coming from the same platform, during which the error in attitude or location may be correlated across time; or it may be due to external sources (such as GPS) having the same error in multiple aircraft. In either case, the geo-location estimates are not truly independent, leading to optimistic estimates of the geo-location uncertainty.

For distributed data fusion applications, correlation-agnostic fusion methods have been developed that can fuse data together regardless of how much correlation may be present between the two estimates. While the results are generally not as impressive as when correlation is perfectly known and taken into account, the fused uncertainty results will always be conservative. In this paper, we apply these correlation-agnostic fusion techniques to the multi-view geo-location problem and analyze their effects on geo-location and predicted uncertainty accuracy. When these results can be effectively applied, and when they do not yield great benefit to the user are both analyzed.

10199-11, Session 2

Quantifying sea ice with unmanned aerial vehicles

Johanna Hansen, Sos S. Agaian, The Univ. of Texas at San Antonio (United States)

This paper presents a framework for understanding sea ice observed from low altitude with a high-resolution camera mounted on an Unmanned Aerial Vehicle (UAV). The approach described is able to automatically build a map from a large set of sea ice images as well as describe ice types and concentration in the scene. This capability is crucial for

scientists trying to understand polar environments and for ships navigating in ice-laden waters. We first present our method for registering images into a mosaic and describe our techniques for determining overlapping regions in images which consist of nearly homogeneous scenes of solid ice or snow. We also evaluate several techniques for pixel classification including morphological operations, clustering, and superpixel calculations for hierarchical classification of

ice types. Finally, we present a technique which combines our knowledge of ice with machine learning techniques to improve performance without human intervention.

10199-12, Session 3

Geoparsing text for characterizing urban operational environments through machine learning techniques

Noah W. Garfinkle, U.S. Army Engineer Research and Development Ctr. (United States) and Univ. of Illinois at Urbana-Champaign (United States); Lucas Selig, Univ. of Illinois at Urbana-Champaign (United States) and U.S. Army Engineer Research and Development Ctr. (United States); Timothy K. Perkins, U.S. Army Engineer Research and Development Ctr. (United States)

Vast amounts of regionally-generated textual content (such as print and social media) introduce a new corpus for analysts seeking to understand the evolution of human activities across place and time. Existing techniques for extracting high-resolution locations from text geoparsing are often inadequate for informing Urban Operations (UO) in Areas of Interest (AOI) with foreign place names, where both gazetteers and named-entity recognition (NER) can benefit from regional customization through machine learning. Our research seeks to improve, integrate, and validate the NER models and place-resolution underpinning geoparsing, comparing performance with analyst-coding of violent events in print media.

10199-13, Session 3

A machine learning pipeline for automated registration and classification of 3D lidar data

Abhejit Rajagopal, Univ. of California, Santa Barbara (United States) and Toyon Research Corp. (United States); Karthik Chellappan, Toyon Research Corp. (United States); Shivkumar Chandrasekaran, Univ. of California, Santa Barbara (United States); Andrew P. Brown, Toyon Research Corp. (United States)

Despite the large availability of geospatial data, registration and exploitation of these datasets remains a persistent challenge in geoinformatics. Popular signal processing and machine learning algorithms, such as non-linear SVMs and neural networks, rely on well-formatted input models as well as reliable output labels, which are not always immediately available. In this paper we outline a pipeline for gathering, registering, and classifying initially unlabeled wide-area geospatial data. As an illustrative example, we demonstrate the training and testing of a convolutional neural network to recognize 3D models in the OGRIP 2007 LiDAR dataset using fuzzy labels derived from OpenStreetMap as well as other datasets available on OpenTopography.org. When auxiliary label information is required, various text and natural language processing filters are used to extract and cluster keywords useful for identifying potential target classes. A subset of these keywords are subsequently used to form multi-class labels, with no assumption of independence. Finally, we employ class-dependent geometry extraction routines to identify candidates from both training and testing datasets. Our regression networks are able to identify the presence of 15 structural classes, including roads, walls, and buildings, in volumes as big as 8000 m^3 in as little as 1.2 seconds on a commodity 4-core Intel CPU. The presented framework is neither dataset nor sensor-modality limited due to the registration process, and is capable of multi-sensor data-fusion. We conclude by offering some insights into neural network topologies suitable for exploiting GIS data.

10199-14, Session 3

General linear hypothesis test: a method for algorithm selection

Soundararajan Ezekiel, Indiana Univ. of Pennsylvania (United States); Larry Pearlstein, The College of New Jersey (United States); Michael Giansiracusa, Indiana Univ. of Pennsylvania (United States)

Algorithm selection is paramount in determining how to implement a process. When the results can be computed directly, an algorithm that reduces computational complexity is selected. When the results less binary there can be difficulty in choosing the proper implementation. Weighing the effect of different pieces of the algorithm on the final result can be difficult to find. In this research we propose using a statistical analysis tool known as General Linear Hypothesis to find the effect of different pieces of an algorithm implementation on the end result. This will be done with transform based image fusion techniques. This study will weigh the effect of different transforms, fusion techniques, and evaluation metrics on the resulting images. We will find the best no-reference metric for image fusion algorithm selection and test this method on multiple types of image sets. This assessment will provide a valuable tool for algorithm selection to augment current techniques when results are not binary.

10199-15, Session 3

Matrix sketching for big data reduction

Soundararajan Ezekiel, Michael Giansiracusa, Indiana Univ. of Pennsylvania (United States)

In recent years, the concept of Big Data has become a more prominent issue as the volume of data as well as the velocity in which it is produced exponentially increases. By 2020 the amount of data being stored is estimated to be 44 Zettabytes and currently over 31 Terabytes of data is being generated every second. Algorithms and applications must be able to effectively scale to the volume of data being generated. One such application designed to effectively and efficiently work with Big Data is IBM's Skylark. Part of DARPA's XDATA program, an open-source catalog of tools to deal with Big Data; Skylark, or Sketching-based Matrix Computations for Machine Learning is a library of functions designed to reduce the complexity of large scale matrix problems that also implements kernel-based machine learning tasks. Sketching reduces the dimensionality of matrices through randomization and compresses matrices while preserving key properties, speeding up computations. Matrix sketches can be used to find accurate solutions to computations in less time, or can summarize data by identifying important rows and columns. In this paper, we investigate the effectiveness of sketched matrix computations using IBM's Skylark versus non-sketched computations. We judge effectiveness based on several factors: computational complexity and validity of outputs. Initial results from testing with smaller matrices are promising, showing that Skylark has a considerable reduction ratio while still accurately performing matrix computations.

10199-16, Session 3

Double-density and dual-tree based methods for image super resolution

Soundararajan Ezekiel, Michael Giansiracusa, Indiana Univ. of Pennsylvania (United States)

When several low-resolution images are taken of the same scene, they often contain aliasing and differing sub-pixel shifts causing different focuses of the scene. Super-resolution imaging is a technique that can be used to construct high-resolution imagery from these low-resolution images. By combining images, high frequency components are amplified while removing blurring and artifacting. Super-resolution reconstruction techniques include methods such as the Nonuniform Interpolation Approach, which is low resource and allows for real-time applications, or the Frequency Domain Approach. These methods make use of aliasing in low-resolution images as well as the shifting property of the Fourier transform. Problems arise with both approaches, such as limited types of blurred images that can be used or creating non-optimal reconstructions. Many methods of super-resolution imaging use the Fourier transformation or wavelets but the field is still evolving for other wavelet techniques such as the Dual-Tree Discrete Wavelet Transform (DTDWT) or the Double-Density Discrete Wavelet Transform (DDDWT). In this paper, we propose a super-resolution method using these wavelet transformations for use in generating higher resolution imagery. We evaluate the performance and validity of our algorithm using several metrics, including Spearman Rank Order Correlation Coefficient (SROCC), Pearson's Linear Correlation Coefficient (PLCC), Structural Similarity Index Metric (SSIM), Root Mean Square Error (RMSE), and Peak-Signal-Noise Ratio (PSNR). Initial results are promising, indicating that extensions of the wavelet transformations produce a more robust high resolution image when compared to traditional methods.

10199-17, Session 3

Standardized acquisition, storing and provision of 3D enabled spatial data

Boris Wagner, Elisabeth Peinsipp-Byma, Sebastian Maier, Fraunhofer-Institut für Optronik, Systemtechnik und Bildauswertung (Germany)

In the area of working with spatial data, in addition to the classic, two-dimensional geometrical data (maps, aerial images, etc.), the needs for three-dimensional spatial data (city models, digital elevation models, etc.) is increasing.

Due to this increased demand the acquiring, storing and provision of 3D enabled spatial data in Geographic Information Systems (GIS) is more and more important. Existing proprietary solutions quickly reaches their limits during data exchange and data delivery to other systems. They generate a large workload and thus will be very costly. However, it is noticeable that these expenses and costs can generally be significantly reduced through the use of standards. The aim of this research is therefore to develop a concept in the field of three-dimensional spatial data that runs on existing standards whenever possible. In this research the military image analysts are the preferred user group of the system.

To achieve the objective of the widest possible use of standards in spatial 3D data, existing standards, proprietary interfaces and standards under discussion have been analyzed. Since the here used GIS of the Fraunhofer IOSB is already using and supporting OGC (Open Geospatial Consortium) and NATO-STANAG (NATO-Standardization Agreement) standards for the most part of it, a special attention for possible use was laid on their standards.

The most promising standard is the OGC standard 3DPS (3D Portrayal Service) with its occurrences W3DS (Web 3D Service) and WVS (Web View Service). A demo system was created, using a standardized workflow from the data acquiring, storing and provision and showing the benefit of our approach.

10199-18, Session 3

Concept for a common operational picture in a guidance vehicle

Ralf Eck, Florian van de Camp, Sebastian Maier, Elisabeth Peinsipp-Byma, Fraunhofer-Institut für Optronik, Systemtechnik und Bildauswertung (Germany)

A Common Operational Picture COP shows many operational aspects in coded form inside a geodata representation like a map. For building a COP a lot of specialized groups produce information. Beside the operating forces these are intelligence, logistics, or the own leaders planning group. Operations in which a COP is used are typically disaster management or military actions.

An existing software for Interactive Visualization of Integrated Geodata runs on Tablet-PCs, PCs, Digital Map Tables and video walls. It is already used by the Deutsche Führungsakademie (military academy) for the education of staff officers. Civil disaster management forces decided to use the Digital Map Table for their intelligence analysis.

In a mobile scenario, however, novel requirements have to be taken into account to adapt the software to the new environment. This paper investigates these requirements as well as the possible adaptions to provide a COP across multiple players on the go. When acting together, the groups do this in a widespread manner. They are physically spread, they use a variety of software and hardware to produce their contribution. This requires hardware to be ruggedized, mobile and to support a variety of interfaces. The limited bandwidth in such a setting poses the main challenge for the software which has to synchronize exchanging a minimum of information. Especially for mobile participants, a solution is planned that scales the amount of data (maps/intelligence data) to the available equipment, the upcoming mission, and the underlying theatre. Special focus is laid on a guidance vehicle leading a convoy.

10199-19, Session 3

Creation of 3D spatial information using unmanned aerial vehicle for calculation of volume

Jeong-Ho Yoon, Kyung-Jin Jeon, Jae-Jin Jeon, Korea Environment Institute (Korea, Republic of); Seong-Ha Lim, Don-Sun Lee, Korea Land and Geospatial Informatix Corp. (Korea, Republic of)

It has recently been considered important to fast capture and survey accurate 3D topographic information. In particular, the need for calculating the volume of 3D topographic space has been increasing in a range of fields. The present study used a fixed-wing UAV (Unmanned Aerial Vehicle) to capture the topography as 3D spatial information and calculate its volume. Pungdo, an island in Ansan Korea was selected as the target site, where the volume of the spot with soil and sand sediments was calculated with an UAV. As a rule, it is necessary to set a precise GCP (Ground Control Point) to minimize the errors in the course of calculating the volume as well as creating ortho-images by matching the images captured by an UAV. The present study set 4 GCPs and processed the captured image data with Photoscan Pro 1.2.4 before calculating the volume. To verify the accuracy of the proposed UAV-based volume calculation, the target site was measured with Terrestrial LiDAR. Then, the results were compared for analysis. Outpacing the existing methods in terms of the high accuracy of data and automated capturing of point data, the applications of Terrestrial LiDAR continue to expand. The calculated volumes were 17,082.05? and 16,933.79? based on the UAV and Terrestrial LiDAR, respectively, showing a negligible difference. In that the present findings indicate UAVs shorten the time taken to generate 3D topographic space and precise calculate its volume, such 3D spatial information seems applicable to diverse fields including environment, civil engineering, architecture and surveying.

Conference 10200: Signal Processing, Sensor/Information Fusion, and Target Recognition XXVI

Monday - Wednesday 10–12 April 2017

Part of Proceedings of SPIE Vol. 10200 Signal Processing, Sensor/Information Fusion, and Target Recognition XXVI

10200-1, Session 1

Tracking initially unresolved thrusting objects in 3D using a single stationary optical sensor

Qin Lu, Univ. of Connecticut (United States)

This paper considers the problem of estimating the 3D states of a salvo of thrusting/ballistic endo-atmospheric objects using 2D Cartesian measurements from the focal plane array (FPA) of a single fixed optical sensor. Since the initial separations in the FP are smaller than the resolution of the sensor there are merged FP measurements, compounding the usual false-alarm and missed-detection uncertainty. We present a two-step methodology. First, we assume a Wiener process acceleration (WPA) model for the motion of the images of the objects in the optical sensor's FPA. We model the merged measurements with increased variance, and thence employ a multi-Bernoulli (MB) filter using the 2D measurements in the FPA. Second, using the set of associated measurements for each confirmed MB track, we formulate a parameter estimation problem, whose maximum likelihood (MLE) solution can be obtained via numerical search and can be used for impact point prediction. Simulation results illustrate the performance of the proposed method.

10200-2, Session 1

Tracking two unresolved moving objects using ML-PMHT

Katherine Domrese, Peter Willett, Yaakov Bar-Shalom, Univ. of Connecticut (United States)

Optical sensors have a finite resolution, making it possible for moving objects in view of the sensors to be unresolved. A tracking algorithm that does not consider the possibility of unresolved (merged) measurements may yield poor results because it may not accurately detect a number of tracks equal to the number of moving objects observed. Several tracking algorithms including particle filtering, the Joint Probabilistic Data Association algorithm, the Nearest Neighbor Joint Probabilistic Data Association algorithm, and the Probabilistic Multi-Hypothesis Tracker (PMHT) have been extended to consider unresolved measurements. The Maximum Likelihood Probabilistic Multi-Hypothesis Tracker (ML-PMHT) is a batch algorithm that maximizes the target motion parameters' log-likelihood ratio based on the PMHT model and allows any number of measurements obtained at a point in time to be assigned to a single target. In this work, ML-PMHT is extended to handle the scenario of two unresolved moving objects in the field of gravity. To this end, the original ML-PMHT log-likelihood ratio is modified to use the probability that the objects being tracked are unresolved i.e., their measurements are merged. The performance of the modified ML-PMHT, which we denote ML-PMHT-M (M for merged) is compared with that of the original algorithm in a notional scenario in which two moving objects are initially unresolved from the point of view of two space-based passive sensors observing them. Results indicate that the ML-PMHT-M performs better than the ML-PMHT.

10200-3, Session 1

Passive ranging using signal intensity observations from a single fixed sensor

Kaipei Yang, Yaakov Bar-Shalom, Peter Willett, Ziv Freund, Ronen Ben-Dov, Univ. of Connecticut (United States)

Passive ranging has been widely used in modern defense system with its significant advantage of stealthiness. Bearings and Doppler-shift are the common measurements that can be used for localization solely or combined with other measurements. Works have validated that the trajectory of a remote target can be fully estimated using angle-only measurements with a maximum-likelihood (ML) estimator in certain conditions. In this paper, a passive ranging problem with elevation angle, azimuth angle and signal intensity measurements is presented. The signal intensity is inversely proportional to the squared distance between target and sensor. While a sensor network involving a large number of inexpensive sensors densely located will make signal intensity based target passive ranging possible and increase the observability, all measurements in this work are assumed to be obtained from a single fixed passive sensor. The observability is investigated through the Fisher Information Matrix (FIM) and Cramer-Rao lower bound (CRLB). The ML estimator is developed for the estimation of the initial condition of the target motion, which is assumed to be noiseless but influenced by the gravity. Target trajectory and the FIM are calculated in a numerical way as there is no explicit expression for them. The normalized estimation error squared (NEES) is used to evaluate the statistical efficiency with a suitable probability interval. Several scenarios with different measurement noise standard deviations are considered in simulations and the results prove the feasibility of passive ranging using signal intensity measurements from a single stationary passive sensor.

10200-4, Session 1

State estimators for tracking sharply-maneuvering ground targets

Radu S Visina, Yaakov Bar-Shalom, Peter K. Willett, Univ. of Connecticut (United States)

This paper presents an algorithm, based on the Interacting Multiple Model Estimator, that can be used to track the state of kinematic point targets, moving in two dimensions, that are capable of making sharp heading maneuvers over short periods of time, such as certain ground vehicles moving in an open field. The targets are capable of up to 60 °/s turn rates, while measurements are received at 1 Hz. We introduce the Non-Zero Mean, White Noise Turn-Rate IMM (IMM-WNTR) that consists of 3 modes based on a White Noise Turn Rate (WNTR) kinematic model that contains additive, white, Gaussian turn rate process noises. Two of the modes are considered maneuvering modes, and they have opposite (left/right), non-zero mean turn rate input noise. The need for non-zero mean turn rate process noise is explained, and Monte Carlo simulations compare this novel design to the traditional (single-mode) White Noise Acceleration Kalman Filter (WNA KF) and the two-mode White Noise Acceleration/Nearly-Coordinated Turn Rate IMM (IMM-CT). Results show that the IMM-WNTR filter achieves better accuracy and real-time consistency between expected error and actual error as compared to the (single-mode) WNA KF and the IMM-CT in all simulated scenarios, making it the best state estimator for targets with sharp coordinated turn capability in 2D.

10200-5, Session 1

Symmetrizing measurement equations for association-free multi-target tracking via point set distances

Ing Uwe D. Hanebeck, Karlsruher Institut für Technologie (Germany); Marcus Baum, Georg-August-Univ. Göttingen (Germany); Peter Willett, Univ. of Connecticut (United States)

No Abstract Available

10200-6, Session 1

Efficiency of sensor location and sensor number in simultaneous target state and sensor bias estimation

Michael Kowalski, Peter Willett, Univ. of Connecticut (United States); Timothy Fair, Toyon Research Corp. (United States)

This paper provides an analysis of several scenarios of target tracking state estimation when additionally estimating the biases of the measuring sensors in the state. Line of Sight (LOS) sensors are used with noisy data and angle biases that are unknown to the estimator. Efficiency is determined by comparing the determinant of the target state components in the Cramer-Rao Lower Bound (CRLB). Estimators with and without bias estimation are compared for accuracy in state estimation with biased sensors. The addition of new state components can potentially be a drawback to the estimator and this is addressed by comparing the accuracy of estimation with 2, 3, and 4 sensors. We analyze the efficiency of bias estimation and the importance of the sensor bias, noise variance, and sensor location on the effectiveness of bias estimation compared to non-bias state estimation.

10200-7, Session 2

'Stone Soup': An open source framework for tracking and state estimation

Paul A. Thomas, Defence Science and Technology Lab. (United Kingdom); Bhashyam Balaji, Defence Research and Development Canada (Canada); Kruger A. White, Defence Science and Technology Group (Australia); Matt Stapleton, AWE plc (United Kingdom)

The ability to detect and follow unambiguously all moving entities in a state-space is important in multiple domains ranging from the traditional defence (e.g. air surveillance, maritime situational awareness, ground moving target indication) to the less conventional (e.g. astronomy, biology, epidemiology, dispersion modelling). However, researchers and practitioners find difficulties recreating state-of-the-art algorithms in order to benchmark their own work. Also system developers need to assess which algorithms meet operational requirements objectively and exhaustively rather than intuitively and driven by personal favourites.

Therefore, this paper reports on the commencement of a collaborative initiative to create an Open Source framework for evaluation of Tracking and State Estimation algorithms. The initiative will develop an open-source (Apache 2 or MIT license) software platform for researchers and practitioners to test, verify and benchmark a variety of multi-sensor and multi-object state estimation algorithms. The initiative is supported by a number of defence and government laboratories, who will contribute to the development effort for the framework.

The tracking and state estimation community will derive significant benefits from this work, including: access to repository of tracking and state estimation algorithms, framework for evaluation of multiple algorithms, standardisation of interface and access to challenging data sets.

10200-8, Session 2

Absolute space-based sensor registration using a single target of opportunity

Djedjiga Belfadel, Fairfield Univ. (United States); Yaakov Bar-Shalom, Peter Willett, Univ. of Connecticut (United States)

Bias estimation for multiple passive sensors using common targets of opportunity has been researched extensively. However, the proposed solutions required the use of multiple (two or more) passive sensors. In order to remove this constraint, we provide in this paper a new methodology using a single exoatmospheric target of opportunity seen in a single satellite borne sensor's field of view to estimate the sensor's biases simultaneously with the state of the target. The satellite is equipped with an optical sensor that provides the Line Of Sight (LOS) measurements of azimuth and elevation to the target. The evaluation of the Cramer-Rao Lower Bound (CRLB) on ´ the covariance of the bias estimates, and the statistical tests on the results of simulations show that this method is statistically efficient.

10200-9, Session 2

Sensor scheduling with probability of detection and tracking accuracy constraints

Peter J. Shea, Evan Oman, Black River Systems Co. (United States); Chee-Yee Chong, Consultant (United States)

A key element of most sensor resource management (SRM) problems is the scheduling of tasks to sensors at specific time slots. At its core, the SRM problem takes a set of pre-defined mission objectives and formulates them as an optimization problem which solves this scheduling problem. At a high-level this scheduling problem can be represented in a form that closely resembles a three-dimensional assignment problem with the dimensions corresponding to tasks, sensors, and time. The primary challenges then become the formulation and solution of this optimization problem.

Our approach for formulation of this problem associates information needs with mission objectives that are conditioned upon the current situational understanding. These information needs are incorporated into the optimization problem as constraints, rather than taking a more traditional approach that generates multiple separate tasks that are individually capable of satisfying a specific information need. This methodology allows for more flexibility in the formulation of the optimization problem and allows the scheduling algorithms to optimize across a larger set of possible tasks.

Once formulated, our solution approach uses a Lagrangian relaxation based approach that relaxes these constraints into the objective function and solves a two-dimensional multi-assignment problem via an auction like approach.

In this paper, we will describe a general formulation of the problem and provide examples of the conversion of information needs for a goal probability of detection and tracking accuracy into problem constraints. In addition, we will describe our scheduling approach based upon Lagrangian relaxation before presenting some preliminary results

10200-10, Session 2

Information theoretic SRM scoring that incorporates adversary understanding

Peter J. Shea, Nathan Nasgovitz, Black River Systems Co. (United States)

A key element in sensor management and sensor scheduling problems is the development of accurate score values for task to sensor to time assignment. Previous work on this topic has used information theoretic scoring measures such as information gain. However most work has focused on only the impact from the perspective of the collection platform while ignoring adversary capabilities. By ignoring the enemy understanding of the situation, sensor tasking decisions may be made that maximize the collection of information in the short run at the expense of the long-term potential damage of the sensing platform.

We have developed an approach that incorporates an adversary estimate into our task scoring methodology. We accomplish this by creating a joint state that combines both our understanding of the situation and an estimate of the adversary's understanding of the situation. This leads to a situation where we make sensing decisions that maximize our knowledge while minimize our adversary's understanding.

This paper will describe our approach for incorporating adversary information with our own collections within an information theoretic approach. Additionally we will present some preliminary results from simulated data sets.

10200-11, Session 3

Tracking correlated, simultaneously evolving target populations, part II

Ronald P. S. Mahler, Random Sets, LLC (United States)

This paper is the sixth in a series aimed at weakening the independence assumptions that are typically presumed in multitarget tracking. Earlier papers investigated Bayes filters that propagate the correlations between two evolving multitarget systems. Last year at this conference we attempted to derive PHD filter-type approximations that account for both spatial correlation and cardinality correlation (i.e., correlation between the target numbers of the two systems). Unfortunately, this approach required heuristic models of both clutter and target appearances in order to incorporate both spatial and cardinality correlation. This paper describes a fully rigorous approach, provided that spatial correlation between the two populations is ignored and only their cardinality correlations are taken into account. We derive the time-update and measurement-update equations for a CPHD filter describing the evolution of such correlated multitarget populations.

10200-12, Session 3

On multitarget pairwise-Markov models, part II

Ronald P. S. Mahler, Random Sets, LLC (United States)

This paper is the seventh in a series aimed at weakening the independence assumptions that are typically presumed in multitarget tracking. Two years ago at this conference, we initiated an exploratory analysis of general multitarget pairwise-Markov (MPMC) systems, which weaken the multitarget Markov assumption. Based on this analysis, we derived an exploratory CPHD filter for MPMC systems. Unfortunately, this approach relied on heuristic models in order to incorporate both spatial and cardinality correlation between states and measurements. This paper describes a fully rigorous approach, provided that only cardinality correlation is taken into account. We derive the time-update and measurement-update equations for a CPHD filter describing the evolution of such an MPMC system.

10200-13, Session 3

On CPHD filters with track labeling

Ronald P. S. Mahler, Random Sets, LLC (United States)

The random finite set (RFS) approach to information fusion addressed target track-labeling from the very start. Because of computational concerns, the first implementations of RFS filters did not do so. Subsequent implementations, e.g., the Gaussian mixture CPHD filter, addressed labels heuristically. The labeled RFS (LRFS) theory of B.-T. Vo and B.-N. Vo was the first systematic, theoretically rigorous formulation of true multitarget tracking, and led to the development of the generalized labeled multi-Bernoulli (GLMB) filter and its approximations. After surveying heuristic labeled CPHD filters, this paper investigates rigorous approaches. The following are shown: (a) The probability generating functional (p.g.fl.) of any LRFS has a simple characterization. (b) A CPHD filter based on labeled i.i.d.c. RFS's is computationally infeasible. (c) Exact time-update equations and approximate measurement-update equations for a "labeled CPHD" (LCPHD) filter are derived. They propagate a labeled spatial distribution and, instead of the usual cardinality distribution, a "label distribution" on the label-sets of the LRFS.

10200-14, Session 3

Particle flow superpositional GLMB filter

Augustin Saucan, Yunpeng Li, Mark Coates, McGill Univ. (Canada)

The majority of multi-object tracking algorithms in the literature are designed for the so-called standard measurement model, where sensor measurements are preprocessed into point observations. Preprocessing is usually non-adaptive, as opposed to the tracking algorithm, and thus incurs a loss of information. The alternative of processing directly the sensor measurements proves to be challenging due to the highly non-linear and superpositional measurement model, i.e., the sensor measurement is the sum of individual object/target contributions. Many sensors generate superpositional measurements, including acoustical amplitude sensors, radio frequency tomography and radar/sonar phased arrays.

The delta-GLMB is a principled filter for track estimation that is capable of estimating the tracks made by a varying number of targets. In this paper, we propose and derive a particle flow particle filter delta-GLMB filter for superpositional measurement models. Particle filter implementations are preferred due to the non-linear measurement function. Additionally, particle flow is employed to produce a measurement-driven importance distribution that serves as a proposal in the delta-GLMB particle filter. The flow is capable of driving samples into regions where the posterior is significant. This is in contrast with the bootstrap particle filter delta-GLMB, that employs the prior as the proposal distribution and suffers from particle degeneracy for state systems with highly informative measurements or with a high-dimensional state space. Indeed, particle flow links the prior and posterior distributions through a log-homotopy and uses partial differential equations to migrate prior particles toward the posterior distribution. Numerical simulations conducted on non-linear and superpositional measurement models highlight the improved performance of the proposed filter.

10200-15, Session 4

Event induced bias in label fusion

Christine M. Schubert Kabban, Alexander M. Venzin, Mark E. Oxley, Air Force Institute of Technology (United States)

In a two class label scenario, classification systems may be used to assess whether or not an element of interest belongs to the "target" or "non-target" class. The performance of the system is summarized visually as a trade-off between the proportions of elements correctly labeled as "target" plotted against the proportion of elements incorrectly labeled as "target."

These proportions are empirical estimates of the true and false positive rates, and their trade-off plot is known as a receiver operating characteristic (ROC) curve. Classification performance can be increased, however, if the information provided by multiple systems can be fused together to create a new, combined system. This research focuses on label-fusion as a common method to increase classification performance and quantifying the bias that occurs when misspecifying the partitioning of the underlying event set. This partitioning will be defined in terms of what be called within and across label fusion. When incorrect assumptions are made about the partitioning of the event set, bias will occur and both the ROC curve and its optimal parameters will be incorrectly quantified. In this work, we analyze the effects of individual classification system performance, correlation, and target environment on the magnitude of this performance bias. This work will then inspire the development of formulas to adjust optimal performance measures to appropriately reflect the fused system performance according to event set partitioning. As such, bias may be appropriately adjusted without redesigning the fused system, allowing greater use of currently fused systems across multiple platforms and environments.

10200-16, Session 4

Fusion within a classification system family

Mark E. Oxley, Christine M. Schubert Kabban, Air Force Institute of Technology (United States)

A detection system outputs two distinct labels. Thus, there are two errors it can make. The Receiver Operating Characteristic (ROC) function quantifies both of these errors as parameters vary within the system. Combining two detection systems typically yields better performance when a combination rule is chosen appropriately. When multiple detection systems are combined, the assumption of independence is usually made in order to mathematically combine the individual ROC functions for each system into one ROC function. This paper investigates label fusion and feature fusion of a single detection system family. Given that one knows the ROC function for each individual detection system, we seek a formula with the resultant ROC function of the fused detection systems as a function (specifically, a transformation) of the respective ROC functions. In this paper we derive this transformation for a certain class of feature rules. An example will be given that demonstrates this transformation. We show how this can be extended to multiple-label classification system family (CSF) involving its ROC manifold. Examples will be given that demonstrates these ideas and the corresponding transformation acting on the ROC manifold

10200-17, Session 4

Generalized Gromov method for stochastic particle flow filters

Frederick E. Daum, Jim Huang, Arjang Noushin, Raytheon Co. (United States)

We derive the optimal covariance matrix of the diffusion in stochastic particle flow for nonlinear filters, using Gromov's method to solve linear underdetermined PDEs, as well as using renormalization group flow borrowed from QFT (quantum field theory). Particle filters generally suffer from the curse of dimensionality owing to particle degeneracy. The purpose of particle flow is to mitigate the problem of particle degeneracy in particle filters. Particle flow moves the particles to the correct region in state space corresponding to Bayes' rule. The flow is from the prior probability density to the posteriori probability density. Particle flow is similar to Monge-Kantorovich transport, but it is much simpler and much faster to compute in real time, because we avoid solving a variational problem. Our transport of particles is not optimal in any sense, but rather it is designed to provide good estimation accuracy and good UQ for a given computational complexity. In contrast to almost all papers on transport theory, we use non-zero diffusion in our particle flow corresponding to Bayes' rule. This talk shows how to compute the best covariance matrix for such diffusion, using several optimization criteria (most stable flow, least stiff flow, robust UQ, best estimation accuracy, etc.). We derive a simple explicit formula for the optimal diffusion matrix.

10200-18, Session 4

Numerical experiments for Gromov's stochastic particle flow

Frederick E. Daum, Jim Huang, Arjang Noushin, Raytheon Co. (United States)

We derive a new stochastic particle flow for nonlinear filters using Gromov's method of solving linear underdetermined PDEs and QFT. Gromov is one of the very few mathematicians who use and respect underdetermined PDEs, whereas most mathematicians do not even consider such PDEs because they are so simple and hence they are beneath contempt. Obviously this is an ill-posed problem by textbook definitions. Gromov's method is like a miracle, because it requires that the number of unknowns be sufficiently large compared with the number of equations plus the dimension of x; this sounds crazy, but it works (see pages 148 to 149 of Gromov's 1986 book and pages 40 to 43 in Gromov's paper on Nash (9 Oct. 2015) for details). An early intimation of this miracle is given in our paper, "exact particle flow for nonlinear filters: seventeen dubious solutions to a first order linear underdetermined PDE," Proceedings of Asilomar Conference, November 2010. We need to invoke renormalization group flow, an idea borrowed from quantum field theory (QFT). This is to avoid the numerical problems due to normalization of the conditional probability density of the state, as explained in Daum & Huang (2015).

10200-19, Session 4

Quantum electrodynamics for quantum sensing: An introductory overview for engineers

Bhashyam Balaji, Defence Research and Development Canada (Canada)

Quantum electrodymanics is the physical theory of charged particles and their interactions via the exchange of photons. In this paper, a brief overview of aspects of quantum electrodynamics relevant to the development of emerging, novel sensors is provided in a manner is easily understandable to the wider engineering community. In particular, no deep knowledge of quantum mechanics or quantum field theory is assumed. A few examples of gain from quantum electrodynamics that illustrate the substantial gain in sensing that is made possible by the exploitation of quantum physics effects is provided. Some aspects of challenges in practical implementation are discussed.

10200-20, Session 4

Quantum detection theory: An introduction

Bhashyam Balaji, Defence Research and Development Canada (Canada)

Classical detection theory is based on classical probability theory. Futhermore, it makes assumptions that are valid only macroscopically. Quantum detection theory recasts classical detection and estimation theory that assumes that the world is described by quantum physics. A brief overview of quantum detection theory, from the pioneering work of Helstrom, is provided. A couple of illustrative examples are provided. Some remarks on challenges of practical realizability of the optimal quantum detectors is presented and a few popular sub-optimal, but practical detectors are provided.

10200-21, Session 5

Data fusion in entangled networks of quantum sensors

Marco O. Lanzagorta, U.S. Naval Research Lab. (United States); Jeffrey Uhlmann, Univ. of Missouri (United States); Oliverio Jitrik, The Rankin Institute (Mexico)

Sensor networks offer improved performance through the use of data fusion algorithms that combine the data from the different nodes to provide optimal target information. On the other hand, quantum sensors are devices that harness quantum phenomena to increase their sensing performance. While sensor fusion and quantum sensors are two active areas of research, their interaction has usually being ignored. In this paper we will describe new theoretical approaches to design entangled quantum networks of quantum sensors. Our radical idea is to treat each quantum sensor state as an evolving qubit in a quantum computer, and then perform amplitude amplification algorithms before the measurements are done. The use of non-local operations to manipulate the entanglement in the sensor network is used to amplify the response of the overall network. In other words, the network becomes a quantum computer where the physical interaction to be measured acts as a quantum oracle.

10200-22, Session 5

A framework for adaptive MaxEnt modeling within distributed sensors and decision fusion for robust ATR

Ivan Kadar, Interlink Systems Sciences, Inc. (United States); Robert W. Schutz, Consultant (United States)

No Abstract Available

10200-23, Session 5

Summary of cyber-physical systems challenges with information fusion

Erik Blasch, Air Force Research Lab. (United States); Ivan Kadar, Interlink Systems Sciences, Inc. (United States); Lynne L. Grewe, California State Univ., East Bay (United States); Wei Yu, Towson Univ. (United States); Richard R. Brooks, Clemson Univ. (United States); Andres Kwasinski, Rochester Institute of Technology (United States); Hairong Qi, The Univ. of Tennessee Knoxville (United States); Stelios C. A. Thomopoulos, National Ctr. for Scientific Research Demokritos (Greece)

Cyber-Physical Systems consist of and depend on the close interaction and integration of the cyber, computational systems, and physical systems. Computational systems can include but are not limited to sensing and computer systems. The Physical can be anything from the human to animal and plants as well as man-made systems. A key part of today's needed development in CPS involves creating new capabilities, adaptability, higher scalabilities, usability as well as security and proficiency. Goals are to create new ways for people and the physical world to be part of and communicate with Cyber-Physical Systems. The objective of this panel was to bring to the attention of the fusion community the importance of the application of Cyber Physical Systems, highlighting issues, illustrating potential approaches and addressing challenges.

10200-24, Session 5

Graph-theoretic information fusion in autonomous heterogeneous resource management

Georgiy M. Levchuk, Aptima, Inc. (United States)

No Abstract Available

10200-26, Session 6

A comparison of synthesis and integrative approaches for meaning making and information fusion

Laurie H. Fenstermacher, Robert Eggleston, Air Force Research Lab. (United States)

No Abstract Available

10200-27, Session 6

Mitigating randomness of consumer preferences under certain conditional choices

Stelios C. A. Thomopoulos, John M. A. Bothos, Giorgos K. Thanos, National Ctr. for Scientific Research Demokritos (Greece)

Agent-based crowd behaviour consists a significant field of research that has drawn a lot of attention in recent years. Agent-based crowd simulation techniques have been used excessively to forecast the behaviour of larger or smaller crowds in terms of certain given conditions influenced by specific cognition models and behavioural rules and norms, imposed from the beginning.

Our research employs conditional event algebra, statistical methodology and agent-based crowd simulation techniques in developing a behavioural econometric model about the selection of certain economic behaviour by a consumer that faces a spectre of potential choices when moving and acting in a multiplex mall.

More specifically we try to analyse the influence of demographic, economic, social and cultural factors on the economic behaviour of a certain individual and then we try to link its behaviour with the general behaviour of the crowds of consumers in multiplex malls using agent-based crowd simulation techniques. We then run our model using Generalised Least Squares and Maximum Likelihood methods to come up with the most probable forecast estimations, regarding the agent's behaviour.

Our model is indicative about the formation of consumers' spectre of choices in multiplex malls under the condition of predefined preferences and can be used as a guide for further research in this area.

10200-28, Session 6

Sensor data monitoring and decision level fusion scheme for early fire detection

Stelios C. A. Thomopoulos, Constantinos Rizogiannis, Giorgos K. Thanos, Dimitris M. Kyriazanos, National Ctr. for Scientific Research Demokritos (Greece)

The aim of this paper is to present the sensor monitoring and decision level fusion scheme for early fire detection that has been developed in the

context of the AF3 Advanced Forest Fire Fighting European FP7 research project, adopted specifically in the OCULUS-Fire control & command system and tested during a firefighting field test in Greece with prescribed real fire, generating early-warning detection alerts and notifications. For this purpose and in order to improve the reliability of the fire detection system, a two-level fusion scheme is developed exploiting a variety of observation solutions from air e.g. UAV infrared cameras, ground e.g. meteorological and atmospheric sensors and ancillary sources e.g. public information channels, citizens smartphone applications and social media. At the first level, a change point detection technique is applied to detect changes in the mean value of each measured parameter by the ground sensors such as temperature, humidity and CO2 and then the Rate-of-Rise of each changed parameter is calculated. At the second level the fire event Basic Probability Assignment (BPA) function is determined for each ground sensor using Fuzzy-logic theory. The corresponding mass values are then combined in a decision level fusion process using Evidential Reasoning theory to estimate the final fire event probability.

10200-29, Session 6

Fire detection and incidents localization based on fusion of public information channels and social media

Stelios C. A. Thomopoulos, Giorgos K. Thanos, Katerina Skroumpelou, Constantinos Rizogiannis, Dimitris M. Kyriazanos, Alkiviadis Astyakopoulos, National Ctr. for Scientific Research Demokritos (Greece)

In this paper a solution is presented aiming to assist the early detection and localization of a fire incident by exploiting crowdsourcing and unofficial civilian online reports. It consists of two components: (a) the potential fire incident detection and (b) the visualization component. The first component comprises of two modules that run in parallel and aim to collect reports posted on public platforms and derive conclusions about potential fire incident locations by fusing the information from the two information channels. The first module collects public reports, distinguishes reports that refer to a potential fire incident, and stores the corresponding information in a structured way. The second module aggregates all these stored reports and concludes about the probable location of a fire incident based on the amount of reports per area, the time and location of these reports. Furthermore, the aggregation result is entered into a fusion module that combines it with information collected by field sensors, if available, in order to provide a more accurate fire event detection capability. The visualization component is a fully operational public information channel which provides accurate and up-to-date information about active and past fires, raises awareness about forest fires and the relevant hazards among citizens. The channel has visualization capabilities for presenting in an efficient way information regarding detected fire incidents, fire expansion areas, and relevant information such as detecting sensors and reporting origin. The paper concludes with the insight to end user current CONOPS with regards to the inclusion of the proposed solution to the current CONOPS of fire detection.

10200-30, Session 6

Dempster Shafer theory in the context of Grothendieck topologies *(Invited Paper)*

Joseph J. Peri, Johns Hopkins Univ. Applied Physics Lab., LLC (United States)

No Abstract Available

10200-52, Session PSTue

Speaker identification for the improvement of the security communication between law enforcement units

Jaromir Tovarek, VŠB-Technical Univ. of Ostrava (Czech Republic)

This article discusses the speaker identification for the improvement of the security communication between law enforcement units. Tha main task of this research was to develop the text-independent speaker identification system which can be used for real-time recognition. This system is designed for identification in the open set. It means that the unknown speaker can be anyone. Communication itself is secured, but we have to check the authorization of the communication parties. We have to decide if the unknown speaker is the authorized for the given action. The calls are recorded by IP telephony server and then these recordings are evaluate using classification If the system evaluates that the speaker is not authorized, it sends a warning message to the administrator. This message can detect, for example a stolen phone or other unusual situation. The administrator then performs the appropriate actions. Our novel proposal system uses multilayer neural network for classification and it consists of three layers (input layer, hidden layer, and output layer). A number of neurons in input layer corresponds with the length of speech features. Output layer then represents classified speakers. Artificial neural network classifies speech signal frame by frame, but the final decision is done over the complete record. This rule substantially increases accuracy of the classification. Input data for the neural network are a thirteen Mel-frequency cepstral coefficients, which describe the behavior of the vocal tract. These parameters are the most used for speaker recognition. Parameters for training, testing and validation were extracted from recordings of authorized users. Recording conditions for training data correspond with the real traffic of the system (sampling frequency, bit rate). The main benefit of the research is the system developed for text-independent speaker identification which is applied to secure communication between law enforcement units.

10200-53, Session PSTue

Deformable patch-based NCC tracker

Yu Xianguo, Yu Qifeng, Shang Yang, Liu Xiaochun, National Univ. of Defense Technology (China)

In this paper we propose a tracking by matching approach based on a new image similarity measurement. The image is represented by a set of overlapping patches. The similarity between two images are then modeled by the similarity between their corresponding patches. Instead of accumulating all similarity scores directly, we propose to combine them in a deformable way to account for image deformations. The patch similarity is evaluated by a modified Normalized Cross Correlation (NCC) measure. In the experiment, we will show that the proposed similarity measure is robust to complex illumination changes as well as partial occlusions. For online tracking, we keep a template for each patch and update it by linear interpolation. We propose two different methods to implement the idea. A traditional method is to randomly select several patches at the initialization stage as many local based approaches. We additionally introduce the dense NCC map which is a compact representation of all patch templates of the same size. Tracking with the dense NCC map is simply a sliding window process. The experiment on challenging image sequences demonstrate that the proposed algorithm is effective and efficient.

10200-54, Session PSTue

Decision-level fusion of SAR and IR sensor information for automatic target detection

Young-Rae Cho, Sung-Hyuk Yim, Hyun-Woong Cho, Pohang Univ. of Science and Technology (Korea, Republic of); Jin-Ju Won, Yeungnam Univ. (Korea, Republic of); Woo-Jin Song, Pohang Univ. of Science and Technology (Korea, Republic of); So-Hyeon Kim, Agency for Defense Development (Korea, Republic of)

We propose a decision-level fusion of synthetic aperture radar (SAR) and an infrared (IR) target detector to reduce false alarm rate. The proposed scheme involves Boolean-Map-Visual Theory- (BMVT) based target detection, target-shape map generation, basic belief assignment, and decision-level fusion stages. The soft outputs of the BMVT target detector on SAR and IR sensor images are used to assign the belief mass based on Dempster-Shafer theory. The hard outputs of BMVT for individual sensors are combined to build a target-shape map to prevent huge objects from being detected erroneously. Belief masses of the two sensors are fused using Dempster's rules of combination. We integrate target-shape map and fusion mass on the decision-level fusion stage. The proposed algorithm was evaluated on pairs of SAR/IR images generated using SE-WORKBENCH simulator. The SAR and IR images in each pair have the same view and the same size of 0.5 km x 0.4 km. The decision-level fusion method achieved high detection rate and reduced the number of false alarms. On average, the BMVT target detector achieved 100% detection rate and 211 false alarms per image in SAR images, and 96% detection rate and 197 false alarms per image in IR images. The proposed fusion algorithm achieved 100% detection rate and 10 false alarms per image. Because of this large reduction in false alarm rate with high detection rate, the proposed algorithm is a significant improvement over single-sensor method.

10200-55, Session PSTue

Development of a variable structure-based fault detection and diagnosis strategy applied to an electromechanical system

Stephen A. Gadsden, Univ. of Guelph (Canada); Thia Kirubarajan, McMaster Univ. (Canada)

Signal processing techniques are prevalent in a wide range of fields: control, target tracking, telecommunications, robotics, fault detection and diagnosis, and even stock market analysis, to name a few. Although first introduced in the 1950s, the most popular method used for signal processing and state estimation remains the Kalman filter (KF). The KF offers an optimal solution to the estimation problem under strict assumptions. Since this time, a number of other estimation strategies and filters were introduced to overcome robustness issues, such as the smooth variable structure filter (SVSF). In this paper, the SVSF is combined with the interacting multiple model (IMM) strategy in an effort to improve detection and diagnosis of faults in an electromechanical system. The results are compared with the KF method, and future work is discussed.

10200-56, Session PSTue

Classifier fusion for VoIP attacks classification

Jakub Safarik, CESNET z.s.p.o. (Czech Republic)

SIP is one of the most successful protocols in the field of IP telephony communication. It establishes and manages VoIP calls. As the number of SIP implementation rises, we can expect a higher number of attacks on the communication system in near future. This work aims at malicious SIP traffic classification. A number of various machine learning algorithms have been developed for attack classification. The paper presents a comparison of current research and the use of classifier fusion method leading to a potential decrease in classification error rate. Use of voting ensembles of classifiers makes a more robust solution to difficulties that may affect single techniques. Different voting schemes, combination rules, and classifiers are discussed to improve the overall performance. All classifiers have been trained on real malicious traffic. The concept of traffic monitoring depends on the network of honeypot nodes. These honeypots run in several networks spread in different locations. Separation of honeypots allows us to gain an independent and trustworthy attack information.

10200-57, Session PSTue

The synthesis of the correlation function of pseudorandom binary numbers at the output shift register

Gennady G. Galustov, Southern Federal Univ. (Russian Federation); Viacheslav V. Voronin, Don State Technical Univ. (Russian Federation)

The sequence generator generates a sequence of pseudorandom binary numbers using a linear-feedback shift register (LFSR). This block implements LFSR using a simple shift register generator (SSRG, or Fibonacci) configuration. In this article we introduce the concept of probabilistic binary element provides requirements, which ensure compliance with the criterion of "uniformity" in the implementation of the basic physical generators uniformly distributed random number sequences. Based on these studies, we obtained an analytic relation between the parameters of the binary sequence and parameters of a numerical sequence with the shift register output. The received analytical dependencies can help in evaluating the statistical characteristics of the processes in solving problems of statistical modeling. It is supposed that the formation of the binary sequence output from the binary probabilistic element is produced using a physical noise process. It is shown that the observed errors in statistical modeling using pseudo-random numbers do not occur if the model examines linear systems with constant parameters, but in case models of nonlinear systems, higher order moments can have a Gaussian distribution.

10200-58, Session PSTue

Use of SIMAC algorithm in potassium line visible missile warning system

Joel B. Montgomery, Catherine Montgomery, M&M Aviation (United States); Eduardo Gutierrez, International Technologies Transfer SAS (Colombia)

M&M Aviation has been working to solve the tactical and strategic missile warning problem for over 20 years. We have worked with UV and mid-IR systems until 2003. During 2005, the Visible Missile Warning concept was brought forth as an attempt to increase the range and performance over current and developmental UV systems, but contain the purchase and life-cycle costs associated with the imaging mid-IR systems. For the past 13 years, extensive work and testing has allowed for transition programs which use the potassium line doublet for detection and discrimination. The associated processing chain has also evolved to accommodate the increase in number of pixels and frame rates. It has been shown that the K-line systems can even detect small arms fire are greater than 3km, while keeping the false alarm rate at a very low level. In this paper we will describe the use of the Spectral Independent Morphological Adaptive Filter (SIMAC) algorithm and it's work in K-line warning sensors. The sensor systems and associated algorithm chain will be shown from a detection through declaration standpoint. We will also discuss the various countermeasure techniques that could be used and potential mitigation. Finally we will discuss future commercial applications.

10200-59, Session PSTue

A bootstrapped PMHT with feature measurements

Qin Lu, Katherine Domrese, Peter Willett, Yaakov Bar-Shalom, Krishna Pattipati, Univ. of Connecticut (United States)

The probabilistic multiple-hypothesis tracker (PMHT), a tracking algorithm of considerable theoretical elegance based on the expectation-maximization algorithm, will be considered for the problem of multiple target tracking with multiple sensors in clutter. Aside from position observations, continuous measurements associated with the unique and constant feature of each target are incorporated to jointly estimate the states and features of the targets for the sake of tracking and classification, leading to a bootstrapped implementation of the PMHT. In addition, we rederived the information matrix for the stacked state vector, consisting of states for all targets at all time steps during the observation time. Simulation results have been conducted for both closely spaced and well separated scenarios with and without feature measurements. It demonstrated that incorporating feature measurements can significantly decrease the track loss rate for closely spaced tracks and provide consistent normalized estimation error squared (NEES) for both scenarios by directly utilizing the covariances from the Kalman smoother, which lead to inconsistent NEES without feature measurements in previous work.

10200-60, Session PSTue

Airburst height computation method of sea impact test

Jinho Kim, Hyungsup Kim, Sungwoo Chae, Sungho Park, Agency for Defense Development (Korea, Republic of)

In general, the height of burst could be calculated by applying the triangulation using two cameras. The cameras should capture explosion images of weapon systems. Some development tests could not use enough powder for explosion. In this case, high speed digital camera (HSDC) might not gather the images of burst. Infrared (IR) camera would be operated to get images of explosion, but the TSPI data could not be computed by using only two infrared cameras because of the calibration problems of IR cameras.

The proposed method is to operate both two HSDC cameras and one IR camera. By using two HSDC cameras, TSPI data could be obtained and compute some results such as velocity, flight attitude and the impact position. In IR images, the relative position from explosion to impact might be calculated. The distance from IR camera to impact position could be computed. However there might be difference between explosion and impact distance from IR camera. This could be result in large errors. Therefore, the computation way is proposed to compensate the distance differences by using TSPI data from HSDC.

10200-61, Session PSTue

Dynamic date association for multi-sensor using self-organizing FNN in clutter

Chi-Shun Hsueh, National Chung-Shan Institute of Science and Technology (Taiwan)

In this paper, improving data association process by increasing the probability of detecting valid data points (measurements obtained from ESM/radar system) in the presence of noise for location and target tracking are discussed. We develop a multi-sensor data association algorithm that fuses information from the multiple ESM receiver and surveillance radar. The proposed novel algorithm is based on self-organizing fuzzy neural network (SO-FNN) for multiple ESM-to-ESM (measurement –to-measurement data association) and ESMs-to-radar (track to track data association) problem in dense clutter environment. An adaptive search based on self-organizing fuzzy neural network (SO-FNN) of the distance threshold measure is then used to detect valid filtered data point for data association. Simulation results demonstrate the effectiveness and better performance when compared to conventional algorithm. The paper is organized as follows. Section 2 is the problem formulation. Section 3 design the new data association algorithm based on self-organizing fuzzy neural network (SO-FNN) data association system design. Section 4 describes ESM-to-ESM (measurement–to-measurement data association) and ESMs-to-radar (track to track data association) scenario and the simulation results are presented and discussed. The summary is drawn in section 5, respectively.

10200-62, Session PSTue

Design and implementation of intelligent electronic warfare decision making algorithm

Hsin-Hsien Peng, National Chung-Shan Institute of Science and Technology (Taiwan)

Electromagnetic signals and the requirements of timely response have been a rapid growth in modern electronic warfare. Although jammers are limited resources, it is possible to achieve the best electronic warfare efficiency by tactical decisions. In this paper, we present an implementation of intelligent electronic warfare making algorithm. In this work, we develop a novel hybrid algorithm based on Particle Swarm Optimization (PSO), Ant Colony Optimization (ACO) and Shuffled Frog Leaping Algorithm (SFLA). We use PSO to solve the problem and combine the concept of pheromones in ACO to accumulate more useful information in spatial solving process and speed up finding the optimal solution. The proposed algorithm finds optimal solution in a reasonable computational time by using the method of matrix transformation in SFLA. The results indicated that jammer allocation was more effective. The system based on the hybrid algorithm provides electronic warfare commanders with relevant information to effectively manage the complex electromagnetic battlefield.

10200-63, Session PSTue

Survey of commercial off the shelf (COTS) software for multisensor data fusion: 2017 edition

Sonya A. H. McMullen, Embry-Riddle Aeronautical Univ. (United States); Mac J. McMullen, U.S. Air Force, Retired (United States); David Ison, Patti J. Clark, Embry-Riddle Aeronautical Univ. (United States)

This paper is next in a series of updates of a survey of commercial off the shelf (COTS) data fusion applications that was first conducted by D. Hall and R. Linn in 1993. The survey was then updated by R. Sherry and S. Hall in 2002 and again by R. Sherry, S. McMullen, and S. Miglani in 2009 for M. Liggins, D. Hall, and J. Llinas (editors) 2009 Handbook of Multisensor Data Fusion: Theory and Practice, Second Edition. The original survey presented available tools for the development of sensor fusion applications for predominately defense applications such as automated target recognition, identification-friend-foe-neutral processing, and battlespace surveillance (McMullen, Sherry, & Miglani, 2009). The survey set forth a framework describing available tools for signal and image processing, statistical estimation, and expert system prototyping. In the two decades since that original paper was published, desktop computing, sensors, analysis, and collaboration tools have evolved dramatically opening a variety of applications far exceeding the original envisioned use of data fusion for defense problems. Capabilities such as data mining, pattern recognition, and knowledge discovery (McMullen, Sherry, & Miglani, 2009) employ tools such as Matlab and Mathematica, as well as tools specifically for qualitative

analysis that could be used for soft-sensor data. The rapid developments in hardware and software capabilities as well as emerging applications, prompt the desire to update this survey.

10200-34, Session 7

Computational intelligence-based optimization of maximally stable extremal region segmentation for object detection

Jeremy Davis, Amy E. Bednar, Christopher T. Goodin, Phillip J. Durst, U.S. Army Engineer Research and Development Ctr. (United States); Derek T. Anderson, Cindy L. Bethel, Mississippi State Univ. (United States)

Particle swarm optimization (PSO) and genetic algorithms (GAs) are two optimization techniques from the field of computational intelligence (CI) for search problems that are considered intractable. One such problem is finding an optimal set of parameters for the maximally stable extremal region (MSER) algorithm to detect areas of interest in imagery. Specifically, this paper describes the design of a GA and PSO for optimizing the five MSER parameters to detect stop signs in imagery produced via simulation for use in an autonomous vehicle navigation system. Several additions to the GA and PSO are required to successfully detect stop signs in simulated images. These additions are a primary focus of this paper and include: the identification of an appropriate fitness function, the creation of a variable mutation operator for the GA, an anytime algorithm modification to allow the GA to compute a solution quickly, the addition of an exponential velocity decay function to the PSO, the addition of an "execution best" omnipresent particle to the PSO, and the addition of an attractive force component to the PSO velocity update equation. Experimentation was performed with the GA using various combinations of selection, crossover, and mutation operators and experimentation was also performed with the PSO using various combinations of neighborhood topologies, swarm sizes, cognitive influence scalars, and social influence scalars.

The results of both the GA and PSO optimized parameter sets are presented. This paper details the benefits and drawbacks of each algorithm in terms of detection accuracy, execution speed, and additions required to generate successful problem specific parameter sets.

10200-35, Session 7

Video processing with the knapsack problem

Trevor Cook, Kevin Chan, U.S. Army Research Lab. (United States)

To increase the effectiveness of video surveillance in tactical networks, we present dynamic programming approaches to maximize quality of information stored on sensor devices given: constraints of storage, energy, and processing power; uncertainty in network conditions; and several methods of extracting useful information from the sensor feed. We consider the situation of a sensor generating a video feed, and which sporadically connects to a tactical network to upload data. Given enough time between uplinks, the ability of the sensor to create data inevitably outstrips the capacity to store the data. There are many techniques for compressing data, including video compression, key frame grabbing, and even sophisticated algorithms for detecting specific types of objects and behaviors. Application of these algorithms have different energy costs, storage savings, and will ultimately effect mission effectiveness depending on the particulars of the mission's requirements for information. Bringing together these diverse concerns into a cohesive model is a complicated problem. We present a model and solution based on the ubiquitous Knapsack Problem. The model is presented as a series of several refinements, each of which introduces further capability, but at the cost of computational complexity which is quantified in terms of the knapsack size. Despite the increased sophistication and complexity of our model, we demonstrate improved or maintained mission effectiveness in certain situations through simulation.

10200-36, Session 7

Optimized static and video EEG rapid serial visual presentation (RSVP) paradigm based on motion surprise computation

Deepak Khosla, David J. Huber, Rajan Bhattacharyya, HRL Labs., LLC (United States)

In our previous work, we introduced COGNIVA, a system for intelligent and rapid search and extraction of "items of interest" (IOI) in video that was developed by combining a saliency-based attention front-end followed by a static image RSVP presentation paradigm and neural decoding to extract and confirm potential IOI, respectively. However, since in many real-world applications, moving IOI are of greater importance, e.g., a dismount or vehicle moving in desert or mountain terrain, it was apparent that the performance of the RSVP could be improved by tuning the system to specialize in detecting moving objects more accurately. This paper describes improvements to our prior system, which was performed by computing a motion surprise map on image sub-regions (chips) of incoming sensor video and then using the surprise maps to label the chips as static or moving. The system then uses a static or video RSVP presentation and decoding algorithm depending on the chip label to optimize EEG based detection in the chips. Thus, it specifically improves upon moving IOI detection and in the process improves static IOI detection as well because it uses RSVP presentation and decoding method (tuned to whether the IOI is static or moving (via separate static and video EEG classifiers)). The motion detection applies only a small additional calculation to that base algorithm, which allows it to be mapped to hardware that conforms to low size, weight, and power constraints.

10200-37, Session 7

Visual attention distracter insertion for improved EEG RSVP target stimuli detection

Deepak Khosla, David J. Huber, Kevin Martin, HRL Labs., LLC (United States)

Most surveillance imagery is visually analyzed by humans to search for "Objects of Interest" (OI) (e.g., targets and suspicious activity in videos from wide field-of-view sensors, UAV drones, satellite imagery, etc.). This work is manual, slow and could miss objects of interest. To overcome these limitations, there has been a surge of interest in developing and using automated computer algorithms and software to aid or/and emulate human visual perception in imagery analysis, present likely targets to a human operator by using RSVP, and decode the human's EEG signal to identify targets via the P300 response. We have previously proposed various RSVP image ordering algorithms for rapid threat search and detection. However, while these algorithms help and perform reasonably well, they are still limited in performance by the threat/distractor ratio. It is well known though not completely understood that humans experience both attentional blink and repetition blindness when searching for OIs in a target rich RSVP. Most work in the area of attentional blink and repetition blindness has been focused on understanding the underlying causes rather than taking advantage of the known effects to insert distractors to optimize detection. The method that we describe in this paper is shown to improve an operator's overall target detection capability when utilizing EEG RSVP stimuli containing an abundance of targets. This method performs better than existing methods by significantly reducing the chance of an operator experiencing attentional blink and repetition blindness, which results in missed threat detections.

10200-38, Session 7

Integrating visual learning within a model-based ATR system

Mark J. Carlotto, General Dynamics Mission Systems (United States)

Automatic target recognition (ATR) systems, like human photo-interpreters, rely on a variety of visual information for detecting, classifying, and identifying manmade objects in aerial imagery. We describe the integration of a visual learning component into the Image Data Conditioner (IDC) for target/clutter and other visual classification tasks. The component is based on an implementation of a model of the visual cortex developed by Serre, Wolf, and Poggio. Visual learning in an ATR context requires the ability to recognize objects independent of location, scale, and rotation. Our method uses IDC to extract, rotate, and scale image chips at candidate target locations. A bootstrap learning method effectively extends the operation of the classifier beyond the training set and provides a measure of confidence. We show how the classifier can be used to learn other features that are difficult to compute from imagery such as target direction, and to assess the performance of the visual learning process itself.

10200-39, Session 7

Enhancing vector shoreline data using a data fusion approach

Mark J. Carlotto, General Dynamics Mission Systems (United States)

Vector shoreline (VSL) data is potentially useful in ATR systems that distinguish between objects on land or water. Unfortunately available data such as the NOAA 1:250,000 World Vector Shoreline and NGA Prototype Global Shoreline data cannot be used by themselves to make a land/water determination because of the manner in which the data are compiled. We describe a data fusion approach for creating labeled VSL data using test points from Global 30 Arc-Second Elevation (GTOPO30) data to determine the direction of vector segments; i.e., whether they are in clockwise or counterclockwise order. We show consistently labeled VSL data be used to easily determine whether a point is on land or water using a vector cross product test.

10200-40, Session 8

Road following for blindBike: an assistive bike navigation system for low vision persons

Lynne L. Grewe, William Overell, California State Univ., East Bay (United States)

blindBike is a system that uses cyberphysical techniques to assist in the process of bicycle driving and navigation for people with low vision. We propose that with the assistance of blindBike it may be possible for those with low vision to be mobile at a new level. However, blindBike can also be assistive to those with normal vision. Through the use of today's smartphones, the blindBike app can affordably assist with navigation and Road Following. The work described here focuses on the important tasks of Road Following and navigation.

blindBike uses the vision sensor on an Android smartphone, in addition to Text to Speech, accelerometer, location services, wireless connectivity on the smart- phone and web services. blindBike uses these sensors to assist the user in biking from point A to point B. This thesis focuses on the task of Road Following but, also, we discuss how route planning and navigation are performed. Computer vision techniques along with mapping are used to solve these problems, combined with an understanding of geographical constraints. A scene labeling approach initiates the vision analysis and continues with determination of the road and finding the bike appropriate right side of the road. Statistical modeling approaches are used and special attention is given to performance needs. Road following will determine what action if any the user should take to stay appropriately located (right side) in the road and on route. Speech recognition and text-to-speech are employed. Results are presented on real data and future work is explored.

10200-41, Session 8

Traffic light detection and intersection crossing using mobile computer vision

Lynne L. Grewe, Christopher Lagali, California State Univ., East Bay (United States)

This work discusses the problem of Intersection Detection and Crossing to support the task of assisted biking for the visually impaired. This work along with a road following application make up the BlindBike system. Traffic light detection and intersection crossing are key needs in the task of biking. These problems are tackled through the use of mobile computer vision, in the form of a mobile application on an Android phone. This research builds on previous Traffic Light detection algorithms with a focus on efficiency and compatibility on a resource-limited platform. Light detection is achieved through blob detection algorithms utilizing training data to detect patterns of Red, Green and Yellow in complex real world scenarios where multiple lights may be present. Also, issues of obscurity and scale are addressed.

Safe Intersection crossing in BlindBike is also discussed. This module takes a conservative "assistive" technology approach. To achieve this we use not only the Android device but, an external bike cadence Bluetooth/Ant enabled sensor. Fine location sensing on Android devices is not possible and the Intersection crossing mode is developed to handle this fact through the use of the cadence sensor. Also, this work focuses on efficiency, detection accuracy and the impact of operating conditions. Real world testing results are given and future work is discussed.

10200-42, Session 8

Utilization-based object recognition in confined spaces

Amir Shirkhodaie, Durga P. Telagamsetti, Azin Poshtyar, Tennessee State Univ. (United States); Alex L. Chan, U.S. Army Research Lab. (United States)

Recognizing substantially occluded objects in confined spaces is a very challenging problem for ground-based persistent surveillance systems. In this paper, we discuss the ontology inference of occluded object recognition in the context of in-vehicle group activities (IVGA) and describe an approach that we refer to as utilization-based occluded object recognition method. We examine the performance of three types of classifiers tailored for the recognition of partially occluded objects, namely, (1) invariant shape classifiers, (2) convolutional neural network classifiers, and (3) Hamming network classifiers. In order to train these classifiers, we have generated multiple imagery datasets containing a mixture of common objects appearing inside a vehicle with full or partial visibility and occultation. To generate dynamic interactions between multiple people, we model the IVGA scenarios using a virtual simulation environment, in which a number of simulated actors may perform a variety of IVGA tasks independently or jointly. This virtual simulation engine produces the much needed imagery datasets for the verification and validation of the efficiency and effectiveness of the selected object recognizers. Finally, we improve the performance of these object recognizers by incorporating human gestural information that differentiates various object utilization or handling methods through the analyses of dynamic human-object interactions (HOI), human-human interactions (HHI), and human-vehicle interactions (HVI) in the context of IVGA.

10200-43, Session 8

Joint object and action recognition via fusion of partially observable surveillance imagery data

Amir Shirkhodaie, Tennessee State Univ. (United States); Alex L. Chan, U.S. Army Research Lab. (United States)

Partially observable group activities (POGA) occurring in confined spaces are epitomized by their limited observability of the objects and actions involved. In many POGA scenarios, different objects are being used by human operators for the conduct of various operations. In this paper, we present an opportunistic technique for joint object and action recognition based on association and correlation of utilized objects in actions and their corresponding human postural sequences, as we can see in partially observable scenarios captured in surveillance imagery data. Inspired by mutual information theory, we treat this problem as two random variables, which are object observation and human posture observation. Initially, the class association of each random variable is probabilistically determined. Then a measure is constructed for the mutual dependence between these two random variables, by which the association and correlation between them are determined. A Modified Conditional Random Field (MCRF) technique is proposed as a classifier that can take context into account in predicting plausible sequences of actions for a set of sequential imagery observations. The proposed MCRF reveals relationships between joint random variables and construct consistent interpretations of their joint sequential observations. To generate the needed imagery data set for the training and testing of newly developed algorithms, a virtual simulation model is employed for dynamic animation of high fidelity scenarios representing in-vehicle group activities under different operational contexts. The results of our comparative investigation are discussed and presented in detail.

10200-45, Session 8

Designing observer trials for image fusion experiments with Latin Squares

Gabriele Schwan, Eckart Michaelsen, Norbert Scherer-Negenborn, Fraunhofer-Institut für Optronik, Systemtechnik und Bildauswertung (Germany)

Multisensor image fusion is the process of combining relevant information from two or more images (e.g. IR and visual) into a single image. Numerous image fusion algorithms have been developed with varying advantages and limitations for different scenarios. The task is to find the best one for the respective use. 1) One may estimate the quality of fused imagery by a representative set of human observers. 2) One may define a quality measure for fused imagery mathematically, and code it for automatic application. While the first solution reveals the best result for the observers, it is very time consuming and cannot be repeated often. The second solution can be used often with very low effort, but the quality measure, which is used, must be found and verified at least once with a human observer trial. This paper aims at the design of such an observer trial for finding the algorithm correlating best with the human observer assessment.

Representative data and a considerable large number of algorithms are required. Representative means the set of test-images should be sufficiently large. Since the number of available observers and the number of trials per observer is restricted, enumerating all combinations for each observer is impossible. Nevertheless maximal exactness and reliability of the results is desired. One possibility is in sampling the combinatorial space using the Monte Carlo algorithm. However there are better alternatives: This paper follows R. Fisher's Design of Experiments approach based on Latin Squares and compares this approach with the Monte Carlo approach.

10200-46, Session 9

All-optical signal processor for protection against electromagnetic weapons

Alastair D. McAulay, Lehigh Univ. (United States)

No Abstract Available

10200-47, Session 9

Multi-ball and one-ball geolocation

Douglas J. Nelson, Jeffrey L. Townsend, National Security Agency (United States)

We present refinements of several of the methods we have previously reported for geolocation of electromagnetic emissions from a single moving receiver. These methods are based on the observation that pseudo TDOA and FDOA may be estimated from the frequency history of the transmitted signal. To accomplish this, we first prove that propagation delay (TOA) may be recovered from the received signal frequency (FOA.) FOA estimation and tracking is accomplished using cross-spectral methods that provide extremely accurate frequency tracking. TOA estimation and tracking is accomplished by integration of the instantaneous FOA polynomial. Geolocation is accomplished by first computing the expected propagation times and Doppler frequency offsets for a grid of possible emitter locations and the receiver ephemerides. The grid coordinate that minimizes the error variances between the predicted propagation delay and the measured TOA and the predicted Doppler offset and the measured FOA is determined to the nearest grid location to the emitter. Iteration at finer grid resolutions refines the geoloaciton. This method is demonstrated to be superior to conventional TDOA/FDOA CAF-plane geolocation.

In developing this geolocation method, several problems were addressed. In particular, cross-spectral frequency estimation and tracking methods were developed to track the frequencies of signals as short as 25 milliseconds with less than one Hz error. Based on the same cross-spectral principle, a cross-spectral cross-correlation function was developed providing up to two orders of magnitude better accuracy than the conventional cross-correlation function. Finally a polynomial approximation function robust to noise and outliers was developed to estimate and track frequency.

10200-48, Session 9

Impact of signal scattering and parametric uncertainties on receiver operating characteristics

D. Keith Wilson, Daniel J. Breton, U.S. Army Engineer Research and Development Ctr. (United States); Chris L. Pettit, U.S. Naval Academy (United States)

The receiver operating characteristic (ROC curve), which is a plot of the probability of detection vs. the probability of false alarm, plays a key role in the classical analysis of the performance of a detector. However, meaningful characterization of the ROC curve can become surprisingly challenging when practically important complications such as variations in source emissions, environmental impacts on the signal propagation, uncertainties in the sensor response, and multiple sources of interference are considered. In this paper, we consider a relatively simple but realistic statistical model for scattered signals to explore how parametric uncertainties can severely alter the ROC curve. In particular, since operation with a very low probability of false alarm and high probability of detection is normally desired, the tails of the signal and noise distributions are very important. We show that parametric uncertainties in quantities such as the mean signal and noise power substantially raise the tails of the distributions, which leads to severely degraded ROC curves. Because full a priori knowledge of such parametric uncertainties is rarely available in practice, analyses must

typically be based on a finite number of environmental states and model predictions, which only partially sample the parameter distributions. We show how this effect further degrades the ROC curve and can provide misleading assessments of system performance. For the cases considered, approximately 16 or more statistically independent sample predictions are needed to accurately predict the ROC curve.

10200-49, Session 9

Radar target classification using compressively sensed features

Ismail I. Jouny, Lafayette College (United States)

The paper focuses on extracting scattering centers of radar targets using compressive sensing. It has been shown that a target's high range resolution profile (HRRP) is sparse in time corresponding to few scatterers that can be associated with target geometry. Compressive sensing helps in identifying those scatterers. Recorded returns using a stepped-frequency radar system are thus compressively sampled, and scattering centers are extracted for an unknown target. Those are features used for target classification by comparison with catalogued features of all possible targets (four in this paper). The recognition system is tested using real radar data recorded in a compact range. Scenarios where the target aspect angle is unknown or known to be within a certain range are examined. Also, situations where the target zero-time reference is known a priori are examined. Scenarios where extraneous scatterers are present along the target are also investigated. The classifier performance is measured as the probability of error versus signal-to additive noise ratio. Classification is carried out using distance based non-parametric techniques and correlation based techniques. Decision-theoretic maximum likelihood classifiers are used when possible for comparison purposes.

10200-50, Session 9

Multi-sensor field trials for detection and tracking of multiple small unmanned aerial vehicles flying at low altitude

Martin Laurenzis, Sebastien Hengy, Institut Franco-Allemand de Recherches de Saint-Louis (France); Alexander Hommes, Fraunhofer-Institut für Hochfrequenzphysik und Radartechnik (Germany); Frank Kloeppel, Fraunhofer Institute for High Frequency Physics and RADAR Techniques (Germany); Alex Shoykhetbrod, Fraunhofer-Institut für Hochfrequenzphysik und Radartechnik (Germany); Thomas Geibig, Winfried Johannes, Fraunhofer Institute for High Frequency Physics and RADAR Techniques (Germany); Pierre Naz, Frank Christnacher, Institut Franco-Allemand de Recherches de Saint-Louis (France)

Small unmanned aerial vehicles (UAV) flying at low altitude are becoming more and more a serious threat in civilian and military scenarios. In recent past, numerous incidents have been reported where small UAV were flying in security areas leading to serious danger to public safety or privacy. In this context, the detection and tracking of small UAV is a widely discussed topic. Especially, small UAV flying at low altitude in urban environment or near background structures and the detection of multiple UAV at the same time is a challenge for state of the art detection technologies.

In the recent past, field trials were carried out to investigate the detection and tracking of multiple UAV flying at low altitude. Here, we present results which were achieved using a heterogeneous sensor network consisting of acoustic antennas, small FMCW RADAR systems and optical sensors. While acoustics and RADAR was applied to monitor a wide azimuthal area (360°) and to simultaneously track multiple UAV, optical sensors were used for sequentially identification with a very narrow field of view.

10200-51, Session 9

Statistics-based filtering for low signal-to-noise ratios, applied to rocket plume imaging

Harald Hovland, Norwegian Defence Research Establishment (Norway)

Extracting image information with low signal to noise ratios poses significant challenges. Noise makes extracting spatial features difficult, in particular extracting large, smooth features as well as point-like features. This work describes a dual statistics approach, able to handle both simultaneously.

The basic idea is that each pixel value represents underlying statistics.

One probability distribution function uses the mean value taken from the individual pixel, and the distribution being either an a priori one based on sensor properties, the single-parameter Poisson distribution, or using the measured temporal pixel statistics. The second distribution is built up using the value distribution of the pixel and a given number of neighboring pixels, for simplicity assumed to be part of a normal distribution. The number of neighboring pixels should be sufficiently small that significant differences between a pixel value and those of its neighbors affect the distribution's standard deviation.

The filter output pixel value is given as the mean value of the product of the (normalized) two probability distributions. It is shown that in the case of a significant spread of the neighboring pixel values, or a significant difference between the pixel and its neighbors, the filtered pixel value approaches that of the unfiltered pixel value, whereas for a more even distribution, the pixel value is drawn closer to the neighboring pixel values. The calculus becomes particularly simple when both probabilities are normal distributions.

As an example, the technique is applied to imaging rocket plumes in the deep ultraviolet range.

Conference 10201: Algorithms for Synthetic Aperture Radar Imagery XXIV

Thursday 13–13 April 2017

Part of Proceedings of SPIE Vol. 10201 Algorithms for Synthetic Aperture Radar Imagery XXIV

10201-1, Session 1

Analysis of speckle and material properties in Laider Tracer

Jacob Ross, AFRL/RYAT (United States); Brian D. Rigling, Wright State Univ. (United States); Edward A. Watson, Univ. of Dayton Research Institute (United States)

The SAL simulation tool Laider Tracer models speckle: the random variation in intensity of an incident light beam across a rough surface. Within Laider Tracer, the speckle field is modeled as a 2-D array of jointly Gaussian random variables projected via ray tracing onto the scene of interest. Originally, all materials in Laider Tracer were treated as ideal diffuse scatterers, for which the far-field return computed uses the Lambertian Bidirectional Reflectance Distribution (BRDF). As presented here, we implement material properties into Laider Tracer via the Nonconventional Exploitation Factors Data System: a database of BRDF values for 400 different materials sampled at various wavelengths and incident angles. We verify the intensity behavior as a function of incident angle after material properties are added to the simulation.

10201-2, Session 1

Airborne synthetic aperture radar online image display with georectification and geocoding

Manikandan Samykannu, Chhabi Nigam, Vardhini J.P., Ramakrishnan S., Defence Research and Development Organisation (India)

In civil and defense applications, airborne Synthetic Aperture Radar (SAR) faces major problem in the SAR image georectification and geocoding, when SAR is applied in large-scale scene and the airborne platform faces large changes due to non linearities. Conventional SAR image formation algorithms assume straight line flight with constant speed, and fixed antenna beam pointing which leads to more geocoding errors in real time. The different sources of errors include deviation of sensor flight path in both translational as well as rotational undesirable motion because of atmospheric turbulence, high altitude winds, or other causes. The translational motion error gives rise to unequal spatial sampling of the acquired SAR raw data, target-to-SAR range errors; which corresponds to the phase error in the SAR signal phase history. The rotational motion error contributes to the antenna beam pointing error. Across track and altitude velocity errors affect the rate of change of slant range and introduce azimuthal position errors. Hence, the geocoding of the SAR image will be become difficult and it is performed offline in most of the airborne SAR. The objective is to display the real time airborne SAR image with georectification and geocoding with reduced positional error irrespective of the platform either manned or unmanned. Sub Aperture based SAR processing, adaptive velocity calculation, Overlapping of pulses, Doppler centroiding, image mosaicing with respect to the aircraft heading, radar geometry, aircraft positional information are considered in this proposed technique to display the SAR image in real time on screen with reduced geocoding errors.

10201-3, Session 1

Deep learning for synthetic aperture image formation

Eric Mason, Bariscan Yonel, Birsen Yazici, Rensselaer Polytechnic Institute (United States)

The recent success of deep learning has lead to interest in applying these methods to develop improved algorithms for solving inverse problems. The application of these methods to inverse problems presents many challenges beyond those typically considered in supervised learning problems. In this paper we focus on SAR imaging, explore the challenges and capabilities associated with using deep learning. We first present a recurrent auto-encoder network architecture based on iterations of the iterative shrinkage thresholding algorithm to define the layers of the network. We then present an off line training method using stochastic gradient descent. We show experimentally that this results in significantly faster convergence and decreased reconstruction error when the learned parameters are used in the iterative shrinkage algorithm

10201-4, Session 1

Closed-form mismatched filter synthesis for complementary range response

Thomas Bell, Technology Service Corp. (United States)

The combined response of a pair of complementary waveforms has zero range sidelobes and could significantly improve synthetic aperture radar (SAR) image quality by reducing multiplicative noise. However, complementary waveforms may not be practical for SAR imaging for reasons such as Doppler tolerance and unimodular waveform constraints. By using mismatched filters to achieve either a complementary or near-complementary response, two or more practical waveforms could be employed and SAR image quality improved. A closed-form approach was developed that calculates mismatched filters so that the coherent sum of the range responses from each waveform and its corresponding mismatched filter is complementary. A second approach reduced sidelobes while retaining a frequency response close to the waveforms' frequency responses. Images processed using X-band radar data collected under the Air Force Gotcha program exhibited improvements in image quality over those processed using matched filters. The closed-form approach is presented for both complementary and reduced-sidelobe mismatched filters and image quality is quantified. The approach developed in this work offers improved image quality, is suitable for near real-time operation, and is independent of the waveforms.

10201-5, Session 1

Extraction of advanced geospatial intelligence (AGI) from commercial synthetic aperture radar imagery

Berkay Kanberoglu, David H. Frakes, Arizona State Univ. (United States)

The extraction of objects from advanced geospatial intelligence (AGI) products based on synthetic aperture radar (SAR) imagery is complicated by a number of factors. For example, accurate detection of temporal changes represented in two color multiview (2CMV) AGI products can be challenging because of speckle noise susceptibility and false positives that result from small orientation differences between objects imaged at different times. These cases of apparent motion can result in 2CMV

detection, but they obviously differ greatly in terms of significance. In investigating the state-of-the-art in SAR image processing, we have found that differentiating between these two general cases is a problem that has not been well addressed. We propose a framework of methods to address these problems. Before object detection, speckle and smoothing filters are used to attenuate the effects of speckle noise. For the detection of the temporal changes while reducing the number of false positives, we propose using 1) adaptive object intensity and area thresholding and 2) relaxed brightness optical flow algorithms that track the motion of objects across time in small regions of interest. Optical flow fields have been effective for removing difficult false positives that result from registration and perspective problems. The proposed framework for distinguishing between actual motion and misregistration can lead to more accurate and meaningful change detection and improve object extraction from a SAR AGI product (2CMV imagery). Results demonstrate the ability of our techniques to reduce false positives up to 60%.

10201-6, Session 1

Experimental fidelity/computation tradeoffs for SAR simulation

Stephen Rosencrantz, Air Force Research Lab. (United States); Emma Sum, Wright State Univ. (United States)

No Abstract Available

10201-7, Session 1

Using field extrapolation to improve the fidelity of SAR simulation

John Nehrbass, Stephen Rosencrantz, Air Force Research Lab. (United States); Emma Sum, Wright State Univ. (United States)

No Abstract Available

10201-8, Session 1

High performance computing strategies for SAR image experiments

Michael A. Saville, David Short, Wright State Univ. (United States); Jeremy Trammell, John P. Kaufhold, Deep Learning Analytics, LLC (United States)

This article presents different strategies for generating very large sets of SAR phase history and imagery for target recognition studies using the open-use Raider Tracer simulation tool. Previous data domes, based on Visual D, produced numerous data sets for ground targets above a flat surface, but each target had a single orientation. Here, the experiment specifies different target types, each above a ground plane, but with arbitrary pose, yaw, and pitch. The customized data set poses challenges to load balancing and file input/output synchronization for a limited cpu hour budget. Strategies are presented to complete each image within a minimal time, and to generate the complete experiment set within a desired time.

10201-9, Session 1

Validation of sparse aperture 3D bistatic SAR simulation and image formation, towards remote sensing of building interiors

Daniel B. Andre, Cranfield Univ. (United Kingdom); Ben Faulkner, Australian Army (Australia); Mark Finnis, Cranfield Univ. (United Kingdom); David Blacknell, Darren B. Muff, Claire Stevenson, Matthew Nottingham, Defence Science and Technology Lab. (United Kingdom)

Interpreting the results from remotely imaging the contents of buildings with low frequency radar can be complicated due to the large amount of clutter and other imaging artefacts that can be present. For example, in two-dimensional SAR collections, one may observe a large amount of clutter overlaid onto the scene from above and below, as well as multipath and specular flash effects. A potential solution to these issues could be provided through the use of three-dimensional bistatic SAR imaging. The three-dimensional aspect would separate clutter overlaid from above and below the scene, and the bistatic geometry can be chosen to reduce multipath and specular flash effects from walls. However, it is often impractical to collect full three-dimensional SAR solid angle apertures remotely, so one must make-do with sub-Nyquist, or sparse, aperture collections, and different sparse aperture collections can introduce varying strong sidelobe structures and resolution. This paper reports an investigation, using both simulation and validating measurement, into the varying image quality obtained when using a variety of sparse three-dimensional apertures. A prototype three-dimensional SAR scanner was developed which has informed the corresponding upgrade to the full scale Cranfield University ground-based laboratory SAR system.

10201-10, Session 1

Deep learning for SAR feature extraction

Rachel Westerkamp, Illinois Wesleyan Univ. (United States); Edmund G. Zelnio, Air Force Research Lab. (United States)

No Abstract Available

10201-11, Session 1

Exploiting the sparsity of edge information in SAR image formation

Theresa Scarnati, Arizona State Univ. (United States); Christopher R. Paulson, Edmund G. Zelnio, Air Force Research Lab. (United States)

No Abstract Available

10201-12, Session 1

Adapting range migration techniques for imaging with metasurface antennas: analysis and limitations

Laura Pulido-Mancera, Thomas Fromenteze, Timothy Sleasman, Michael Boyarsky, Mohammadreza F. Imani, Duke Univ. (United States); Matthew S. Reynolds, Univ. of Washington (United States); David R. Smith, Duke Univ. (United States)

Electromagnetic metamaterial technology uses subwavelength tunable radiators embedded in a waveguide in order to create high quality beams that can be used from satellite communications to microwave imaging. This technological innovation opens vast opportunities for security screening, through wall imaging and medical diagnosis, using antennas with versatile performance, low weight and no moving parts. Particularly, for synthetic aperture radar (SAR) we have proposed a dynamic aperture antenna that illuminates the region of interest with diverse beams, and we have adapted the Range Migration Algorithm to be compatible with the measurements taken with this antenna. This process allows us to generate fast image reconstructions in good agreement with slower computational imaging techniques. This work is focused on the analysis and limitations on the adapted RMA for the image reconstruction, based in the particular modeling of the metamaterial antenna and its characteristics, such as size, sampling of tunable elements, and tunable states.

10201-13, Session 1

Implications of SAR ambiguities in estimating the motion of slow targets

David A. Garren, Naval Postgraduate School (United States)

This paper examines the implications pertaining to the problem of attempting to invert synthetic aperture radar (SAR) measurement data to yield unique estimates of the underlying motion of slow targets in the imaged scene. A recent analysis [1] has demonstrated that ambiguities exist in estimating the kinematics parameters of surface targets for general bistatic SAR collection data. In particular, any number of alternate target trajectories can be constructed which yield the same set of SAR measurements as that of the true target motion. Thus, the transmission and reception beams of the radar determine the possible locations of a moving target. The current paper extends the earlier analysis by generating specific numeric examples of alternate target trajectories corresponding to the motion of a given slowly moving target. This slow-target case reveals the counter-intuitive result that a single SAR collection data set can be generated by target trajectories with significantly different, and possibly opposing, heading directions. For example, the true motion of a given target can be moving towards the mean radar position during the SAR collection interval, whereas a valid alternate trajectory can correspond to a target that is moving away from the radar. The present analysis demonstrate the extent of the challenges associated with attempting to estimate of the underlying motion of targets using SAR measurement data.

[1] Garren, D. A., "Ambiguities in Target Motion Estimation for General SAR Measurements," IET Radar, Sonar & Navigation; DOI: 10.1049/iet-rsn.2016.0024; Online ISSN 1751-8792; Available online as an IET E-First article: 28 April 2016.

10201-14, Session 1

An acceleration framework for synthetic aperture radar algorithms

Youngsoo Kim, San José State Univ. (United States) and North Carolina A&T State Univ. (United States)

The goal of this paper is to understand infrequently undertaken work in Synthetic Aperture Radar (SAR) processing for exploring high level design options directed toward the optimization of radar signal processing algorithms. We developed a comprehensive acceleration framework for various radar signal applications including SAR and floating point operations.

An implementation case study is presented as a means to reduce efforts in terms of time and resources while achieving high performance computation in a restricted space and power budget. This allows system designers to quickly build an FPGA accelerator based on our proposed hardware template. As a result, a shorter system development time greatly reduces the overall design time. A package with an efficient simulation model template for hardware implementation and a set of pre-built template libraries for simulation with MATLAB are also presented.

Early estimation at the system level can solve early performance estimation problems and reduce the time-to-market taking into consideration designers' changing requirements including throughput, power, pipelining, and parallelism. Our case studies showed that HW designers can achieve a linear throughput increase by employing dataflow schemes available in our methodology.

Memory requirement reduced significantly by re-writing a 2D Discrete Wavelet Transform algorithm with line and block scan dataflow concepts.

We believe it is necessary to reduce the time it takes to design and refine hardware by using this approach.

This methodology can be used directly for the hardware refinement process for various filtering application algorithms in radar processing.

10201-15, Session 2

A novel latent Gaussian copula framework for modeling spatial correlation in quantized SAR imagery with applications to ATR

Brian T. Thelen, Ismael Xique, Joseph W. Burns, Michigan Tech Research Institute (United States); George S. Goley, Adam R. Nolan, Etegent Technologies, Ltd. (United States); Jonathan W. Benson, Leidos, Inc. (United States)

No Abstract Available

10201-16, Session 2

The efficiency of algorithms to match unique scatterer locations in joint 3D azimuth and elevation synthetic aperture radar scenarios

Matthew P. Pepin, SAIC (United States)

Integral in locating point scatterers in Synthetic Aperture Radar (SAR) data is the ability to match location estimates in each dimension. This is due in some sense to the fact that the fundamental theorem of algebra finds unique locations only in one dimension. In SAR images this involves at least a search of four possible combination for one scatterer. In a set of multiple elevation SAR (3-D) images with more than one scatterer combinations increase factorially. The paper examines several suboptimal methods and their efficiency matching scatterer to match multiple scatterer to their unique locations compared the (unachievable) exhaustive search. Many heuristic methods exist in two dimension (location maxima, alternating maximization in each dimension) and some (radar tracking) methods exist in three dimensions (Munkres, probabilistic maximization). Algorithms range from simply selecting maximums (easy in 2D; complex in multiple images, 3D) to multidimensional constrained interpolations. In some algorithms the extra degrees of freedom present in two dimensional localization are exploited to increase accuarcy. These methodologies can also be extended to three dimensions. The paper examines proposed combinations of these especially suitable to the 3-D SAR problem. Simulations compare promising alternatives to solve this problem and results are presented for airborne and space-borne scenarios.

10201-17, Session 2

Wide-angle SAR recognition experiments

Christopher R. Paulson, Air Force Research Lab. (United States); Jervon Wilson, Univ. of Cincinnati (United States); Travious Lewis, Rose-Hulman Institute of Technology (United States)

No Abstract Available

10201-18, Session 2

Using phase for radar scatterer classification

Linda J. Moore, Edmund G. Zelnio, Air Force Research Lab. (United States)

No Abstract Available

10201-19, Session 2

Machine Learning (ML) Algorithms: An overview of various techniques for target detection and classification

Uttam K. Majumder, Air Force Research Lab. (United States)

No Abstract Available

10201-20, Session 2

Synthetic aperture radar imagery classification using deep neural networks on a neurosynaptic processor

Uttam K. Majumder, Air Force Research Lab. (United States)

No Abstract Available

10201-21, Session 2

Limited persistence models for SAR automatic target recognition

Nithin Sugavanam, Emre Ertin, The Ohio State Univ. (United States)

Resource constraints can limit the different views of a target available for ATR design. In this paper we study the problem of designing multiples classifiers for SAR data from signatures subsampled in azimuth. We adopt a target model that is sparse in spatial domain and limited persistence in azimuth and link it to the subsampled phase history data through a forward model. Using a convex problem formulation we provide a reconstruction of the target in image domain indexed by persistence. Next, we train an ATR system on the reconstructed imagery from a larger number view angles that is available in the training data. We present simulation results using civilian vehicle data dome.

10201-22, Session 2

Divergences and estimating tight bounds on Bayes error with applications to multivariate Gaussian copula and latent Gaussian copula

Brian T. Thelen, Ismael Xique, Joseph W. Burns, Michigan Tech Research Institute (United States)

No Abstract Available

Conference 10202: Automatic Target Recognition XXVII

Monday - Tuesday 10–11 April 2017

Part of Proceedings of SPIE Vol. 10202 Automatic Target Recognition XXVII

10202-1, Session 1

Robust fusion-based processing for military polarimetric imaging systems

Duncan L. Hickman, Moira I. Smith, Tektonex Ltd. (United Kingdom); Kyung Su Kim, Hyun-Jin Choi, Agency for Defense Development (Korea, Republic of)

Polarisation information provides additional scene information which can be exploited in military systems to give enhanced target detection and recognition performance. However, the performance gain achieved is highly dependent on factors such as the geometry, viewing conditions, and the target surface finish. Such performance sensitivities are highly undesirable in many tactical military systems where operational conditions can vary significantly and rapidly during a mission. Within this paper, a range of processing methods for detection and ATR is reviewed in terms of their practical viability. These techniques range from the multi-band fusion of source imagery with derived polarimetric information to more simplistic data fusion methods of regional highlighting and target cueing. Although higher levels of performance can be achieved through complex and specific processing design solutions, the required level of automated tuning and parameter optimisation increases and achieving a consistent level of performance becomes increasingly difficult and impractical. An alternative processing design approach is to focus on robustness rather than performance. Generally, lower performance algorithms offer a simpler design solution with less sensitivity to changes in the image content but with a sub-optimal level of performance. This trade-off between performance and robustness will be reviewed. Polarimetric information alone is often not sufficient to achieve an acceptable level of ATDR performance. As such, polarimetric processing must not be allowed to compromise other discriminatory scene information in the spectral and spatial domains. Factors in the trade-off between performance and robustness are highlighted using trials imagery obtained from visible, SWIR, MWIR, and LWIR cameras.

10202-2, Session 1

Efficient generation of image chips for training deep learning networks

Sanghui Han, Alex Farfard, John P. Kerekes, Emmett J. Ientilucci, Michael G. Gartley, Andreas Savakis, Rochester Institute of Technology (United States)

Training deep convolutional networks for satellite or aerial image analysis often requires a large amount of training data. For a more robust algorithm, training data need to have variations not only in the background and target, but also radiometric variations in the image such as shadowing, illumination changes, atmospheric conditions, and imaging platforms with different noise levels and collection geometry. Data augmentation is a commonly used approach to generating additional training data by utilizing geometric transformations, contrast variations, noise injection, etc. Alternatively, using simulation can be an efficient way to augment training data that incorporates all these variations as well as much more realistic variations, such as changing backgrounds, that may be encountered in real data. We used the Digital Imaging and Remote Sensing Image Image Generation (DIRSIG) model that generated synthetic imagery taken from different sensors with variation in collection geometry, spectral response, solar elevation and angle, atmospheric models, target, and background. For our research, we selected ground vehicles as target objects and incorporated a traffic simulation model to generate scenes with moving vehicles. The vehicles were tracked and images of them were captured at defined time increments. Using this method, we can quickly generate hundreds of 64x64 pixel image chips, with the target vehicle at the center. Computation time is optimized because any background pixel that is not needed is not computed. Each simulation instance generated 500 image chips in less than an hour, and the instances could be run simultaneously. In total, each simulation generated 120,000 chips.

10202-3, Session 1

Radiometric features for vehicle classification with infrared images

Seçkin Özsaraç, ASELSAN A.S. (Turkey); Gozde Bozdagi Akar, Middle East Technical Univ. (Turkey)

A vehicle classification system, which uses features based on radiometry, is developed for single band infrared (IR) image sequences. In this context, the process is divided into three components. These are moving vehicle detection, radiance estimation, and classification. The major contribution is the usage of the statistics of the radiance values as features (radiometric features), other than the raw output of IR camera output. Radiometric features are proposed to improve the classification performance of the detected objects while having very low computational power requirements for a real time system. The motivation is that each vehicle class has a discriminating radiance value that originates from the source temperature of the object modified by the intrinsic characteristics of the radiating surface and the environment. As a consequence, performance improvements are achieved by the use of radiance values in classification for the utilized measurement system.

10202-4, Session 1

Enhancing long range ATR using spatial context

Iain Rodger, Thales UK (United Kingdom); Barry Connor, Thales Optronics Ltd. (United Kingdom); Rachael Abbott, Neil M. Robertson, Queen's Univ. Belfast (United Kingdom)

We present a novel approach to improve automatic target recognition (ATR) performance in challenging long range surveillance scenarios. Representative data is collected using a multi-modal sensor platform in a rural environment, where we employ a high quality long wave infrared (LWIR) thermal imager and colour band sensor. To perform target recognition we exploit recent state of the art machine learning methods and train a deep convolutional neural network (CNN), for several object classes using LWIR imagery. The trained network is demonstrably robust at short to medium ranges, where output class probabilities are reliably accurate. However, performance suffers when targets exist at long range. This is due to the low signal quality captured as objects appear smaller at increasing distance.

To solve this problem we utilise corresponding colour band data and create a Bayesian framework to affect recognition probabilities via spatial context. This method relies on semantic segmentation and prior object knowledge to effectively guide CNN scores towards the correct object class. The result is very pronounced and we achieve robust target classification by mobilising contextual information.

The overall system performance is evaluated using challenging multi-modal test sequences, containing more than 10000 ground-truth examples. The contextual framework is shown to increase long range ATR classifier accuracy from approximately 40% to over 90%. This is a considerable performance gain and highlights the benefit of using additional information to complement advanced machine learning methods.

10202-5, Session 1

Open set recognition of aircraft in aerial imagery using synthetic template models

Aleksander B. Bapst, Jonathan Tran, Mark W. Koch, Mary M. Moya, Sandia National Labs. (United States); Robert Swahn, Defense Threat Reduction Agency (United States)

Fast, accurate and robust automatic target recognition (ATR) in optical aerial imagery can provide game-changing advantages to military commanders and personnel. ATR algorithms must reject non-targets with a high degree of confidence in a world with an infinite number of possible input images. Furthermore, they must learn to recognize new targets without requiring massive data collections. Whereas most machine learning algorithms classify data in a closed set manner by mapping inputs to a fixed set of training classes, open set recognizers incorporate constraints that allow for inputs to be labelled as unknown. We have adapted two template-based open set recognizers to use computer generated synthetic images of military aircraft as training data, to provide a baseline for military-grade ATR: (1) a frequentist approach based on probabilistic fusion of extracted image features, and (2) an open-set extension to the one-class support vector machine (SVM). These algorithms both use histograms of oriented gradients (HOG) as features as well as artificial augmentation of both real and synthetic image chips to take advantage of minimal training data. Our results show that open set recognizers trained with synthetic data and tested with real data can successfully discriminate real target inputs from non-targets. However, there is still a requirement for some knowledge of the real target in order to calibrate the relationship between synthetic template and target score distributions. We conclude by proposing algorithm modifications that may improve the ability of synthetic data to represent real data.

10202-6, Session 2

SAL target separability study with a sparse representation classifier

Jacob Ross, AFRL/RYAT (United States)

In this study, we analyze the performance of a sparsity based classifier on synthetically generated Synthetic Aperture LADAR (SAL) imagery. SAL shows promising potential for exploitation purposes, given it has some significant advantages over current electro-optical (EO) systems: it is an active sensing technique, and can produce high resolution imagery with a smaller aperture. SAL also has several benefits over Synthetic Aperture RADAR (SAR) such as having more transmit beams allowing for a lower intercept rate, shorter wavelengths which lead to more realistic imagery through finer spatial resolution, support for higher squint angle operation, and shorter acquisition baselines and times. The motivation of this work is to gain an understanding of how a classifier can distinguish targets given a variety of operating conditions (OCs) that can affect SAL image formation. We show classifier performance as a function of elevation and image resolution. We also show the effects that obscuration, noise, and atmosphere have on classifier performance. Images are generated via the asymptotic modeling approach proposed last year, now known as Laider Tracer. Atmospheric effects are applied to Laider Tracer output in post processing via piston profiles generated with an atmospheric modeling toolbox. Finally, the sparisty based classifier is trained on pristine Laider Tracer output, and tested on images that have been noised and obscured as described above.

10202-7, Session 2

Combining high-speed SVM learning with CNN feature encoding for real-time target recognition in high-definition video for ISR missions

Christine Kroll, Monika von der Werth, Holger Leuck, Christoph Stahl, Klaus Schertler, Airbus Defence and Space (Germany)

For Intelligence, Surveillance, Reconnaissance (ISR) missions of manned and unmanned air systems typical electro-optical payloads provide high-definition video data which has to be exploited with respect to relevant ground targets in real-time by automatic/assisted target recognition software. Airbus Defence and Space is developing required technologies for real-time sensor exploitation since years and has combined the latest advances of Deep Convolutional Neural Networks (CNN) with a proprietary high-speed Support Vector Machine (SVM) learning method into a powerful object recognition system with impressive results on relevant high-definition video scenes compared to conventional target recognition approaches.

This paper describes the principal requirements for real-time target recognition in high-definition video for ISR missions and the Airbus approach of combining an invariant feature extraction using pre-trained CNNs and the high-speed classification ability of the novel frequency-domain SVM training method. The frequency-domain approach allows for a highly optimized implementation for General Purpose Computation on a Graphics Processing Unit (GPGPU) and also an efficient training of large training samples. The selected CNN which is pre-trained only once on domain-extrinsic data reveals a highly invariant feature extraction. This allows for a significantly reduced adaptation and training of the target recognition method for new target classes and mission scenarios. A comprehensive training and test data set was defined and prepared using relevant high-definition airborne video sequences. The assessment concept is explained and performance results are given using the established precision-recall diagrams, average precision and run-time figures on representative test data. A comparison to legacy target recognition approaches shows the impressive performance increase by the proposed CNN+SVM machine-learning approach and the capability of real-time high-definition video exploitation.

10202-8, Session 2

Deep learning based multi-category object detection in aerial images

Lars W. Sommer, Fraunhofer-Institut für Optronik, Systemtechnik und Bildauswertung (Germany) and Karlsruher Institut für Technologie (Germany); Tobias Schuchert, Fraunhofer-Institut für Optronik, Systemtechnik und Bildauswertung (Germany); Jürgen Beyerer, Fraunhofer-Institut für Optronik, Systemtechnik und Bildauswertung (Germany) and Karlsruher Institut für Technologie (Germany)

Multi-category object detection in aerial images is an important task for many applications such as surveillance, tracking or search and rescue tasks. In recent years, deep learning approaches using features extracted by convolutional neural networks (CNN) significantly improved the detection accuracy on detection benchmark datasets like Pascal VOC compared to traditional approaches based on hand-crafted features that are generally used for object detection in aerial images. However, these approaches are not transferable one to one on aerial images as the used network architectures have an insufficient resolution of feature maps for handling small instances and consequently result in poor localization accuracy or missed detections as the network architectures are explored and optimized

for datasets that considerably differ from aerial images in particular in object size and image fraction occupied by an object.

In this work, we propose a deep neural network derived from the Faster R-CNN approach for multi-category object detection in aerial images. We show how the detection accuracy can be improved by replacing the network architecture by an architecture especially designed for handling small object sizes. Furthermore, we investigate the impact of different parameters of the detection framework on the detection accuracy for small objects. Finally, we demonstrate the suitability of our network for object detection in aerial images by comparing our network to traditional baseline approaches and deep learning based approaches on the publicly available DLR 3K Munich Vehicle Aerial Image Dataset that comprises multiple object classes such as car, van, truck, bus and camper.

10202-9, Session 2

Re-identification of persons across aerial and ground-based cameras by deep feature fusion

Arne Schumann, Jürgen Metzler, Fraunhofer-Institut für Optronik, Systemtechnik und Bildauswertung (Germany)

Person re-identification is the task of correctly matching visual appearances of the same person in image or video data while distinguishing appearances of different persons.

The traditional scenario for re-identification is a network of fixed cameras.

However, in recent years mobile aerial cameras mounted on unmanned aerial vehicles (UAV) have become increasingly useful for security and surveillance tasks.

Aerial data has many different characteristics than typical camera network data.

Thus, re-identification approaches designed for a camera network scenario can be expected to suffer a drop in accuracy when applied to aerial data.

In this work, we investigate the suitability of features which were shown to give robust results for re-identification in camera networks for the task of re-identifying persons between a camera network and a mobile aerial camera. Specifically, we apply hand-crafted covariance features and features extracted by convolutional neural networks which were learned on separate data.

We evaluate their suitability for this new and as yet unexplored scenario.

We propose modification to the features in order to more accurately bridge the gap between aerial and camera network data. Finally, we use deep learning to combine both features into a new representation.

We evaluate the features on our own dataset. The dataset consists of twelve people moving through a scene recorded by four fixed cameras and one mobile camera mounted on a small UAV. We discuss strengths and weaknesses of the features in the new scenario and show that our combined approach is able to outperform each individual feature.

10202-10, Session 2

Probabilistic SVM for open set automatic target recognition on high range resolution radar data

Jason Roos, Arnab Shaw, Wright State Univ. (United States)

The application of Automatic Target Recognition (ATR) on High Range Resolution (HRR) radar data in a scenario that contains unknown targets is of great interest for military and civilian applications. HRR radar data provides greater resolution of a target as well as the ability to perform ATR on a moving target, which gives it an advantage over other imaging systems. With the added resolution of HRR comes the disadvantage that a change in the aspect angle or orientation results in greater changes in the collected data, making classical ATR more difficult. Closed set ATR on HRR radar data is defined when all potential targets are assumed to be part of the training target data base. Closed set ATR has been able to achieve higher rates of correct classification by the selection of proper feature extraction algorithms, however, only a few methods for performing open set ATR have been developed. Open set ATR is the ability to identify and discard when a target is not one of the trained targets. By identifying these untrained targets, the number of misclassified targets is reduced, thereby, increasing the probability of a correct classification in a realistic setting. While the open set ATR produces a more realistic approach, the classical closed-set ATR is the standard method of ATR. One of the more popular classification algorithms currently used today is the Support Vector Machine (SVM). The SVM by nature only works on a binary closed-set problem. However, by extracting probabilities from an SVM, this classification algorithm can be applied to open set.

The feature extraction methods established in closed-set ATR are modified to facilitate the application of the Probabilistic Open Set Support Vector Machine (POS-SVM). Utilizing the Eigen Template (ET) and Mean Template (MT) feature extraction methods developed for closed-set ATR, in combination with centroid alignment, an open set ATR Probability of correct classification (P CC) rate of 80% has been achieved. Utilizing POS-SVM, it is possible to successfully perform open set ATR on HRR data with a high PCC.

10202-11, Session 2

Infrared image segmentation with Gaussian mixture modeling

Seokwon Yeom, Daegu Univ. (Korea, Republic of)

Infrared (IR) imaging has been researched for various applications such as surveillance. IR radiation has the capability to detect thermal characteristics of objects under low-light conditions. However, automatic segmentation for finding the subject of interest would be challenging since the IR detector often provides the low spatial and contrast resolution image with no color and texture information. Another hindrance is that the image can be degraded by noise and clutter. This paper proposes multi-level segmentation for extracting regions of interest (ROIs) and objects of interest (OOIs) in the IR scene. Each level of the multi-level segmentation is composed of the k-means clustering, an expectation-maximization (EM) algorithm, and a decision process. The k-means clustering initializes the parameters for the Gaussian mixture model (GMM), and the EM algorithm estimates those parameters iteratively. During the multi-level segmentation, the area extracted at one level becomes the input to the next level segmentation. Thus, the segmentation is consecutively performed narrowing the area to be processed. The foreground objects are individually extracted from the final ROI windows. In the experiments, the effectiveness of the proposed method is demonstrated using several IR images, in which human subjects are captured at a long distance. The average probability error is compared to conventional methods.

10202-12, Session 3

Enhancement of thermal imagery using a low-cost high-resolution visual spectrum camera for scene understanding

Ryan Smith, Derek T. Anderson, Cindy L. Bethel, Christopher Archibald, Mississippi State Univ. (United States)

Thermal cameras are used in numerous computer vision applications such as human detection and scene understanding. However, the cost of high quality and high resolution thermal sensors is often a limiting factor. Conversely, high resolution visual spectrum cameras are readily available and generally inexpensive. Herein, we explore the creation of higher quality upsampled thermal imagery using a high resolution visual spectrum camera and Markov random field theory. This paper also presents a discussion of the tradeoffs and effects of the upsampling, both quantitatively and qualitatively. Our results demonstrate the successful use of this approach for human detection and accurate propagation of thermal measurements within the image for more general tasks like scene understanding. Tradeoff analyses of the cost to performance as the resolution of the thermal camera decreases are provided.

10202-13, Session 3

Target recognition and phase aquisition by using incoherent digital holographic imaging

Mun Seob Lee, Byung-Tak Lee, Electronics and Telecommunications Research Institute (Korea, Republic of)

In this study, We proposed the Incoherent Digital Holographic Imaging (IDHI) for recognition and phase information of dedicated target. Although recent development of a number of target recognition techniques such as lidar, there have limited success in target discrimination, in part due to low-resolution, low scanning speed, and computation power. In the paper, the proposed system consists of the incoherent light source, for example LED etc, Michelson interferometer, and digital CCD for acquisition of four phase shifting image. First of all, to compare with relative coherence, we used a source as laser, LED and natural light, respectively. Through numerical reconstruction by using the four phase shifting method and fresnel diffraction method, we recovered the intensity and phase image of USAF resolution target apart from about 1.0m distance. In this experiment, we show 1.2 times improvement in resolution compared to conventional imaging. Finally, to confirm the recognition result of camouflaged targets with the same colour from background, we carry out to test holographic imaging in incoherent light. In this result, we showed the possibility of a target detection and recognition that used three dimensional shape and size signatures, numerical distance from phase information of obtained holographic image.

10202-14, Session 3

Key features for ATA / ATR database design in missile systems

Kemal Arda Özertem, Roketsan A.S. (Turkey)

Automatic target detection and automatic target recognition are two vital tasks for missile systems, and having a robust detection and recognition algorithm is crucial for overall system performance. In order to have a robust target detection and recognition algorithm, an extensive image database is required. Automatic target recognition algorithms use the database of images in training and testing steps of algorithm. This directly affects the recognition performance, since the training accuracy is driven by the image database. In addition, the performance of an automatic target detection algorithm can be measured effectively by using this image database. There are two main ways for designing an ATA – ATR database. The first and easy way is by using a scene generator. A scene generator can model the objects by considering its material information, the atmospheric conditions, detector type and the territory. Designing image database by using a scene generator is inexpensive and it allows creating many different scenarios quickly and easily. However the major drawback of using a scene generator is its low fidelity, since the images are created virtually. The second and difficult way is designing it using real-world images. Designing image database with real-world images is a lot more costly and time consuming; however it offers high fidelity, which is critical for missile algorithms. In this paper, critical concepts in ATA – ATR database design with real-world images are discussed. Each concept is discussed in the perspective of ATA and ATR separately. For the implementation stage, some possible solutions and trade-offs for creating the database are proposed, all the possible solutions are compared each other with regards to their pros and cons.

10202-15, Session 3

A video dataset for evaluating the performance of multi-class multi-object tracking

Avishek Chakraborty, Univ. of South Australia (Australia); Sebastien C. Wong, Defence Science and Technology Group (Australia); Victor Stamatescu, David Kearney, Grant Wigley, Univ. of South Australia (Australia)

One of the challenges in evaluating multi-object detection, tracking and classification systems is having publicly available datasets with which to compare different systems. However, the measures of performance for tracking and classification are different. Datasets that are suitable for evaluating tracking systems may not be appropriate for classification. Tracking video datasets typically only have ground truth track IDs, while classification video datasets only have ground truth class-label IDs. The first identifies the same object over multiple frames, while the second identifies the type of object in individual frames. This paper describes an advancement of the ground truth meta-data for the DARPA Neovision2 Tower dataset to allow both the evaluation of tracking and classification. The ground truth datasets presented in this paper contain unique object IDs across 6 different classes of object (car, bus, truck, person, cyclist) for 24 videos of 871 image frames. In addition to the object IDs and class labels, the ground truth data also contains the original bounding box coordinates together with new bounding boxes in instances where un-annotated objects were present. The unique IDs are maintained during occlusions between multiple objects or when objects re-enter the field of view. This will provide: a solid foundation for evaluating the performance of multi-object tracking of different types of objects, a straightforward comparison of tracking system performance using the standard Multi Object Tracking (MOT) framework, and classification performance using the Neovision2 metrics. These data have been hosted publicly, along with the source code used to annotate the dataset.

10202-16, Session 4

Underwater visual odometry for passive surveillance and navigation

Firooz A. Sadjadi, Sekhar Tangirala, Scott Sorber, Lockheed Martin Corp. (United States)

Passive navigation is a critical issue in underwater surveillance. Underwater vehicles are usually equipped with sonar and Inertial Measurement Unit (IMU) - an integrated sensor package that combines multiple accelerometers and gyros to produce a three dimensional measurement of both specific force and angular rate with respect to an inertial reference frame for navigation. This paper summarizes the results of studies in underwater odometery using a video camera for estimating the velocity of an unmanned underwater vehicle (UUV). In this study, we investigate the use of odometry information obtainable from a video camera mounted on a UUV to extract vehicle velocity relative to the ocean floor. A key challenge with this process is the seemingly bland (i.e. featureless) nature of video data obtained underwater which could make conventional approaches to image-based motion estimation difficult. To address this problem, we perform image enhancement, followed by frame to frame image transformation, registration and mosaicking/stitching. With this approach the velocity components associated with the moving sensor (vehicle) are readily obtained from (i) the components of the transform matrix at each frame; (ii) information about the height of the vehicle above the seabed; and (iii) the sensor resolution. Preliminary results are presented.

10202-17, Session 4

Motion-seeded object-based attention for dynamic visual imagery

David J. Huber, Deepak Khosla, Kyungnam Kim, HRL Labs., LLC (United States)

Humans can analyze a visual scenes very quickly and efficiently, effortlessly noticing objects of interest, regardless of whether they happen to be moving or not. However, capturing this simple paradigm in an artificial vision system provides a great challenge. In this paper, we describe a system that employs a motion processing engine and advanced segmentation algorithms to find objects of interest for further processing by either a human operator or a target recognition system. For a given video feed, either from recorded or streamed footage, the system processes the scene for some number of frames during a temporal window using an advanced motion detection algorithm, which determines small regions in the scene that appear to be moving conspicuously. At the end of each of these windows, the system computes a series of feature maps and feature regions for each frame in which the motion algorithm detects an object of interest, and performs ordered segmentation of the salient objects by drawing a boundary around the object, which is represented as an outline drawn tightly around the object, and not as a bounding box or vague ellipsoidal region. Since each feature region in each frame cannot appear in multiple objects, the system will not revisit previously attended objects, which ensures that the detection mechanism performs efficiently. The proposed technology can be applied to a large range of natural scenes exhibiting a variety of lighting conditions that cause trouble for other object-based attention systems.

10202-18, Session 4

Fast legendre moment computation for template matching

Bingcheng Li, Lockheed Martin Systems Integration-Owego (United States)

Template matching, finding matches in images to given templates, has many applications in image processing, computer vision and pattern recognition. In this paper, we propose Legendre moment approach for fast template matching and show that the computational cost of this new method is independent of template mask sizes which is faster than traditional mask size dependent approaches. Legendre polynomials have been widely used in solving Laplace equation in electrodynamics in spherical coordinate systems, and solving Schrodinger equation in quantum mechanics. In this paper, we extend Legendre polynomials from physics to computer vision and pattern recognition fields, and demonstrate that Legendre polynomials can help to reduce the computational cost of template matching significantly.

First, we decompose both templates and target images into Legendre polynomial bases and use polynomials to approximate templates and target images. Since Legendre polynomials are orthogonal, the decomposition coefficients are Legendre moments and can be implemented by simple inner product. Instead of direct pixel comparison between templates and target images, we may use Legendre polynomial approximated templates and target images comparison to compute template matching. We show that this approximated comparison can be converted into the decomposition coefficient comparison. The number of coefficients is small and independent of template sizes, and therefore, the computational cost for the coefficient comparison is very low. Thus, the major implementation cost of template matching is now dependent on Legendre moment computation.

In order to reduce the computational cost of Legendre moments for fast template matching, we propose an integral method to compute Legendre moments. The proposed integral approach includes three steps. In step 1, global Legendre moments are computed for each pixel. Using precomputed Legendre polynomials, we can compute the global Legendre moments with only one addition for each moment at each pixel location. In step 2, we develop a formula to compute Legendre moment in a rectangular window by linear combination of global Legendre moments at four corners of the rectangular window. In step 3, we compute the template and target image comparison by linear combination of Legendre moments in the rectangular window, and find template matching location.

Finally, we conduct theoretical analysis and experiments for computational cost of the new method. Both theoretical analysis and experimental results show that the computational cost of the new method is independent of template mask sizes and is significant lower than the conventional techniques.

10202-19, Session 4

Automatic threshold selection for multi-class open set recognition

Matthew Scherreik, Brian D. Rigling, Wright State Univ. (United States)

Multi-class open set recognition is the problem of supervised classification with additional unknown classes encountered after a model has been trained. An open set classifer often has two core components. The first component is a base classifier which estimates the most likely class of a given example. The second component consists of open set logic which estimates if the example is truly a member of the candidate class. Such a system is operated in a feed-forward fashion. That is, a candidate label is first estimated by the base classifier, and the true membership of the example to the candidate class is estimated afterward. Previous works have developed an iterative threshold selection algorithm for rejecting examples from classes which were not present at training time. In those studies, a Platt-calibrated SVM was used as the base classifier, and the thresholds were applied to class posterior probabilities for rejection. In this work, we investigate the effectiveness of other base classifiers when paired with the threshold selection algorithm and compare their performance with the original SVM solution.

10202-20, Session 4

Automatic small target detection in synthetic infrared images

Ozan Yardimci, Roketsan Roket Sanayii ve Ticaret A.S. (Turkey)

Automatic target detection is very important for defense and security applications and should be performed with high precision immediately as target appears. It is the key task which must be completed before further processing such as target tracking and recognition.

Automatic target detection from very long distances has some limitations. The apparent size of the target is very small in the image, such as a few pixels. Another problem is the lack of gray level intensity values. Especially when the background is cluttered, targets may not be distinguished even from noise. All of these problems make the detection process more difficult than bigger size target detection.

A typical automatic target detection algorithm has mainly three stages: pre-processing, detection (could be a simple thresholding), post-processing.

Each stage has a unique role on the overall detection performance. In the pre-processing stage, image is prepared for the further stages. Especially, noise and background clutter are eliminated. Thus, it can directly affect the detection stage performance. In the detection stage, target and background pixels are separated from each other. In the post-processing stage, false alarms are processed to be eliminated.

In this paper, first of all, we studied many possible pre-processing, thresholding/detection and post-processing methods available in the literature. We tested these methods and compared them using a synthetic image database. For evaluation, we used precision and recall measurements. For applications where very small target detection is required, precision is more important than recall. Thus, first of all, we selected a combination of pre-processing, thresholding and post-processing methods based only

on high precision values. Then, we evaluated various target detection approaches and proposed a small target detection system which has the highest precision performance. However, we realized that the methods usually have low recall values although they can reach 100 % precision values. Besides, available post-processing approaches in the literature decrease precision while increasing recall. Considering the limitations of the literature methods and keeping the main constraint of having the highest possible precision, a new post-processing approach was proposed which increases recall while keeping precision high.

10202-21, Session 4

Physics based modeling tool development for spectral sensing measurements under atmospheric attenuation

Xifeng Xiao, David G. Voelz, New Mexico State Univ. (United States); Joseph R. Montoya, U.S. Army Research Lab. (United States)

Remote sensing of natural and man-made optical sources can provide measurements that characterize the source including size, temperature, and composition. Radiometric calculations that involve the source, medium, and sensor system are incorporated with the detected signal. Improved source signature analysis methods will lead to improved design concepts and increased performance in existing systems. However, in an experimental setting where new sensing techniques are being developed and the source/medium/system parameters are in a constant state of change, a flexible radiometric prediction tool can be essential for experimental design and analysis. In this work, a physics-based modeling tool is developed to accommodate the need for rapid and flexible radiometric calculations. The tool provides a variety of options for characterizing the features of the source, medium, and sensor system and employs rigorous radiometric calculations based on physics modeling. The tool is implemented in MATLAB in a user-friendly GUI format. It allows a variety of sources ranging from Lambertian, non-Lambertian, experimentally-measured, and point sources. The medium is characterized by the transmittance function that is modeled by the software MODTRAN. It incorporates the line-by-line transfer equations for the full band pass spectrum. The sensor system includes a single detector featuring specified bandpass filters, or a multispectral imaging system. The tool provides a variety of outputs including spectral plots for the source, transmission and sensor. As well as radiometric and SNR quantities. Support is also provided for the import of user-defined spectral characterization files for the source, transmission and sensor. In general, the tool provides users with a practical interface to quickly extrapolate or predict spectral sensing results for specific scenarios, accounting for extensive variations that are caused by atmospheric conditions and sensor characteristics.

10202-22, Session 4

Emotion recognition from brain waves

Amy Wong, Shawn Mathew, The City College of New York (United States); Izidor Gertner, The City College fof New York (United States)

Recognizing other people's emotion is important. One of the interesting applications is to enhance computer and human interaction. Some popular approaches in estimating emotions are based on facial expression, speech, heart rate, perspiration, and brain waves. In this paper, we will discuss portable brainwave sensors (EEG), relevant classification algorithms, and present preliminary results.

10202-23, Session 5

Heterogeneous sharpness for cross-spectral face recognition *(Invited Paper)*

Zhicheng Cao, Natalia A. Schmid, West Virginia Univ. (United States)

Matching images acquired in different electromagnetic bands remains a challenging problem. An example of this type of comparison is matching active or passive infrared (IR) against a gallery of visible face images, known as cross-spectral face recognition. Among many unsolved issues is the one of quality disparity of the heterogeneous images – images acquired in different spectral bands are of unequal image quality due to distinct imaging mechanism, standoff distances, or imaging environment, etc. To reduce the effect of quality disparity on the recognition performance, one can manipulate images to either improve the quality of poor-quality images or to degrade the high-quality images to the level of the quality of their heterogeneous counterparts. To estimate the level of discrepancy in quality of two heterogeneous images a quality metric such as image sharpness is needed. It provides a guidance of how much quality improvement or degradation is appropriate. However, existing biometric image quality metrics are not designed to compare quality of heterogeneous images. They are not able to quantify the relative amount of degradation in heterogeneous images reliably. In this work we consider sharpness as a relative measure of heterogeneous image quality. We propose a generalized definition of sharpness by first achieving image quality parity and then finding and building a relationship between the image quality of two heterogeneous images. Therefore, the new sharpness metric is named heterogeneous sharpness. Image quality parity is achieved by experimentally finding the optimal cross-spectral face recognition performance where quality of the heterogeneous images is varied using a Gaussian smoothing function with different standard deviation. During the process of building this relationship we first conduct a regression analysis on the heterogeneous sharpness and then use a neural network to find a mapping between the heterogeneous images. To analyze the effect of the metric on the problem of face recognition, we use composite operators developed in our lab to extract features from heterogeneous face images and then apply Kullback-Leibler distance to find the matching score. Images from three different spectral bands – visible light, near infrared, and short-wave infrared – are considered in this work. Both regression error and validation error of neural networks are analyzed.

10202-24, Session 5

Object shape extraction from cluttered baggage *(Invited Paper)*

Nikolay M. Sirakov, Texas A&M Univ.-Commerce (United States)

The passengers flow at the US airports increased in the recent years along with the increase of the security requirements and the accuracy of threats detection. The larger number of passengers demands for lower number of false alarms. On the other hand the process of screening is conducted by a scanner operator, which makes the process subjective. A tool to aid the operator for accurate threats detection will increase the accuracy of detection and decrease the false positives.

To address the above demands we present a method designed to detect possible explosive containers in X-Ray, and or CT luggage images. The method detects salient points of possible explosive containers in a query image and the image of the scanned baggage. From every salient point robust features (SURF) [1] are extracted. For this purpose the Hessian matrix, of a Gaussian filter convolved on the both images, is applied [1]. Thus, the salient points of the image regions are detected and 64 features are extracted from every salient point. The extracted features from the query and the scanned images are organized as vectors with 64 [1]. Further the query vectors are matched with the vectors from the luggage image. If a match is found a region of interest (ROI) is detected. A shrinking active contour, based on the heat PDE, is applied on the detected ROI [2]. This contour extracts the boundaries of the object(s) located at the ROI. The method is rotationally and scaling invariant, and is tested on number of CT images taken from cluttered baggage.

References:

1. H. Bay, A. Ess, T. Tuytelaars, L. Van Gool, Speeded-Up Robust Features (SURF), Computer Vision and Image Understanding, V. 110, Issue 3, June 2008, pp 346–359, (2008)

2. Sirakov, N.M., Kojouharov, H, Sirakova, N.N, 2010, Neutrophils and Bacteria Tracking by Active Contours in Video Sequences, IEEE SSIAI 2010, May 23-25, Austin, TX, pp.5-8, ISBN: 978-1-42447800-2, IEEE Catalog No.:CFP10401-CDR, IEEE XPlore

10202-25, Session 5

THz identification and Bayes modeling *(Invited Paper)*

Andre U. Sokolnikov, Visual Solutions and Applications (United States)

THz Identification is a developing technology. Sensing in the THz range potentially gives opportunity for short range radar sensing because THz waves can better penetrate through obscured atmosphere, such as fog, than visible light. The lower scattering of THz as opposed to the visible light results also in significantly better imaging than in IR spectrum. A much higher contrast can be achieved in medical trans-illumination applications than with X-rays or visible light. The same THz radiation qualities produce better tomographical images from hard surfaces, e.g. ceramics. This effect comes from the delay in time of reflected THz pulses detection. For special or commercial applications alike, the industrial quality control of defects is facilitated with a lower cost. The effectiveness of THz wave measurements is increased with computational methods. One of them is Bayes modeling. Examples of this kind of mathematical modeling are considered.

10202-26, Session 5

Detecting necessary and sufficient parts for assembling a functional weapon *(Invited Paper)*

Christian F. Hempelmann, Divya Solomon, Abdullah N. Arslan, Salvatore Attardo, Grady P. Blount, Nikolay M. Sirakov, Texas A&M Univ.-Commerce (United States)

Visual identification of weapons is generally assumed to happen within a fairly constrained scenario that involves a system scanning an image, identifying a weapon, such as a pistol, and calculating the threat level presented by the weapon in a given context. Our own work [1-7] operates in this paradigm. However, alternative possibilities exist. Consider a scenario in which a terrorist attempts to smuggle a gun into an airport by disassembling it and passing each separate part through security, at different security check-points, and at different times. The problem becomes now to determine if a given set of parts can be assembled to form an operational gun, as the threat level changes significantly once a workable gun may be assembled. Also, many parts are too small (screws, springs) or cannot serve as "diagnostics" (i.e., characteristic parts that allow the system to identify a specific gun). A further complication is that several gun parts are interchangeable and may be used in different models. We developed a system to determine if an operational weapon may be assembled from a given set of parts. For every part, extracted from a scene, all bottom-up paths in the meronomy will be exploited. The path intersections will be used to determine if a weapon could be assembled with the objects detected. Our visual and conceptual ontologies contain more than 153 labeled (750 unlabeled) individual frames and over 50 parts which allows us to test the capacity of our system within a realistic, non-toy framework.

[1] Arslan, A. N., Sirakov, N. M., Attardo, S. 2012. "Weapon Ontology Annotation Using Boundry Describing Sequences," Proc. IEEE SSIAI, Santa Fe, New Mexico, April 22-24: 101-104.

[2] Arslan, A. N., Hempelmann, C. F., Di Ferrante, C., Attardo, S., Sirakov, N.M. 2013. "From Shape to Threat: Exploiting the Convergence Between Visual and Conceptual Organization for Weapon Identification and Threat Assessment." In: Sadjadi, Firooz A. and Abhijit Mahalanobis. Eds. ATR XXIII. Proc. of SPIE 0277-768X, V. 8744. Bellingham, WA: SPIE. 87440P: 1-15. DOI: 10.1117/12.2015591.

[3] Arslan, A. N., Hempelmann, C. F., Attardo, S., Blount, G. P., Sirakov, N. M. 2015a. "Threat assessment using visual hierarchy and conceptual firearms ontology," Optical Engineering 54-5: 053109. doi:10.1117/1.OE.54.5.053109.

[4] Arslan, A. N., Hempelmann, C. F., Attardo, S., Blount, G. P., Sirakova, N. N., Sirakov, N. N. 2015b. "Identification of partially occluded firearms through partonomy." in: Firooz A. Sadjadi; Abhijit Mahalanobis. Eds. Automatic Target Recognition XXV. Proceedings of SPIE Vol. 9476. SPIE, Bellingham, WA, 94760U.

[5] Hempelmann, C. F., Arslan, A. N., Attardo, S., Blount, G. P., Sirakov, N. M. 2014. "Assessing the Threat of Firearms: New Threat Formula, Resources, and Ontological Linking Algorithms." In: Kadar, Ivan. Ed. Signal Processing, Sensor/Information Fusion, and Target Recognition XXIII. Proceedings of SPIE Vol. 9091. Bellingham, WA: SPIE. 90910U: 1-12. doi: 10.1117/12.2050814.

[6] Sirakov, N. M., Suh, S., Attardo, S. 2011a. "Integration of low level and ontology derived features for automatic weapon recognition and identification." SPIE Defence Security and Sensing, ATR XXI. Ed. F. A. Sadjadi, A. Mahalanobis Proc. SPIE Vol. 8049 (Bellingham, WA 2011) 80490X.

[7] Sirakov, N. M., Suh, S., Attardo, S. 2011b. "Automatic Object Identification Using Visual Low Level Feature Extraction and Ontological Knowledge." J. of Integrated Design and Process Science 15, 1.

10202-27, Session 5

Multi-ball and one-ball geolocation and location verification *(Invited Paper)*

Douglas J. Nelson, National Security Agency (United States)

We present refinements of several of the methods we have previously reported for geolocation of electromagnetic emissions from a single moving receiver. These methods are based on the observation that pseudo TDOA and FDOA may be estimated from the frequency history of the transmitted signal. To accomplish this, we first prove that propagation delay (TOA) may be recovered from the received signal frequency (FOA.) FOA estimation and tracking is accomplished using cross-spectral methods that provide extremely accurate frequency tracking. TOA estimation and tracking is accomplished by integration of the instantaneous FOA polynomial. Geolocation is accomplished by first computing the expected propagation times and Doppler frequency offsets for a grid of possible emitter locations and the receiver ephemerides. The grid coordinate that minimizes the error variances between the predicted propagation delay and the measured TOA and the predicted Doppler offset and the measured FOA is determined to the nearest grid location to the emitter. Iteration at finer grid resolutions refines the geoloaciton. This method is demonstrated to be superior to conventional TDOA/FDOA CAF-plane geolocation.

In developing this geolocation method, several problems were addressed. In particular, cross-spectral frequency estimation and tracking methods were developed to track the frequencies of signals as short as 25 milliseconds with less than one Hz error. Based on the same cross-spectral principle, a cross-spectral cross-correlation function was developed providing up to two orders of magnitude better accuracy than the conventional cross-correlation function. Finally a polynomial approximation function robust to noise and outliers was developed to estimate and track frequency.

Conference 10203: Pattern Recognition and Tracking XXVIII

SPIE. DCS DEFENSE+ SECURITY

Wednesday - Thursday 12–13 April 2017

Part of Proceedings of SPIE Vol. 10203 Pattern Recognition and Tracking XXVIII

10203-1, Session 1

Contemporary deep recurrent learning for recognition *(Invited Paper)*

Khan M. Iftekharuddin, Old Dominion Univ. (United States)

Large scale feed forward neural networks have seen intense application in many computer vision problems. However, these networks can get hefty and computationally intensive with increasing complexity of the task. This work, for the first time in literature, introduces a Simultaneous Recurrent Network (SRN) based hierarchical neural network for object detection. CSRN has shown to be more effective to solving complex tasks such as maze traversal and image processing when compared to generic feed forward networks. While deep neural networks (DNN) have exhibited excellent performance in object detection and recognition, such hierarchical structure has largely been absent in neural networks with recurrency. This work attempts to introduce deep hierarchy in SRN for object detection. The simultaneous recurrency results in an unfolding effect of the SRN through time, potentially enabling the design of an arbitrarily deep network. This invited talk shows experiments using face and character recognition tasks for the proposed model and compares recognition performance with that of generic five layer stacked auto-encoder (SAE). Finally we demonstrate the flexibility of incorporating our proposed recognition framework in a humanoid robotic platform called NAO.

10203-2, Session 1

Neural network based multi-spectral IR image segmentation *(Invited Paper)*

Thomas T. Lu, Stephen Heim, Andrew Luong, Maharshi Patel, Kang F. Chen, Tien-Hsin Chao, Edward Chao, Jet Propulsion Lab. (United States); Gilbert Torres, Naval Air Warfare Ctr. Weapons Div. (United States)

Image segmentation is one of the important steps in computer vision and image understanding. In multi-spectral IR images, the shorter the wavelength, the more difficult to segment the object from the background due to variations of reflectance from the objects and the background. On the other hand, the lowgwave images are relatively easier to segment based on the thermal intensity differences between the object and the background. We first use cross-correlation and self-correlation to identify common features on the same object in the multi-spectral images. Based on the corresponding coordinates of the features, we perform image registration and geometric transformation of the images so that all spectral bands are aligned to each other. A neural network is trained on the features of the objects as well as the background in the longwave images. The output of the neural network gives the confidence of the local area as either part of an object, the background, or the boundary of the object. Multiple iterations of training are performed until the accuracy of the segmentation in the longwave images reaches satisfactory level. The segmentation boundary of the longwave image is used to segment the midwave and shortwave images. A second neural network is trained to detect the local discontinuities and refine the accuracy of the local boundaries in the longwave, midwave and shortwave. Test results have shown significantly increased accuracy and robustness of this neural network based segmentation scheme for multi-spectral IR images as compared to commonly used segmentation methods.

10203-3, Session 1

Identifying positioning-based attacks against 3D printed objects and the 3D printing process

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

Zeltmann, et al. have demonstrated the damage to object structural integrity and other quality aspects that can be caused by changing the position of an object on the build plate. Due to the way certain additive manufacturing systems work, object surfaces and support members may be stronger when oriented so that they can be printed without requiring diagonal movements, for example. Objects may be designed and tested for compliance and safety with a certain printing orientation in mind. If this orientation is changed, either through operator error (including carelessness) or deliberate action, the object may no longer be as strong as the tested one (in certain areas; other parts may be stronger, due to their new orientation). Other quality or cosmetic issues may also be introduced.

As with assurance for other cyber-physical systems, the challenge presented by the need to assure 3D printed object orientation is that this can be altered in numerous places throughout the system. These range from the designer's workstation (where this can be altered in the initial CAD model) to production preparation systems to the printer itself. Operator error may introduce a difficult-to-recognize change at any point. If this change is made through ordinary means, the error may go undetected until an object happens to be tested for compliance again (potentially leading to an expensive recall). This paper considers the more nefarious attack scenario. It discusses where attacks that change printing orientation can occur in the process and presents an imaging-based solution to combat this problem.

10203-4, Session 1

Comparative analysis of zero aliasing logarithmic mapped optimal trade-off correlation filter

Sara Tehsin, Saad Rehman, Ahmed Bilal, Qaiser Chaudry, Omer Saeed, Muhammad Abbas, National Univ. of Sciences and Technology (Pakistan); Rupert Young, Univ. of Sussex (United Kingdom)

Correlation filters are a well established means for target recognition tasks. However, the unintentional effect of circular correlation has a negative influence on the performance of correlation filters as they are implemented in frequency domain. The effects of aliasing are minimized by introducing zero aliasing constraints in the template and test image. In this paper, the comparative analysis of logarithmic zero aliasing optimal trade off correlation filters has been carried out for different types of target distortions. The zero aliasing Maximum Average Correlation Height (MACH) filter has been identified as the best choice based on our research for achieving enhanced results in the presence of any type of variance which are discussed in results section. The reformulation of the MACH expressions with zero aliasing has been made to demonstrate the achievable enhancement to the logarithmic MACH filter in target detection applications.

10203-5, Session 1

Robust rotation estimation for object tracking

Yu Xianguo, Qifeng Yu, Shang Yang, National Univ. of Defense Technology (China)

Many existing tracking algorithms lack an efficient and effective rotation estimation method to tackle with scenarios where targets undergo fast rotation variation in images. To deal with this problem, we propose to learn a discriminative correlation filter to detect the object rotation change. Specifically, we train a 1D correlation filter in the Fourier domain based on the ridge regression and the circulant matrices theories. Further more, we combine it with a translation estimation filter and a scale estimation filter to estimate different forms of target motions respectively. The resulting tracking is thus a concatenation of three separate correlation filters. Experiments against state-of-the-arts on challenging scenarios demonstrate the efficiency and the effectiveness of the proposed tracker and the rotation estimation method. The proposed rotation estimation approach is generic, which can be used to augment any existing tracking methods without an effective rotation detection module.

10203-6, Session 1

Feature extraction using decision boundary on deep neural network

Seongyoun Woo, Chulhee Lee, Yonsei Univ. (Korea, Republic of)

Feature extraction is a process to reduce the data dimension using various transforms, while preserving the discriminant characteristics of the original data. Feature extraction has been an important issue in pattern recognition problems, since it can reduce the computational complexity and provide a simplified structure of classifier. Among various feature extraction algorithms, linear feature extraction has been widely used, which applies a linear transform to the original data to reduce the data dimension. They include PCA (Principal Component Analysis), FLD (Fisher's Linear Discriminant) and DBFE (Decision Boundary Feature Extraction). Among them, DBFE can be used for non-linear decision boundaries, which can be produced by neural networks. DBFE retains only informative directions for discriminating among classes. DBFE has been applied to various parametric and non-parametric classifiers, including GML (Gaussian Maximum Likelihood), k-NN (k-nearest neighbor), SVM (Support Vector machine) and neural networks. In this paper, we apply DBFE to deep neural networks. This algorithm is based on the non-parametric version of DBFE, which was developed for neural networks. The feature extraction algorithm was applied to various UCI database and remote sensing database and the result show improved classification accuracy for reduced dimensionality.

10203-8, Session 2

Fully invariant wavelet enhanced minimum average correlation energy filter for object recognition in cluttered and occluded environments

Sara Tehsin, Saad Rehman, Farhan Riaz, Omer Saeed, Ali Hassan, Muazzam Khan, National Univ. of Sciences and Technology (Pakistan); Muhammad S. Alam, Texas A&M Univ. (United States)

A fully invariant system helps in resolving difficulties in object detection when camera or object orientation and position are unknown. In this paper, the proposed correlation filter based mechanism provides the capability to suppress noise, clutter and occlusion. Minimum Average Correlation Energy (MACE) filter yields sharp correlation peaks while considering the controlled correlation peak value. Difference of Gaussian (DOG) Wavelet has been added at the preprocessing stage in proposed filter design that facilitates target detection in orientation variant cluttered environment. Logarithmic transformation is combined with a DOG composite minimum average correlation energy filter (WMACE), capable of producing sharp correlation peaks despite any kind of geometric distortion of target object. The proposed filter has shown improved performance over some of the other variant correlation filters which are discussed in the result section.

10203-9, Session 2

Wavelet filtered shifted phase-encoded joint transform correlation for face recognition

Md. Moniruzzaman, Nfina Technologies, Inc. (United States); Mohammad S. Alam, Texas A&M Univ.-Kingsville (United States)

A new Wavelet-filtered-based Shifted- phase-encoded Joint Transform Correlation (WPJTC) technique has been proposed for efficient face recognition. The proposed technique uses discrete wavelet filter as preprocessing and can effectively accommodate various 3D facial distrotions, effects of noise, and illumination variations. After analyzing different forms of wavelet basis functions, an optimal method has been proposed by considering the discrimination capability and processing speed as performance trade-offs. The proposed technique yields better correlation discrimination compared to alternate pattern recognition techniques such as phase-shifted phase-encoded fringe-adjusted joint transform correlator. The performance of the proposed WPJTC has been tested using the Yale facial database and extended Yale facial database under different environments such as illumination variation, noise, and 3D changes in facial expressions. Test results show that the proposed WPJTC yields better performance compared to alternate JTC based face recognition techniques.

10203-10, Session 2

Multispectral iris recognition based on group selection and game theory

Foysal Ahmad, Kaushik Roy, Albert Esterline, North Carolina A&T State Univ. (United States)

A commercially available iris recognition system uses only a narrow band of the near infrared spectrum (700-900 nm) while iris images captured in the wide range of 405 nm to 1550 nm offer potential benefits to enhance recognition performance of an iris biometric system. A parallel game theoretic approach is applied to segment these wide spectral varieties of iris images. In this segmentation approach, a region-based segmentation approach is utilized along with edge-based methods to compensate for the weaknesses of each method. The novelty of this research is that a group selection algorithm based on coalition game theory is explored to select the best patch subset. In this algorithm, patches are divided into several groups based on their maximum contribution in different groups. Shapley values are used to evaluate the contribution of patches in different groups.

10203-11, Session 2

Phase conjugate Michelson interferometer for optical logic

Jed Khoury, Lartec, Inc. (United States)

We have demonstrated an arrangement of Michelson interferometer by replacing the two ordinary mirrors by a single externally pumped phase conjugate mirror. In this new arrangement, we find that for an interferometer with two equal arms, the path length difference is depend solely on the initial alignment of the two input beams , and only one state of the interferometer is possible by varying the direction of the readout beam vertically. However, small vertical changes in the direction of the readout beam do not cause any variation in the overlap between the output beams. Horizontal misalignment of the readout beam critically effect the output mainly due the Bragg mismatched conditions. The interferometer is proposed for the design all optical logic and associated fuzzy logic for ultrafast optical pattern recognition.

10203-12, Session 3

Point based interactive image segmentation using multiquadrics splines

Prakash Duraisamy, Univ. of Central Missouri (United States); Sachin Meena, Univ. of Missouri (United States)

Multiquadrics (MQ) are radial basis spline function that can provide an efficient interpolation of data points located in a high dimensional space. MQ were developed by Hardy [1] to approximate geographical surfaces and terrain modelling. In this paper we frame the task of interactive image segmentation as a semi-supervised interpolation where an interpolating function learned from the user provided seed points is used to predict the labels of unlabeled pixel and the spline function used in the semi-supervised interpolation is MQ. This semi-supervised interpolation framework has a nice closed form solution which along with the fact that MQ is a radial basis spline function lead to a very fast interactive image segmentation process.

Quantitative and qualitative results on the standard datasets show that MQ outperforms other regression based methods, GEBS [2], Ridge Regression [3] and Logistic Regression, and popular methods like Graph Cut [4], Random Walk [5] and Random Forest [6].

10203-13, Session 3

Utilization of the modified forward backward linear predication approach to isolate anomalous events

Vahid R. Riasati, Raytheon Space and Airborne Systems (United States)

The Modified Forward Backward Linear Prediction, MFBLP, is powerful technique that enables an adaptive dimensionality reduction of the data through the estimation of the frequency domain representation of the data poles and the utilization of the ensuing transfer function for dimensionality reduction of the data. In this work, we isolate a data-region that is expected to encompass the statistical majority of a given anomalous event relative to the statistical common data points. The isolated anomalous events are the compared with the adaptively filtered data extracted by using the MFBLP and the comparison is utilized to isolate the anomalous events of interest. A Markov Chain Monte Carlo enables us to provide some statistics for the performance of this approach for anomalous events isolation.

10203-14, Session 3

Automatic parking availability detection using multi sensor fusion

Prakash Duraisamy, Sachin Meena, Univ. of Central Missouri (United States)

The availability of parking spaces on the University or Commercial lot campus is a significant problem, and looking through crowded lots for available spots during peak hours is both frustrating and time-consuming. In this proposal we propose to develop an economical system which will be handy and easy to use for the driver. In our approach, drivers are notified by a phone app when they search for a parking spot. Instead of searching for the spot by a random search, a phone app will direct the driver to the nearest available spot based on their current position. Specifically, this would be an important application for visitors to the parking lot during peak hours. This application is done with the help of fusing camera sensor and LiDAR. This approach can be used for all climatic conditions

10203-15, Session 3

Time-to-impact estimation in passive missile warning systems

Mehmet Cihan Sahingil, TÜB?TAK B?LGEM ?LTAREN (Turkey)

A Missile Warning System (MWS) is one of the most crucial Electronic Support systems of an Electronic Warfare (EW) suit on air platforms. It can detect incoming missile threat(s) and automatically cue the other Electronic Attack systems in the suit, such as Directed Infrared Counter Measure–DIRCM system and/or Counter Measure Dispensing System–CMDS. The most MWSs are currently based on passive sensor technology operating in either Solar Blind Ultraviolet (SBUV) or Midwave Infrared (MWIR) bands on which there is an intensive emission from the exhaust plume of the threatening missile. Although the passive MWSs have some clear advantages over pulse-Doppler radar (PDR) based active MWSs, they shows poorer performance in terms of time-to-impact (TTI) estimation which is critical for optimizing the countermeasures and also "passive kill assessment". Estimating the TTI from passive measurements is a difficult problem due to inherent "low observability"of the parameter. In this paper, we consider this problem, namely, TTI estimation from passive measurements and present a TTI estimation scheme which can be used in passive MWSs. Our problem formulation is based on Extended Kalman Filter (EKF). The algorithm uses the area and intensity parameters of the threat plume which are derived from the used image frame. We present the estimation results using Monte Carlo simulations.

10203-16, Session 3

Compressed imagery detection rate through map seeking circuit and histogram oriented gradient pattern recognition

Kathy Newtson, Johns Hopkins Univ. Applied Physics Lab., LLC (United States); Charles C. Creusere, New Mexico State Univ. (United States)

This research investigates the features retained after image compression for automatic pattern recognition purposes. Many raw images with vehicles in them were collected for these experiments. These raw images were significantly compressed using open-source JPEG and JPEG2000 compression algorithms. The original and compressed images were processed with a Map Seeking Circuit (MSC) pattern recognition algorithm, then a Histogram Oriented Gradient (HOG) with Support Vector Machine (SVM) pattern recognition program. Detection rates were plotted for these images and demonstrated the feature extraction capabilities as well as false alarm rates when the compression increased. JPEG2000 compression results show preservation of the features needed for automatic pattern recognition was better than the JPEG standard image compression.

10203-26, Session PWed

Image encryption with chaotic map and Arnold transform in the gyrator transform domains

Jun Sang, Pei Guo, Chongqing Univ. (China); Jun Zhao, Huazhong Univ. of Science and Technology (China); Xiaofeng Xia, Hong Xiang, Bin Cai, Chongqing Univ. (China)

Gyrator transform is a new optical transform, which has been used for image encryption in recent years. Chaotic maps or Arnold transform can be used in gyrator transform based image encryption with different ways to enhance the security or improve the efficiency of the encryption methods.

In this paper, an image encryption method combing chaotic map and Arnold transform in the gyrator transform domains was proposed. Firstly, a random binary sequence is generated with a logistic map. Then, the original secret image is XOR-ed with the binary sequence. After that, a gyrator transform is performed. Finally, the amplitude and phase of the gyrator transform are permutated by Arnold transform. In the proposed method, the secret keys include the control parameter and the initial value of the logistic map, the rotation angle of the gyrator transform, and the transform number of the Arnold transform. Therefore, the key space is large, while the key data quantity is small. The numerical simulation was conducted to demonstrate the effectiveness of the proposed method and the security analysis was performed in terms of the histogram of the encrypted image, the sensitiveness to the secret keys, decryption upon ciphertext loss, and resistance to the chosen-plaintext attack.

10203-27, Session PWed

Comparison of sub-scaled to full-scaled aircrafts in simulation environment for air traffic management

Mohamed I. Elbakary, Khan M. Iftekharuddin, Yiannis E. Papelis, Brett Newman, Old Dominion Univ. (United States)

Air Traffic Management (ATM) concepts are commonly tested in simulation to obtain preliminary results and validate the concepts before adoption. Recently, the researchers found that simulation is not enough because of complexity associated with ATM concepts. In other words, full-scale tests must eventually take place to provide compelling performance evidence before adopting full implementation. Testing using full-scale aircraft produces a high-cost approach that yields high-confidence results but simulation provides a low-risk/low-cost approach with reduced confidence on the results. One possible approach to increase the confidence of the results and simultaneously reduce the risk and the cost is using unmanned sub-scale aircraft in testing new concepts for ATM. This paper presents the simulation results of using unmanned sub-scale aircraft in implementing ATM concepts compared to the full scale aircraft. The results of simulation show that the performance of sub-scale is quite comparable to that of the full-scale which validates use of the sub-scale in testing new ATM concepts.

10203-18, Session 4

Wavelet filtered local phase pattern for face recognition

Md. Moniruzzaman, Nfina Technologies, Inc. (United States); Mohammad S. Alam, Texas A&M Univ.-Kingsville (United States)

A new image representation method is proposed for face recognition called wavelet filtered local phase pattern (WLPP). In WLPP, the quadrant-bit codes are first extracted from faces based on the wavelet transformation using Daubechies basis function. Local phase pattern (LPP) are then proposed to encode the phase variations. Recognition is performed by shifted phase-encoded joint transform correlator (SPJTC) classifier with histogram intersection as the similarity measurement. The proposed algorithm can effectively accommodate various 3D facial distrotions, effects of noise, and illumination variations. After analyzing different order of Daubechies wavelet basis functions, an optimal method has been proposed by considering the discrimination capability and processing speed as performance trade-offs. The proposed technique yields better correlation discrimination compared to alternate pattern recognition techniques such as local phase based fringe-adjusted joint transform correlator. The performance of the proposed WLPP has been tested using the Yale and extended Yale facial database under different environments such as illumination variation, noise, and 3D changes in facial expressions. Test results show that the proposed WLPP yields better performance compared to alternate JTC based face recognition techniques.

10203-19, Session 4

Multi-texture local ternary pattern for face recognition

Almabrok Essa, Vijayan K. Asari, Univ. of Dayton (United States)

In imagery and pattern analysis domain a variety of descriptors have been proposed and employed for different computer vision applications like face detection and recognition. Many of them are affected under different conditions during the image acquisition process such as variations in illumination and presence of noise, because they totally rely on the image intensity values to encode the image information. To overcome these problems, a novel technique named Multi-Texture Local Ternary Pattern (MTLTP) is proposed in this paper. MTLTP combines the edges and corners based on the local ternary pattern strategy to extract the local texture features of the input image. Then returns a spatial histogram feature vector which is the descriptor for each image that we use to recognize a human being. Experimental results using a library for support vector machines (LIBSVM) classifier on two publicly available datasets justify our algorithm for efficient face recognition in the presence of extreme variations of illumination/lighting environments and slight variation of pose conditions.

10203-20, Session 4

Human face analysis on improving instructional techniques

Prakash Duraisamy, Univ. of Central Missouri (United States)

Data Mining is an interesting tool which will give some direct and hidden knowledge about what we are mining. In this paper, we propose a novel technique using human face analysis using computer vision techniques on class room. This computer vision technique classifies various gestures like curiosity, interesting, sad , happy , fun. This gesture will help to improve the teaching methodology in the class room and to understand the student's comfort level in the class and knowledge acquired by students. Data sets are taken from different classes and the results are promising.

10203-21, Session 4

All optical logic for optical pattern recognition and networking applications

Jed Khoury, Lartec, Inc. (United States)

In this paper, we propose architectures for all possible digital gates from two inputs based phase conjugate Michelson interferometer. Some of the gates need one interferometric step while other needed an interferometric operation consisting of two steps. The proposed optical gates can be used in several applications in optical network including, but not limited to all-optical packet routers switching, and implementation of all-optical error detection. The optical logic gates can also be used in recognition of noiseless rotation and scale invariant objects such as finger prints for home land security applications.

10203-22, Session 5

Extreme learning machine with variance inflation factor for robust pattern recognition

Sidike Paheding, Almabrok Essa, Maher Qumsiyeh, Vijayan K. Asari, Univ. of Dayton (United States)

Extreme Learning Machine (ELM), as a single hidden layer feedforward neural network, has shown very effective performance in pattern analysis and machine intelligence; however, there are some limitations that constrain further advances and applications in ELM, such as multicollinearity which refers to a scenario that two or more explanatory variables can be represented by a linear combination of each other, in other words, they are moderately or highly correlated. The generalization capability of ELM could be significantly deteriorated when multicollinearity is present in the Hidden Layer Output Matrix (HLOM) which causes the matrix becomes singular or ill-conditioning. To overcome such a problem, ridge regression can be utilized. The conventional way to avoid multicollinearity in ELM is achieved by precisely adjust ridge constant, which may not be a sophisticate solution to obtain the optimal value. In this paper, we present a solution for finding satisfactory ridge estimates by incorporating Variance Inflation Factors (VIF) during calculating output weights in ELM, we termed this technique as ELM-VIF. To be more specific, we first consider the standardized regression model and then compute VIF using HLOM. Consequently, we choose the ridge constant where the VIF is closest to 1. The reason is that at this value the multicollinearity in the data has insignificant impact on the ridge estimates. Experimental results on pattern classification show that the proposed ELM-VIF, compared with the original ELM, has better stability and generalization performance.

10203-23, Session 5

An approach to detecting deliberately introduced defects and micro-defects in 3D printed objects

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

The negative impact that can be created by defects of various sizes in 3D printed objects has been previously demonstrated by Zeltmann, et al. These defects may make the object unsuitable for its application or even present a hazard, if the object is being used for safety-critical applications or will be used by young children. Attackers may physically impair the printer or attack the printer, object files, settings or other key printing aspects electronically. This paper applies a quality assurance technology based on visible light sensing to this challenge and assesses its capability for detecting introduced defects of multiple sizes.

10203-24, Session 5

Rapid prototyping of FPGA-based real-time vision system: application to face recognition

Maher Jridi, Ayman Alfalou, ISEN Brest (France)

A great interest exist in implementing image processing techniques in FPGA to take advantage of the increasing computational capabilities of these devices. Today, the trend are about the rapid prototyping of embedded systems to tackle the complexity of the low-level description languages which represent to the developers of embedded vision systems. Thus, Multi-CPU/FPGA platforms have been introduced and considered as a serious solution for embedding vision applications such as Zynq family where the same chip contains ARM processor, configurable logic and many communication interfaces

By this paper, the major goal is to investigate the Multi-CPU/FPGA SoC (System on Chip) design flow and to transfer a know-how and skills to rapidly design embedded real-time vision system. Our aim is to show how the use of these devices can be benefit for system level integration since they make possible simultaneous hardware and software development. We will extend our existing work about implementation of image processing algorithms, and then move from algorithmic and VLSI architectures of DSP modules to a system level integration in order to perform vision systems. We take the facial recognition as case study since it has a great potential to be used in several applications such as video surveillance, building access control and criminal identification.

The designed system use the Xilinx Zedboard platform. Thisplatform is the central element of the developed vision system. The video acquisition is performed using either standard webcam connected to the Zedboard via USB interface or several camera IP devices. A network of 7 IP cameras has been developed behind a WiFi router which is connected to the SoC via Ethernet interface. The visualization of video content and intermediate results are possible with HDMI interface connected to HD display. Moreover, to gain in flexibility, we make the use of keyboard and mouse connected with a hub USB to the system. We have also installed in the Linux operating system an apache server to access the system functionalities via http request. This make possible the use of WiFi connected tablets and smart phones to ask some treatments and to visualize the results. Finally, the treatments embedded in the system are as follow: (i) pre-processing such as face detection implemented in the ARM and in the reconfigurable logic, (ii) software implementation of face recognition using either digital correlation or LBP (Local Binary Pattern), and (iii) database management to add and delete persons from the database.

10203-25, Session 5

FPGA design of FFT-2D for correlation-based pattern recognition

Maher Jridi, Ayman Alfalou, ISEN Brest (France)

Optical/Digital pattern recognition and tracking based on optical/digital correlation is a well-known technique to detect, identify, and localize a target object in a scene. Generally, the realization of optical correlation is based on the optical setup called 4f. Despite the simplicity of the correlation all-optical setup, its integration presents stringent requirements such as portability, aberration effects, alignment of components, and cost of optoelectronic devices. Thus alternate digital realization offers a serious solution. It consists in determining the degree of similarity between input image f(x,y) and a reference image (correlation filter H(u,v)).

Despite the limited number of treatments required by the correlation scheme, computational time and resources are relatively high. The most computational intensive treatment required by the correlation is the transformation from spatial to spectral domain and then from spectral to spatial domain. More particularly, the complexity of these transformations evolves nonlinearly with the image size and bit-width. Therefore, we need to understand these transformations in order to design them efficiently in hardware device. Indeed, the implementation of image processing application in electronic devices is an interesting opportunity to export treatments from digital simulators to real-life applications based on vision system prototypes.

Among several hardware targets, Xilinx FPGAs are interesting since they offer flexible tools and extensive IP libraries to accelerate embedded designs. We have designed FFT-2D and IFFT-2D along with the filter multiplication and memory management to obtain the correlation scheme. The hardware architecture of FFT-2D and IFFT-2D are very similar and based on the column/row separation technique (this means that we treat FFT-1D of the columns, we store the results in a transposition memory and we then treat FFT-1D of the row of the transposition memory). Moreover, FFT-2D and IFFT-2D architectures are designed to treat reference images taken from successive frames of a given video stored in a ROM. A ROM counter is used to give address of frame in the ROM video and to generate synchronization signals for FFT-1D modules. Then, 8-bit pixels of the ROM are used as input to the FFT1D module, where the outputs of the last are written in two RAMs to store real and imaginary coefficients. Two more counters are used to simultaneously write/read data in/from the ROM. Hence, we can write the FFT-1D coefficients of the second frame in the RAM and read in the same time the FFT-1D coefficients of the first frame. Accordingly, both FFT-1D modules work simultaneously in order to have a pipelined design which can speed-up the pattern recognition system. Finally, to alleviate constraints of the correlation, we used only the sign of the POF filter to perform the correlation. We have also studied the compromise between the robustness of the correlation in terms of recognition and the hardware performances of the correlation by varying the bit width of FFT-2D outputs.

10204-1, Session 1

Spline warp model for registering pushbroom multispectral imagery

Suhail Saquib, Matt Egan, Christopher M. Gittins, UTC Aerospace Systems (United States)

We describe an algorithm for registering spectral images acquired by a pushbroom multispectral scanner operating on an airborne or spaceborne platform subject to uncontrolled motion, i.e., time-dependent attitude (pitch, roll, and yaw) and non-linear variation in platform position with time. In contrast to imagery collected during straight and level flight, uncontrolled platform motion typically causes each band to be "warped" with respect to the others. The consequence of warping is that band-to-band misregistration cannot be corrected by a rigid translation (or rotation) of one image with respect to the other. Rigid translation compensates for gross band-to-band misregistration but residual misregistration post-rigid-translation must be corrected by a "de-warping" transformation. Determination of the de-warping transformation from image data is challenging. In this paper we formulate a powerful yet efficient model for the warp that takes into account both the detector array geometry and the imaging geometry. The physically-based geometric constraints imposed by the model enable it to distinguish effectively between image-to-image warp due to uncontrolled variations in the sensor line-of-sight and spatial variations in image content and measurement noise. Results show that the model is capable of recovering the true warp in areas where there is little or no correlation in spatial content between the bands. For the test cases studied, the spline-warp model described reduced misregistration by a factor of ≥10 relative to rigid translation alone.

10204-2, Session 1

Passive long-range imaging with a multi-view telescope system

Kristofor B. Gibson, Space and Naval Warfare Systems Command (United States)

Pristine optical imaging in the Earth's atmosphere is a difficult accomplishment---it not impossible---due mostly to atmospheric scattering, absorption and turbulence. The scattering and absorption is dependent on the type of light in the day, either overcast or cloudless in addition to the type and size of particulates in the air. This scattering and absorption decreases the contrast in the image of an object viewed through the atmosphere. Additionally, the turbulence causes the light to bend randomly as it reaches the camera sensor which causes the image to warp, dance, and appear blurry. All of these factors are amplified with long range imaging since the light propagates along even more atmosphere.

For increasing the contrast of images, many contrast enhancement techniques exist and are effective for long range imaging systems. However, contrast enhancement comes at a cost of also enhancing noise [1]. The SNR stays the same but the noise floor is raised and becomes observable by the human vision system because contrast masking no longer plays a role in hiding the noise [2]. In order to reduce the noise and effectively improve the SNR, our approach is to align and average the multiple images obtained simultaneously from the Multiview Telescope System.

Our approach to mitigating the turbulence is to also utilize the frame aligned images from the multiple imaging systems. This approach, however, is essentially long exposure imaging and thus the scene becomes blurred. In order to reduce the blur, a deconvolution method is used that is parameterized by the atmospheric coherence parameter, r0 [3]. In our approach is based on methods in [4,5] where we present a way to estimate the r0 parameter using the multiple views of the same scene.

References:

[1] Gibson, Kristofor B., and Truong Q. Nguyen. "An analysis and method for contrast enhancement turbulence mitigation." Image Processing, IEEE Transactions on 23, no. 7 (2014): 3179-3190.

[2] Moorthy, Anush Krishna, and Alan Conrad Bovik. "Blind image quality assessment: From natural scene statistics to perceptual quality." Image Processing, IEEE Transactions on 20, no. 12 (2011): 3350-3364.

[3] Fried, David L. "Statistics of a geometric representation of wavefront distortion." JOSA 55, no. 11 (1965): 1427-1431.

[4] Gibson, Kristofor B. "Stereo image motion monitor for atmospheric mitigation and estimation." In SPIE Optical Engineering+ Applications, pp. 961404-961404. International Society for Optics and Photonics, 2015.

[5] Whiteley, M. R.; Washburn, D. C. & Wright, L. A. "Differential-tilt technique for saturation-resistant profiling of atmospheric turbulence" International Symposium on Optical Science and Technology, 2002, 221-23

10204-3, Session 1

A comparison of optical architectures for constrained long-range imaging

Craig Olson, Timothy D. Goodman, Andrew W. Sparks, Craig S. Wheeler, L-3 Sonoma EO (United States)

Long-range airborne full-motion-video systems require large apertures to maximize multiple aspects of system performance, including spatial resolution and sensitivity. As systems push to larger apertures for increased resolution and standoff range, both mounting constraints and atmospheric effects limit their effectiveness. This paper considers two questions: first, under what atmospheric and spectral conditions does it make sense to have a larger aperture; second, what types of optical systems can best exploit movement-constrained mounting?

Airborne FMV gimbals often take one of two forms -- smaller, tactical targeting EOIR systems in which the entire payload is stabilized and slewed, or larger systems that only slew the large telescope mass. Although rules of thumb exist for system budgeting, few published studies exist that investigate practical aperture constraints for large-aperture non-directed-energy systems. The swept-volume-to-aperture (SV/A) ratio represents a good system metric for comparison, since system mass and power will generally scale as some power with swept volume.

We briefly explore the transition between aperture-limited MTF and turbulence-limited MTF regimes for long-range, high-altitude imaging in visible, SWIR, and MWIR spectral bands. After identifying relevant trades between aperture and range for various atmospheric models, we compare in more detail the SV/A differences between coudè-path variants of a Richtey-Chrétien (RC) telescope and off-axis three-mirror anastigmat (TMA). Restriction to the coudè-path architecture allows isolation of maximum possible aperture size as well as comparison among performance, mounting constraints, and mass-power characteristics.

10204-4, Session 1

pyBSM: A Python package for modeling imaging systems (Rising Researcher Presentation)

Daniel A. LeMaster, Michael T. Eismann, Air Force Research Lab. (United States)

There are a number of calculations that are common to all electro-optical and infrared imaging system performance models. Examples include calculation of modulation transfer function and signal-to-noise ratio. Code to implement these models has been generated many times over in government, academia, and industry at great expense in terms of time and money. The purpose of this Python Based Sensor Model (pyBSM) is to mitigate this expense in the future by providing an open source code-base for other researchers to build upon. Specifically, pyBSM implements many of the functions found in the ERIM Image Based Sensor Model (IBSM) V2.0 along with some suggested improvements. In addition to introducing

the model, this paper includes a use-case demonstration of a long range imaging system taken from the literature.

10204-5, Session 2

UAV imagery analysis: challenges and opportunities *(Invited Paper)*

Barbara G. Grant, Grant Drone Solutions, LLC (United States)

As UAV imaging continues to expand, so too do the opportunities for improvements in data analysis. These opportunities, in turn, present their own challenges including the need for real time radiometric and spectral calibration; the continued development of quality metrics facilitating exploitation of strategic and tactical imagery; and the need to correct for platform-induced artifacts in sensor data. This presentation will address these and related issues.

10204-6, Session 2

Enhancing data from commercial space flights

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

Video tracking of rocket launches inherently must be done from long range. Due to the high temperatures produced, cameras are often placed far from launch sites and their distance to the rocket increases as it is tracked through the flight. Consequently, the imagery collected is generally severely degraded by atmospheric turbulence. In this talk, we present our experience in enhancing commercial space flight videos. We will present the mission objectives, the unique challenges faced, and the solutions to overcome them.

10204-7, Session 2

Photo-acoustic and video-acoustic methods for remote sensing of distant sound sources

Dan Slater, Consultant (United States); Stephen T. Kozacik, Eric J. Kelmelis, EM Photonics, Inc. (United States)

Long range telescopic video imagery of distant terrestrial scenes along with aircraft, rockets and other aerospace vehicles can be a powerful observational tool. But what about the associated acoustic activity? A new technology, Remote Acoustic Sensing (RAS), may provide a means to remotely listen to the acoustic activity near these objects.

Local acoustic activity sometimes weakly modulates nearby ambient illumination in a way that can be remotely sensed. RAS is a new type of microphone that separates an acoustic transducer into two spatially separated components: 1) a naturally formed in situ acousto-optic modulator (AOM) located within the distant scene and 2) a remote sensing readout device that recovers the distant audio. These two elements are passively coupled over long distances at the speed of light by naturally occurring ambient light energy or other electromagnetic fields.

Stereophonic, multi-channel and acoustic beam forming are all possible using RAS techniques and when combined with high-definition video imagery it can help to provide a more cinema like immersive viewing experience.

A practical implementation of the remote acousto-optic readout device is a challenging problem. The acoustic influence on the optical signal is generally weak and with a strong bias term. The optical signal is often further degraded by atmospheric seeing turbulence. In this paper, we consider two fundamentally different optical readout approaches: 1) a low pixel count photodiode based RAS photoreceiver or 2) audio extraction directly from a video stream. Most of our RAS experiments to date have used the first method for reasons of performance and simplicity. But there are potential advantages to extracting audio directly from a video stream including the straight forward ability to work with multiple AOMs (useful for acoustic beam forming), simpler optical configurations, and a potential ability to use certain preexisting video recordings. However, doing so requires overcoming significant limitations typically including much lower sample rates, reduced sensitivity and dynamic range, more expensive video hardware, and the need for sophisticated video processing. The ATCOM real time image processing software environment provides much of the needed capabilities for researching video-acoustic signal extraction. It already provides a powerful tool for the visual enhancement of atmospheric turbulence distorted telescopic views. In order to explore the potential of acoustic signal recovery from video imagery we modified ATCOM to extract audio waveforms from the same telescopic video sources.

In this paper, we demonstrate and compare both readout techniques for several aerospace test scenarios to better show where each has advantages.

10204-8, Session 3

Comparing multiple turbulence restoration algorithms performance on noisy anisoplanatic imagery

Michael Rucci, U.S. Air Force (United States)

No Abstract Available

10204-9, Session 3

Quantifying the improvement of turbulence mitigation technology

Stephen T. Kozacik, Aaron L. Paolini, Ariel Sherman, James Bonnett, Eric J. Kelmelis, EM Photonics, Inc. (United States)

Atmospheric turbulence degrades imagery by imparting scintillation and warping effects that can reduce the ability to identify key features of the subjects. While visually, a human can intuitively understand the improvement that turbulence mitigation techniques can offer in increasing visual information, this enhancement is rarely quantified in a meaningful way. In this paper, we measure the potential improvement on system performance video enhancement algorithms can provide by exploring two metrics. We will look at datasets that include resolution targets to quantify improvements in resolvable features and MTF and we will use human subjects to determine the increase in performance of facial recognition algorithms after processing.

10204-10, Session 3

On the simulation and mitigation of anisoplanatic optical turbulence for long-range imaging

Russell C. Hardie, Univ. of Dayton (United States); Daniel A. LeMaster, Air Force Research Lab. (United States)

We present a numerical wave propagation method for simulating long range imaging of an extended scene under anisoplanatic conditions. Our approach computes an array of point spread functions (PSFs) for a 2D grid on the object plane. The PSFs are then used in a spatially varying weighted sum operation, with an ideal image, to produce a simulated image with realistic optical turbulence degradation. A novel validation analysis is presented

where we compare simulated outputs with the theoretical anisoplanatic tilt correlation and differential tilt variance. This is in addition to comparing the long- and short-exposure PSFs, and isoplanatic angle. Our validation analysis shows an excellent match between the simulation statistics and the theoretical predictions. The simulation tool is also used to quantitatively evaluate a new block-matching and Wiener filtering (BMWF) method for turbulence mitigation. A block-matching registration algorithm is used to provide geometric correction for each of the individual input frames. The registered frames are then averaged and processed with a Wiener filter for restoration. A novel aspect of the proposed BMWF method is that the PSF model used for restoration takes into account the level of geometric correction achieved during image registration. This way, the Wiener filter is able fully exploit the reduced blurring achieved by registration. The proposed BMWF method is relatively simple computationally, and yet, has excellent performance in comparison to state-of-the-art benchmark methods in our study.

10204-11, Session 3

Development of an embedded atmospheric turbulence mitigation engine

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

Methods to reconstruct pictures from imagery degraded by atmospheric turbulence have been under development for decades. The techniques were initially developed for observing astronomical phenomena from the Earth's surface, but have more recently been modified for ground and air surveillance scenarios. Such applications can impose significant constraints on deployment options because they both increase the computational complexity of the algorithms themselves and often dictate a requirement for low size, weight, and power (SWaP) form factors. Consequently, embedded implementations must be developed that can perform the necessary computations on low-SWaP platforms. Fortunately, there is an emerging class of embedded processors driven by the mobile and ubiquitous computing industries. We have leveraged these processors to develop embedded versions of the core atmospheric correction engine found in our ATCOM software. In this paper, we will present our experience adapting our algorithms for embedded systems on a chip (SoCs), namely the NVIDIA Tegra that couples general-purpose ARM cores with their graphics processing unit (GPU) technology and the Xilinx Zynq which pairs similar ARM cores with their field-programmable gate array (FPGA) fabric.

10204-12, Session 4

Image quality characterization in highly anisoplanatic conditions

Zhijun Yang, Univ. of Dayton (United States); Svetlana L. Lachinova, Optonicus (United States); Mikhail A. Vorontsov, Univ. of Dayton (United States) and Optonicus (United States); Daniel A. LeMaster, Air Force Research Lab. (United States)

Image quality metrics that are commonly used in astronomical applications for performance evaluation of adaptive optics systems (e.g. sharpness functions) were developed under assumption of isoplanatic or quasi-isoplanatic imaging conditions. Under these conditions, atmospheric turbulence causes the image blur. Another type of turbulence-induced image distortions characterized by the presence of geometric image warping is observed in highly anisoplanatic imaging conditions typical for airborne surveillance over slant paths in the atmosphere. Characterization of anisoplanatic images requires the development of new image quality metrics that are sensitive to both the image blur and warping. In this paper, we present new image quality metrics which can potentially be used for characterization of incoherent anisoplanatic images obtained in the presence of a spatially localized turbulent layer along the imaging path. The analysis is performed by means of numerical simulations based on the brightness function technique.

10204-13, Session 4

Enhancement of DARPA SRVS data with a real-time commercial turbulence mitigation software

Stephen T. Kozacik, Aaron L. Paolini, EM Photonics, Inc. (United States); Richard L. Espinola, U.S. Army RDECOM CERDEC NVESD (United States); Ariel Sherman, Eric J. Kelmelis, EM Photonics, Inc. (United States)

When capturing image data over long distances, images are often degraded by atmospheric turbulence, especially when imaging paths are close to the ground or in hot environments. These issues manifest as time-varying scintillation and warping effects that decrease the effective resolution of the sensor and reduce actionable intelligence. In recent years, several image processing approaches to turbulence mitigation have shown promise. EM Photonics has been developing image-processing-based turbulence mitigation technology since 2005 as a part of our ATCOM image processing suite. The performance of this technology is effected by the strength of the turbulence, range to target and subject. In 2012 a comprehensive dataset was collected to test the DARPA Super Resolution Vision System. This data set contains several different subjects including people holding weapons and other items, faces, and resolution targets at several ranges and turbulence strength. Each video is associated with a given turbulence strength measured using a scintillometer and a range. In this paper, we present our results processing data collected from this experiment with our commercially-available, real-time, GPU-accelerated turbulence mitigation software suite.

We will quantify the level of enhancement provided by our software using objective and subjective methods. The results of this evaluation should serve to provide system designers with an anticipated performance level that they can obtain by adding our technology to their current imaging systems for a given range and turbulence.

10204-14, Session 4

Open source acceleration of wave optics simulations on energy efficient high-performance computing platforms

Jeffrey R. Beck, Jeremy P. Bos, Michigan Technological Univ. (United States)

Wave Optics Simulations (WOS) are commonly used to model the effect of atmospheric turbulence on laser beam propagation and imaging. Within WOS operations involving the Fast Fourier Transform makes up a bulk of the computation time. Utilizing High Performance Computing (HPC) resources it is often possible to perform extensive WOS campaigns spanning wide swaths of a parameter space. However, there is increasing concern within the HPC community that escalating power consumption will outstrip improvements In processor speed improvement and algorithmic efficiency. Improving both execution time and reducing power consumption for WOS-type simulations is the primary objective of this work.

When we first introduced WavePy we touted an advantage of an open-source Python-based application as wide platform support. In addition, we mentioned the wide availability of new feature support, and optimized libraries. This work provides a first step in exploring those possibilities.

Our initial built of WavePy leveraged Numpy under Python 2.7 for handling array creation and transformation. Unlike regular Python, Numpy has the ability to easily cast data into multidimensional arrays and matrices and perform many different operations on said structures.

While the initial implementation of WavePy met the need for an open-

source WOS atmospheric propagation toolkit, it was still much slower in most scenarios than comparable WOS toolkits available on closed-source platforms. This lead to a profiling effort that revealed that most of the computation time was spent on executing the FFTs. Our next step was then to find and identify a faster implementation of the FFT within Python. The first solution we identified was to use Intel's Math Kernel Library(MKL) distribution of Python/Numpy, which boasted increased speeds with minimal integration effort. The Open Source Computer Vision Library(OpenCV) was identified as another candidate for testing as it leveraged the parallel processing capabilities of Nvidia's CUDA toolkit for array operations. The OpenCV implementation was alluring, because it provided the option to take full advantage of the embedded CUDA processing power of the Jetson TK1 and standard workstations. The power of OpenCV is further evidenced by a 17% decrease in execution time between Numpy and OpenCV implementations of WavePy when benchmarking several small scale demos. As the size and complexity of the simulation increases we believe that the GPU driven WavePy approach will outstrip the CPU based implementation by wider and wider margins.

Leveraging GPU-based solutions often leads to large increases in power consumption. Embedded parallel processing platforms such as the Nvidia Jetson TK1 can provide a small, cost effective solution for performing the same WOS that a High Performance Computing(HPC) resource can. While the TK1 is a much less powerful device, its power to performance ratio cannot be ignored when initial power usage benchmarks show a typical workstation using approximately 0.150kW versus the TK1 consuming only 0.015kW during the same simulation.

This paper will detail a benchmarking campaign between OpenCV, Intel MKL, and Numpy across several simulation scenarios in WavePy and across several different computing platforms. We show not only a significant decrease in execution time by leveraging OpenCV, but a significant decrease in relative power consumption when using Nvidia's Jetson TK1.

10204-15, Session 4

Anisoplanatic image propagation along a slanted path under low atmosphere phase turbulence in the presence of encrypted chaos

Monish R. Chatterjee, Ali A. Mohamed, Univ. of Dayton (United States)

In recent research, anisoplanatic electromagnetic (EM) wave propagation along a slanted path in the presence of low atmosphere phase turbulence (modified von Karman spectrum or MVKS) has been investigated assuming a Huffnagel-Valley (HV) type structure parameter. Preliminary results indicate a strong dependence on the slant angle especially for long range transmission and relatively strong turbulence. The investigation was further divided into two regimes, viz. (a) one where the EM source consisted of a plane wave modulated with a digitized image, which is propagated along the turbulent path and recovered via demodulation at the receiver; and (b) transmit the plane wave without modulation along the turbulent path through an image transparency and a thin lens designed to gather the received image in the focal plane. In this paper, we re-examine the same problem (part (a) only) in the presence of a chaotic optical carrier where the chaos is generated in the feedback loop of an acousto-optic Bragg cell. The image information is encrypted within the chaos wave, and subsequently propagated along a similar slant path and identical turbulence conditions. The recovered image extracted via heterodyning form the received chaos is compared quantitatively (through image cross-correlations and mean-squared error measures) for the non-chaotic versus the chaotic approaches. Generally, "packaging" the information in chaos improves performance through turbulent propagation, and results are discussed from this perspective. Concurrently, we will also examine the effect of a non-encrypted plane EM wave propagation through a transparency-lens combination. These results will be presented at a follow-up meeting.

10204-16, Session PSTue

Large-scale object's measurement method research based on multi-view reconstruction

Shaowen Ding, Xiaohu Zhang, Qifeng Yu, Jie Wang, National Univ. of Defense Technology (China)

Large scale object is difficult to measure its size because of the complicated shape.

The traditional contact measuring method's range is limited, and is not suitable for curved structure. Optical non-contact measurement is a better choice to deal with this situation. Multi-view reconstruction measurement method is used in this paper. It belongs to passive measurement in optical non-contact measurement. It only uses a digital camera to take pictures of large objects from a number of locations and angles.

Establish the matching relationship between the images, and get the matching pairs of any two frame image. Select two images with high coincidence degree and suitable for the two view intersection, and build the initial point cloud by calculating the triangle intersection with camera's information. Calculate the other images' camera position at the reference coordinate system by using rear intersection of PNP and adjustment of the beam method. Then update the point cloud by triangle intersection with the other images, and obtain the whole and accurate spatial point cloud. The point cloud is different from the actual size by a scaling factor. Therefore, we add a scale rod in the field of view, and then scale the reconstructed point cloud to the actual size. The key points in the cloud space coordinates can be calculated to obtain the desired results of the object.

The experimental results show that the method can effectively reconstruct the sparse point cloud of large objects, and accurately measure the size and other information. For 5m to 10m objects, the measurement accuracy is less than 1mm.

Conference 10205: Open Architecture/Open Business Model Net-Centric Systems and Defense Transformation 2017

SPIE. DCS DEFENSE+ SECURITY

Tuesday - Thursday 11–13 April 2017

Part of Proceedings of SPIE Vol. 10205 Open Architecture/Open Business Model Net-Centric Systems and Defense Transformation 2017

10205-1, Session 1

Sensor open system architecture (SOSA) evolution for collaborative standards development *(Invited Paper)*

Ilya Lipkin, Air Force Life Cycle Management Ctr. (United States)

No Abstract Available

10205-2, Session 1

GBU-X: Bounding requirements for highly flexible munitions *(Invited Paper)*

Jonathan D. Shaver, Air Force Research Lab. (United States)

No Abstract Available

10205-3, Session 1

Mission systems open architecture *(Invited Paper)*

Kenneth Littlejohn, Air Force Research Lab. (United States)

No Abstract Available

10205-5, Session 1

A standards based approach to multi-INT payload integration *(Invited Paper)*

George C. Dalton, KEYW Corp. (United States)

No Abstract Available

10205-6, Session 2

Introduction to model based design

Patrick Jungwirth, U.S. Army Research, Development and Engineering Command (United States)

We present an introduction to model based design. Model based design is a visual representation, generally a block diagram, to model and incrementally develop a complex system. Model based design is a commonly used design methodology for digital signal processing, control systems, and embedded systems. Model based design's philosophy is to solve a problem: a step at a time. The approach can be compared to a series of linear steps to converge to a solution. A block diagram simulation tool allows a design to be simulated with real world measurement data. For example, if an analog control system is being upgraded to a digital control system, the analog sensor input signals can be recorded. The digital control algorithm can be simulated with the real world sensor data. The output from the simulated digital control system can then be compared to the old analog based control system.

Model based design can compared to Agile software develop. The Agile software development goal is to develop working software in incremental steps. Progress is measured in completed and tested code units. Progress is measured in model based design by completed and tested blocks.

We present a concept for a simple control system and then use a model based design to iterate the design to a working solution.

10205-7, Session 2

EASEE: An open architecture approach for modeling battlespace signal and sensor phenomenology

Lauren E. Waldrop, D. Keith Wilson, Michael T. Ekegren, U.S. Army Engineer Research and Development Ctr. (United States)

Open architecture in the context of defense applications encourages collaboration across government agencies and academia. This paper describes a success story in the implementation of an open architecture framework that fosters transparency and modularity in the context of EASEE (Environmental Awareness for Sensor and Emitter Employment), a complex physics-based software package that models the effects of terrain and atmospheric conditions on signal propagation and sensor performance. Among the highlighted features in this paper are the following: (1) a code re-factorization to separate sensitive parts of EASEE, thus allowing collaborators the opportunity to view and interact with non-sensitive parts of the EASEE framework with the end goal of supporting collaborative innovation, (2) a data exchange and validation effort to enable the dynamic addition of signatures within EASEE thus supporting a modular notion that components can be easily added or removed to the software without requiring a recompilation effort by developers, and (3) a flexible and extensible XML interface that aids in decoupling graphical user interfaces from EASEE's calculation engine, and thus encourages adaptability to many different defense applications. In addition to the outlined points above, this paper also addresses EASEE's ability to interface with both proprietary systems such as ArcGIS and MATLAB, and open GIS systems like OpenLayers3. A specific use case regarding the implementation of an ArcGIS toolbar that leverages EASEE's XML interface and enables users to set up an EASEE compliant configuration for probability of detection or optimal sensor placement calculations in various modalities is discussed as well.

10205-8, Session 2

Supporting Army modular open system architecture, utilizing open standards (FACE and CS), extending legacy NAVSEA product line architecture, and engineering through model driven development

Ronald W. Townsen, Matthew L. Wagner, General Dynamics Mission Systems (United States)

The Army (PM UAS) with software support from General Dynamics Mission Systems (GDMS) is developing a Product Line approach for Unmanned Vehicle Control Systems governed by the Future Airborne Capability

Environment (FACE™, a Modular Open System Architecture) standard, engineered through Model Driven Development (based on OMG standards of UML, SysML and UPDM – DoDAF tools) and leverages the Naval Sea Systems Command (NAVSEA) Shipboard Combat Systems Product Line Architecture. The approach employs the UAS Control Segment (UCS) design modularity to define and integrate modular processing sections. GDMS brings to the Army the expertise of developing the first two major modules for target tracking and base infrastructure design, referred to as the Component Frameworks (CF), in the NAVSEA Product Line to enable the DoD's "Better Buying Power" initiative.

10205-9, Session 2

Using virtual reality and game technology to assist command and control

Lorien Riead, ADG Creative (United States); James Straub, Joe Mangino, General Dynamics Mission Systems (United States)

Recent improvements in virtual reality technology have brought this technology to the point where low-cost commercially available devices can realistically provide an immersive alternative to the traditional monitor and keyboard view of the tactical space. Using the Unity Game Engine and the HTC Vive, we have created a concept of such a display to allow for real-time immersive planning and strategy.

This concept includes a virtual table providing an overhead view of the operational environment, with controls to allow for pan and zoom to allow the table operator to examine the surrounding area. This operator can also place objects to represent units and camps, or iconography. This also has the ability to connect to existing tactical information sources, allowing real-time updates and positioning that reflects ground truth.

The operator can also enter the map, placing themselves at scale inside the environment. Through the use of game objects and/or imported LIDAR data, this allows the operator to explore the terrain and gain a sense of the environment at scale.

To allow for collaboration, we were able to use the positioning provided by the HTC Vive to create an avatar within the space that mimics the head and hand gestures of each user. This allows for collaboration and communication within the VR space, which is otherwise limited by the headset.

By using a game engine to create this environment, we are able to build upon concepts that allow us to quickly add value to the space, such as user controls, artificial gravity, and interaction. This allows for rapid prototyping of new objects and spaces, and reduces the time from initial concept to working simulation.

10205-10, Session 3

Communication networks for the tactical edge *(Invited Paper)*

Joseph B. Evans, Defense Advanced Research Projects Agency (United States); Steven G Pennington, Benjamin J Ewy, Tactical Blue Laboratories, LLC (United States)

No Abstract Available

10205-11, Session 3

Multi-node, multi-sensor image tracking and localization for target engagement *(Invited Paper)*

Anthony Rotolo, U.S. Army Tank-Automotive and Armaments Command (United States)

No Abstract Available

10205-12, Session 3

Low-cost attritable aircraft technologies *(Invited Paper)*

Trenton White, Air Force Research Lab. (United States)

No Abstract Available

10205-13, Session 3

Evaluation of Q-learning based rendezvous for cognitive radio networks in a dynamic spectrum emulated environment

Clifton L. Watson, Reginald Cooper, Vasu Chakravarthy, Air Force Research Lab. (United States); Subir Biswas, Michigan State Univ. (United States)

Defense, government, and commercial wireless sectors rely heavily upon access to the electromagnetic spectrum. The growing need for more spectrum by all sectors has led to the need to develop spectrum sharing technologies that provide a more efficient use of spectrum. Such technologies are known as dynamic spectrum access (DSA), where unlicensed secondary users operate on licensed spectrum while not impeding the rights of licensed primary users (PUs). As key enablers of DSA technologies, cognitive radios (CRs) are based on software-defined architectures and thus have the capability to sense, learn, and adapt to the spectrum environment. To establish a network, these radios must be able to rendezvous or find each other on a common channel to create a link for exchanging data and information. This is a challenging problem because PUs may appear on a channel at any time. Competing CRs may transmit on the same channel and collide with each other which exacerbates the problem. In this paper, we evaluate a Q-learning based rendezvous protocol for cognitive radio networks in the dynamic spectrum access emulator known as DYSE. We show that the protocol outperforms existing rendezvous approaches in various DSA environments.

10205-14, Session 3

System architecture of communication infrastructures for PPDR organisations

Wilmuth Müller, Fraunhofer-Institut für Optronik, Systemtechnik und Bildauswertung (Germany)

The growing number of events affecting public safety and security (PS&S) on a regional scale with potential to grow up to large scale cross border disasters puts an increased pressure on organizations responsible for PS&S. In order to respond timely and in an adequate manner to such events Public Protection and Disaster Relief (PPDR) organizations need to cooperate, align their procedures and activities, share the needed information and be interoperable.

Existing PPDR/PMR technologies do not provide broadband capability,

which is a major limitation in supporting new services hence new information flows and currently they have no successor. There is also no known standard that addresses interoperability of these technologies.

The paper at hands provides an approach to tackle the above mentioned aspects by defining an Enterprise Architecture (EA) of PPDR organisations and a System Architecture of next generation PPDR communication networks for a variety of applications and services on broadband networks, including the ability of inter-system, inter-agency and cross-border operations.

The Open Safety & Security Architecture Framework (OSSAF) provides a framework and approach to coordinate the perspectives of different types of stakeholders within a PS&S organisation. It aims at bridging the silos in the chain of commands and on leveraging interoperability between PPDR organisations. The framework incorporates concepts of several mature enterprise architecture frameworks including the NATO Architecture Framework (NAF). However, OSSAF is not providing details on how NAF should be used for describing the OSSAF perspectives and views.

In this contribution a mapping of the NAF elements to the OSSAF views is provided. Based on this mapping, an EA of PPDR organisations with a focus on communication infrastructure related capabilities is presented. Following the capability modelling, a system architetcure for secure and interoperable communication infrastructures for PPDR organisations is presented. This architetcure was implemented within a project sponsored by the European Union and succesfully demonstrated in a live validation exercise in June 2016.

10205-15, Session 3

Sensor network architecture for monitoring turtles on seashore

Manuel Alejandro Diaz, Blanca E. Carvajal-Gamez, Instituto Politécnico Nacional (Mexico); Carolina Escobar, Abilene Colin, ASUPMATOMA A.C. (Mexico); Victor Cruz, Andrea Franco, Chadwick Carreto, Instituto Politécnico Nacional (Mexico)

In the last decade advances in information and communication technologies (ICT) have allowed that use of sensor networks has been diversified with the aim to sense, automate and optimize processes of distinct knowledge areas (medicine, economy, education, environmental protection, etc.). Such is the case in recent years have been used distinct types of sensor networks to study and research different species of animals in their natural habit. The characteristics of a sensor network (flexibility and autonomy) make them one useful technology tool to study some species of animals without modifying or invade their habitat and avoiding changes in their behavior.

Turtles are one of the species of which we can obtain valuable information to analyze climate change on the planet, this is due to these specimens travel great distances across the oceans and their nesting cycles are highly related environmental conditions. Because of this reason we present a design, development and implementation of a sensor network architecture for acquire information of turtles that arrive to the coast of Baja California Sur, Mexico. This will allow that through non-invasive methods for the species and their habitat, get information that is usefull for investigations, such as the position of the specimen, ambient temperature, humidity, water salinity, etc., with a higher degree of accuary to the conventional techniques, and allowing to store the information in databases that allow further analysis.

10205-16, Session 3

Application of assurance-driven design to capability set management

Joseph B. Kroculick, Winifred Associates, LLC (United States)

The Army's Network Modernization strategy is based on rolling out network capabilities. In the capability set management approach, capabilities are implemented across multiple systems of systems and delivered as a unified whole. The future Tactical Internet is likely to be increasingly varied in the type and number of network devices which interact to deliver dynamically changing service requirements. Initiatives such as software-defined networks, cloud computing and the internet of things present complex configurations and usage scenarios that need to be tested. Network behavior will increasingly be determined through a configuration strategy that determines how resources will be placed in service. As a result, network management processes must find new configuration validation solutions that are automated and fast in proving that a service works.

An increasing number of provisioning options and resource types motivates the need for new tools to provide assurance to a network administrator that the network devices are provisioned correctly and avoid unintended human errors. Reliable network systems depend on well-designed software and configuration options provided to an administrator.

This paper describes an assurance-driven design process to engineer desired network behaviors directly from device configuration commands. An important step towards increasing network dependability is to establish that the infrastructure actions enable desired service requirements to be achieved. Assurance cases, also known as dependability cases and safety cases, can demonstrate that capability requirements are achieved by connecting the goals of the capability to particular network resource configurations. These implementation decisions are structured into a proof that the capability's associated service level agreement is met. A case study is provided to ensure that mission command applications can select the best network to convey high-priority command and control messages.

10205-17, Session 4

Hardware ppen systems technology (HOST) *(Invited Paper)*

Charles Collier, U.S. Navy (United States)

The Hardware Open Systems Technology (HOST) effort is focused in the development of a common set, or suite of hardware modules that are essential building blocks which gives an end user the capability to easily generate a build based upon their specific set of operational requirements. Each module is scalable and flexible in that its inherent capabilities sufficient as a solution to other associated applications. The key to the success of the effort is adherence and conformance to an agreed upon set of interfaces that provide sufficient scope for a vendor, while enabling innovation inside the interfaces.

10205-18, Session 4

The next generation space interconnect standard (NGSIS) *(Invited Paper)*

Charles Collier, U.S. Navy (United States)

The Next Generation Space Interconnect Standard (NGSIS) effort is a Government-Industry collaboration effort to define a set of standards for interconnects between space system components with the goal of cost effectively removing bandwidth as a constraint for future space systems. The NGSIS team has selected the ANSI/VITA 65 OpenVPX(TM) standard family for the physical baseline. The RapidIO protocol has been selected as the basis for the digital data transport. The NGSIS standards are developed to provide sufficient flexibility to enable users to implement a variety of system configurations, while meeting goals for interoperability and robustness for space. The NGSIS approach and effort represents a radical departure from past approaches to achieve a Modular Open System Architecture (MOSA) for space systems and serves as an exemplar for the civil, commercial, and military Space communities as well as a broader high reliability terrestrial market.

10205-19, Session 5

Open architecture research support of AFRL electronic Warfare *(Keynote Presentation)*

Michael Nowak, Air Force Research Lab. (United States)

No Abstract Available

10205-20, Session 5

Blue Guardian: open architecture intelligence, surveillance, and reconnaissance (ISR) demonstrations *(Invited Paper)*

Russell Shirey, U.S. Air Force (United States); Luke Borntrager, Mark DiPadua, Air Force Research Lab. (United States); David Green, U.S. Air Force (United States)

The Air Force Research Laboratory Sensors Directorate has developed the Blue Guardian program to demonstrate advanced sensing technology utilizing open architectures in operationally relevant environments. Blue Guardian has adopted the core concepts and principles of the Air Force Rapid Capabilities Office (AFRCO) Open Mission Systems (OMS) initiative to implement an open Intelligence, Surveillance and Reconnaissance (ISR) platform architecture. Using this new OMS standard provides a business case to reduce cost and program schedules for industry and the Department of Defense (DoD). Blue Guardian is an early adopting program of OMS and provides much needed science and technology improvements, development, testing, and implementation of OMS for ISR purposes. This paper presents results and lessons learned under the Blue Guardian Project Shepherd program which conducted Multi-Int operational demonstrations in the Joint Interagency Task Force – South (JIATF-S) and USSOUTHCOM area of operations in early 2016. Further, on-going research is discussed to enhance Blue Guardian Multi-Int ISR capabilities to support additional mission sets and platforms, including unmanned operations over line of sight (LOS) and beyond line of sight (BLOS) datalinks. An implementation of additional OMS message sets and services to support off-platform sensor command and control using OMS/UCI data structures and dissemination of sensor product data/metadata is explored. Lastly, the Blue Guardian team is working with the AgilePod™ program to use OMS in a full Government Data Rights Pod to rapidly swap these sensors to different aircraft. The union of the AgilePod™ and OMS technologies under Blue Guardian programs is discussed.

10205-21, Session 6

Mission execution using a collaborative team of fixed wing aerial robots *(Invited Paper)*

Charles E. Pippin, Georgia Tech Research Institute (United States)

No Abstract Available

10205-22, Session 6

Multi-layer open system architecture for UAS swarm operations *(Invited Paper)*

Ryan K. Hersey, Georgia Tech Research Institute (United States)

No Abstract Available

SPIE. DCS DEFENSE+ SECURITY

10206-33, Session 1

Advancements in computing and computer architectures *(Keynote Presentation)*

Raju Namburu, U.S. Army Research Lab. (United States)

No Abstract Available

10206-1, Session 2

Digital modulation and achievable information rates of thru-body haptic communications

Natalie Hanisch, Massimiliano Pierobon, Univ. of Nebraska-Lincoln (United States)

The ever increasing biocompatibility and pervasive nature of wearable and implantable devices demand novel sustainable solutions to realize their connectivity, which can impact broad application scenarios such as the military, medical, and entertainment. Where wireless electromagnetic communications are facing challenges such as device miniaturization, energy scarcity, and limited range, solutions not only inspired but also based on natural communication means might result into valid alternatives. In this paper, modulation schemes where digital information is propagated through the nervous system are proposed and compared on the basis of their achievable information rates. In particular, these modulation schemes are based on an analytical and experimental frameworks previously proposed by the same authors, where the response of a system based on haptic (tactile) information transmission and ElectroEncephaloGraphy (EEG)-based reception is modeled and characterized. Computational neuroscience models of the somatosensory signal representation in the brain, coupled with empirical models of the noise sources at the EEG reception arising from cognitive processes and person-to-person variability, are employed in this paper to understand different options in encoding information bits into tactile stimulation, and decoding them from the recorded brain activity. In particular, action potential rate coding and temporal coding present in the nervous system are coupled with variable stimuli parameters, such as intensity, frequency, and location, and different techniques to process EEG data to compute the maximum bitrates achievable with absence of decoding errors at the receiver. Analytical results are validated by experimental data obtained through a real testbed implementation of the communication system.

10206-2, Session 2

Modular system for measuring a speech quality in the IP telephony infrastructures using autonomous probes

Filip Rezac, Miroslav Voznak, Jan Rozhon, Jakub Safarik, Lukas Macura, CESNET z.s.p.o. (Czech Republic)

Nowadays, the technology for Internet telephony - VoIP is widely used in the corporate sector as well as in SOHO (Small Office, Home Office) environments. This is because that the audio or video packet data communications bring not only economic benefit, but also the consolidation of transmission networks. It is common for most IP telephony infrastructures that in order to reduce the payload, the stream is separated from the rest of the network using virtual LANs (Local Area Networks), even though, it is desirable to monitor the quality of calls on each node.

The proposed system offers an elegant way to using network probes to measure and monitor speech quality on the route. The measured data are then sent to a central server in the form of Zabbix monitoring unit that allows the visualization of the results in the form of network maps, where peaks represent the probes and the measurement paths are shown in the form of evaluated edges. Probes and distances between them are displayed in the form of the actual geographic location. An implementation into network topology can be done using the virtual machine image, as well as tarball packages with source code designated for compilation. The stand-alone operating system based on Linux distribution is also available.

The system is developed mainly within research of the Czech educational and scientific network, but the tool can be deployed generally in any VoIP infrastructure. In order to assess speech quality, an intrusive measurement has been applied.

10206-3, Session 2

An energy-efficient and secure hybrid algorithm for wireless sensor network using a mobile data collector

Karanam Ravichandran Dayananda, Jeremy Straub, North Dakota State Univ. (United States)

This paper proposes a new hybrid algorithm which incorporates both distributed and hierarchal algorithms. It uses a mobile data collector (MDC) to collect information in order to save the energy of sensor nodes in a wireless sensor network as, in most networks, these sensor nodes have limited energy. Wireless sensor networks are prone to security problems because it is easy to use a rogue sensor node to eavesdrop on or alter the information being transmitted.

To prevent this, the proposed system also introduces a security algorithm. A key goal of this algorithm is to protect the confidentiality of the information sent by the sensor nodes. The sensor nodes are deployed in random fashion and form group structures called clusters. Each cluster will have a cluster head. The cluster head collects data from other nodes using the time-division multiple access (TDMA) protocol. The sensor nodes send their data to the cluster head for transmission to the base station node for further processing. The MDC acts as an intermediate node between the cluster head and base station. The MDC, using its dynamic acyclic graph (DAG) path, collects the data from the cluster head and sends it to base station. This approach is useful for applications including warfighting, intelligent building and medicine.

To assess the proposed system, the paper presents a comparison of its performance with other approaches and algorithms that can be used for similar purposes. Its performance under multiple defense-relevant scenarios is presented and assessed.

10206-4, Session 3

Multi-physics analysis of hybrid graphene/semiconductor plasmonic terahertz sources

Mona Nafari, Univ. at Buffalo (United States); Gregory R. Aizin, Kingsborough Community College (United States); Josep M. Jornet, Univ. at Buffalo (United States)

Wireless data rates have doubled every eighteen months for the last three decades. Following this trend, Terabit-per-second links will become a reality within the next five years. In this context, Terahertz (THz) band (0.1-10 THz) communication is envisioned as a key technology of the next decade. Despite major progress towards developing THz sources, compact signal generators above 1 THz able to efficiently work at room temperature

are still missing. Recently, the use of hybrid graphene/semiconductor high-electron-mobility transistors (HEMT) has been proposed as a way to generate Surface Plasmon Polariton (SPP) waves at THz frequencies. Compact size, room-temperature operation and tunability of the graphene layer, in addition to possibility for large scale integration, motivate the exploration of this approach. In this paper, a simulation model of hybrid graphene/semiconductor HEMT-based THz sources is developed. More specifically, first, the necessary conditions for the so-called Dyakonov-Shur instability to arise within the HEMT channel are derived, and the impact of imperfect boundary conditions is analyzed. Second, the required conditions for coupling between a confined plasma wave in the HEMT channel and a SPP wave in graphene are derived, by starting from the coupling analysis between two 2DEG. Multi-physics simulation are conducted by integrating the hydrodynamic equations for the description of the HEMT device with Maxwell's equations for SPP modeling. Extensive results are provided to analyze the impact of different design elements on the THz signal source. This work will guide the experimental fabrication and characterization of the devices.

10206-5, Session 3

An optofluidic channel model for in vivo nanosensor networks in human blood

Pedram Johari, Josep M. Jornet, Univ. at Buffalo (United States)

In vivo Wireless Nanosensor Networks (iWNSNs) consist of nano-sized communicating devices with unprecedented sensing and actuation capabilities, which are able to operate inside the human body. iWNSNs are a disruptive technology that enables the monitoring and control of biological processes at the cellular and sub-cellular levels. Compared to ex vivo measurements, which are conducted on samples extracted from the human body, iWNSNs can track (sub) cellular processes when and where they occur. Major progress in the field of nanoelectronics, nanophotonics and wireless communication is enabling the communication among nanosensors. Among others, plasmonic nanolasers with sub-micrometric footprint, plasmonic nano-antennas able to confine light in nanometric structures, and single-photon detectors with unrivaled sensitivity, enable the communication among implanted nanosensors in the near infrared and optical transmission window. Motivated by these results, in this paper, an optofluidic channel model is developed to investigate the communication properties and temporal dynamics between a pair of in vivo nanosensors in the human blood. The developed model builds upon the authors' recent work on light propagation modeling through multi-layered single cells and cell assemblies and takes into account the geometric, electromagnetic and microfluidic properties of red blood cells in the human circulatory system. The proposed model will not only guide the development of practical communication strategies among nanosensors, but also enables new nano-biosensing strategies able to identify diseases by detecting the slight changes in the channel impulse response, caused by either the change in shape of the blood cells or the presence of pathogens.

10206-6, Session 3

Temporal dynamics of frequency-tunable graphene-based plasmonic grating dtructures for ultra-broadband terahertz communication

Josep M. Jornet, Univ. at Buffalo (United States); Ngwe Thawdar, Air Force Research Lab. (United States); Ethan Woo, SUNY CNSE/SUNYIT (United States); Michael A. Andrello III, Virginia Polytechnic Institute and State Univ. (United States)

Wireless data rates have doubled every eighteen months for the last three decades. Following this trend, Terabit-per-second links will become a reality within the next five years. In this context, Terahertz (THz) band (0.1-10 THz) communication is envisioned as a key technology. Despite major progress towards developing THz sources, compact signal generators above 1 THz able to efficiently work at room temperature are still missing. Recently, the use of hybrid graphene/semiconductor high-electron-mobility transistors (HEMT) has been proposed as a way to generate Surface Plasmon Polariton (SPP) waves at THz frequencies. Compact size, room-temperature operation and tunability of the graphene layer, in addition to potential large-scale integration, motivate the exploration of this approach. In this paper, a simulation model of hybrid graphene/semiconductor HEMT-based THz sources is developed. First, the necessary conditions for the so-called Dyakonov-Shur instability to arise within the HEMT channel are derived, and the impact of imperfect boundary conditions is analyzed. Second, the required conditions for coupling between a confined plasma wave in the HEMT channel and an SPP wave in graphene are derived, by starting from the coupling analysis between two 2DEG. Multi-physics simulations are conducted by integrating the hydrodynamic equations for the description of the HEMT device with Maxwell's equations for SPP modeling. Extensive results are provided to analyze the impact of different design elements on the THz signal source. This work will guide the experimental fabrication and characterization of the devices.

10206-7, Session 4

Smart cyber-sensor for cyber-physical systems *(Invited Paper)*

Steve Hutchinson, Jason E. Ellis, Charmaine C. Sample, ICF International (United States)

The role of a cyber-sensor is to examine network traffic to which it is exposed, and then to collect and represent features of this traffic that can be used to analyze the current state of a monitored network. The traditional approach has been to use one or more sensors to collect everything (every packet), and then to organize these into batches and transmit each to an 'analysis preparation process'.

We believe that collection and representation should be tailored, even optimized to the analysis and decision processes they feed. Some analysis processes are packet-oriented; they attempt to categorize and label each packet analyzed to identify suspicious packets. Other processes are message and topology oriented, such as network flows and flow-analysis in which a sequence of packets are aggregated into a descriptive flow-record. Unfortunately, only very few packets can ever contain evidence features to inform an analysis process. Also, network flows will not contain indicator patterns (or signatures) and only represent half of the activity (a flow is a single direction sequence of messages from one process to another).

LSS (left-sided session) is the collection and representation algorithm used in the FEAT (session Feature Extraction and Analysis Tool) method. It allows heuristic- and selection-functions to determine which packets to collect and label. It also represents the features of sessions, the interleaving of the two constituent flows, to accurately represent the activity and causation of each.

10206-8, Session 4

Verification of OpenSSL version via hardware performance counters

James P. Bruska, Zander Blasingame, Chen Liu, Clarkson Univ. (United States)

Many forms of malware and security breaches exist today. One type of breach downgrades a cryptographic algorithm program by employing a man in the middle attack. One such attack is FREAK (Factoring Attack on RSA-EXPORT Keys) which downgrades the OpenSSL communication to use export cryptography. Previous research indicated that hardware events could be used to detect FREAK. This paper discusses the utilization of hardware events in conjunction with machine learning to detect which

version of OpenSSL is being run during the encryption process. This allows for the immediate detection of any unknown downgrade attacks in real-time.

In order to validate the concept, preliminary testing was conducted for TLS 1.0, TLS 1.1, and TLS 1.2. The testing collected data from hardware events by employing hardware performance counters within a custom compiled OpenSSL build. The hardware events were recorded whenever the encryption process was used within the initial connection protocol. A softmax regression neural network was then implemented in order to classify the data. The network takes in a vector of the hardware performance counters and returns an index corresponding to each class or OpenSSL version. The results showed that 5,000 sets of training data resulted in 100% accuracy for 5,000 sets of testing data. Additionally, preliminary testing showed that this method could be deployed in real-time situations.

10206-9, Session 4

Micromanaging the IOT space *(Invited Paper)*

Irak Mayer, ICF International (United States)

The Internet Of Things (IOT) devices will be an embedded part of our homes, work and daily life activities in the upcoming years. The challenges on device management, data extraction and security are an important on-going topic of research. This paper presents an approach to proper categorize and classify of these devices that will make device access, data analysis, network security and personal privacy efficient at an analytical and deployment juncture in the IOT space. The proposed methodology creates an architecture to simplify the addition of new devices into the local ecosystem by micromanaging similar populations of IOT devices and services.?

10206-10, Session 4

Disruptive innovation in cyber security *(Invited Paper)*

Misty Blowers, Air Force Research Lab. (United States)

No Abstract Available

10206-11, Session 4

Application of graph-based semi-supervised learning for development of cyber COP and network intrusion detection *(Invited Paper)*

Georgiy M. Levchuk, John Colonna-Romano, Aptima, Inc. (United States)

The United States increasingly relies on cyber-physical systems to conduct military and commercial operations, such as logistics, transportation, information sharing, energy production and distribution, financial transactions, elections, and infrastructure management. Attacks on these systems have increased dramatically around the globe. For example, the first known successful cyber-attack downed Ukrainian power grid in 2015. Even the U.S. is not immune from these attacks: for example, in 2016 the Russian hackers gained access to the Democratic Congressional Campaign Committee and to the Democratic National Committee, including a D.N.C. voter analytics program, and many voters' registration databases were under intrusion attacked throughout the year.

Cyber networks are traditionally protected by networked IDS systems coupled with active scanning appliances. However, these systems can only detect the penetration traffic with known intrusion signatures, and are highly ineffective against unknown threats. After the intruders gained access to the internal systems, traditional enterprise defenses are only effective in detecting obvious activities such as data exfiltrations. This is because the intelligent intruders may execute the operations that would individually appear legitimate. Still, they do not have the full visibility into the intruded network, and their actions may change the functional behavior of the network devices under their control. Thus, the technology is needed that can detect the functions of the network resources, and identify anomalies in the functional behaviors over time.

The data needed for traditional machine learning algorithms to construct the signatures and patterns of the devices' functional behavior is just not available. This is due to the fact that only a limited set of network traffic and device objects have accurate labels of the functions that corresponding devices execute. Most of the devices and traffic flows are unlabeled. This problem can be posed and solved using semi-supervised learning models, which can use unlabeled data in conjunction with a small amount of labeled data to produce considerable improvement in learning accuracy compared to supervised learning models.

In this paper, we present an application of graph-based semi-supervised learning (GSSL) to infer functions of networked devices. The model was selected due to its scalability to large number of data points, and the efficiency in handling the temporal changes in functions of the network resources.

10206-12, Session 5

Application of free energy minimization to the design of adaptive multi-agent teams *(Invited Paper)*

Georgiy M. Levchuk, Aptima, Inc. (United States); Krishna R. Pattipati, Univ. of Connecticut (United States); Adam Fouse, Daniel Serfaty, Aptima, Inc. (United States)

DoD confronts extraordinarily complex problems ranging from multi-source multi-modal information fusion, to crisis relief missions, to cyber exploitation and defense, to ground and air campaigns planning. To succeed, DoD planners organize available personnel and technologies into mission-based teams and organizations. Enabled by next generation of sensors, increasing capabilities of robotic platforms, and advances in machine learning and artificial intelligence for inference and control applications, the new types of teams are emerging that include autonomous collaborating human and machine actors.

Current methods to design these teams only exploit the strengths provided by each actor individually (e.g. large memory, processing speed, and precision of machines, or the generalization, learning & adaptation proficiencies of humans). However, most state-of-the-art team design solutions are able to construct only simple homogeneous human-machine organizations (e.g., a pilot and a set of UAVs, or an analyst and a set of information processing resources). Rarely, if ever, do these methods enable one type of agents (human or machine) to dynamically compensate for the weaknesses of the other (e.g., the lack of critical cognitive abilities in current machines, the prevalence of cognitive biases among human operators). Never are these methods capable of learning to improve the interoperation between human and machine actors. These capabilities are essential for designing heterogeneous teams operating in many uncertain environments where multiple actors with diverse capabilities are needed. One of the examples of such domains is the cyber-physical operations, which is critical to the U.S.'s national security and where the detections of intrusions and attacks require human analysts collaborating with distributed reconnaissance and exploitation technologies.

In this paper, we present a model based on free energy minimization to design an adaptive heterogeneous teams. The design consists of robust and adaptive team structure and strategy. The structure includes roles, relations, and the assignment of the human and machine actors to these roles. The team strategy is defined as an adaptive collaborative control and inference model to select the actions and update state inferences, respectively. Proposed energy-based design model was tested in several domains. The

teams executing our design showed high performance comparable to best empirical teams, with strategy adaptation executed in collaborative manner that mimicked natural human collaboration via influence belief messages.

Variational free energy is a functional of outcomes and a probability density over their (hidden) causes. Free energy principle explains how the biological systems maintain their order by restricting themselves to a limited set of internal states. Variational free energy minimization was shown to unify the perception (inference) and action (control). Previous applications included single-agent and multi-agent cooperative policy design. Our model is the first to couple the design of the team structure, including actor assignment, roles, and relations, with the design of the system's adaptive perception-action policy. We showcase the abstractions and principles of the energy-based team design in several domains, including command and control, cooperative problem solving, and cyber-physical planning and exploitation.

10206-13, Session 5

Cross domain optimization *(Invited Paper)*

Gustave W. Anderson, Lockheed Martin Corp. (United States)

No Abstract Available

10206-14, Session 5

Sensor and RFID integrity assurance against exploitation of dairy and herd management systems *(Invited Paper)*

Val Red, Air Force Research Lab. (United States); Michael Hellman, Syracuse Univ. (United States); Nick Ingersoll, Mohawk Valley Community College (United States)

Many industries apply sensors and remote frequency identification (RFID) in concert to achieve increased efficiency via automation; some, such as the meat and dairy industries, are additionally mandated to apply such mechanisms in certain countries for legal accountability. The United Stated Department of Agriculture, for example, requires that all livestock utilize RFID ear tags. Several of USDA approved ear tags – of varying sophistication – exist. Furthermore, herd management and dairy quality monitoring require sensors and management systems not unlike other forms of industrial control systems. Like other forms of industrial control systems, the aforementioned sensors and systems demand a modern security assessment and suggestions for design improvements for authentication and integrity assurance against potential wireless attacks with physical consequences. This paper examines dairy and herd management as a case study for cyber-physical attacks by scrutinizing industry standards among sensors, RFID devices, and their communication protocols in the context of authentication and communications' integrity concerns that could negatively impact meat and dairy production. Transponders, transceivers, and processing software are scrutinized in conjunction with their communication protocols. Additionally, device implementation-level and communications protocol-level improvements are recommended to mitigate future implementations of assuring integrity in sensors and RFID communications overall.

10206-15, Session 5

A computational framework for modeling targets as complex adaptive systems

Eugene S. Santos Jr., Dartmouth College (United States); Eunice E. Santos, John Korah, Suresh Subramanian, Vairavan Murugappan, Illinois Institute of Technology (United States)

Modeling large military targets is a challenge as they can be complex systems encompassing myriad combinations of human, technological, and social elements that interact, leading to complex behaviors. Moreover, such targets have multiple components and structures, extending across multiple spatial and temporal scales, and are in a state of change, either in response to events in the environment or changes within the system. Complex adaptive system (CAS) theory can help in capturing the dynamism, interactions, and more importantly various emergent behaviors, displayed by the targets. However, a key stumbling block is incorporating information from various intelligence, surveillance and reconnaissance (ISR) sources, while dealing with the inherent uncertainty, incompleteness and time criticality of real world information. To overcome these challenges, we present a probabilistic reasoning network based framework called complex adaptive Bayesian Knowledge Base (caBKB). caBKB is a rigorous, overarching and axiomatic framework that models two key processes, namely information aggregation and information composition. While information aggregation deals with the union, merger and concatenation of information and takes into account issues such as source reliability and information inconsistencies, information composition focuses on combining information components where such components may have well defined operations. Since caBKBs can explicitly model the relationships between information pieces at various scales, it provides unique capabilities such as the ability to de-aggregate and de-compose information for detailed analysis. Using a scenario from the Network Centric Operations (NCO) domain, we will describe how our framework can be used for modeling targets with a focus on methodologies for quantifying NCO performance metrics.

10206-16, Session 5

Data provenance assurance in the cloud using blockchain

Sachin S. Shetty, Old Dominion Univ. (United States); Val A. Red, Charles A. Kamhoua, Kevin A Kwiat, Air Force Research Lab. (United States)

[PENDING PUBLIC AFFAIRS APPROVAL] The Space Surveillance Network (SSN) is a distributed network of sensors which aid in tracking the position and velocity of all orbiting objects. The integration of SSN with cloud computing platform will realize on-demand surveillance sensor services. However, SSN-cloud is vulnerable to security threats, which allow adversaries to modify sensor data and impact accurate tracking. To realize a secure SSN cloud, there is a need for assured data provenance which will track changes to the data and identify the entity which caused the change. Blockchain technology has attracted interest due to a shared, distributed and fault-tolerant database that every participant in the network can share, ability to nullify adversaries by harnessing the computational capabilities of the honest nodes and information exchanged is resilient to manipulation.

In this paper, we present a cloud based data provenance framework using block chain which traces data record operations and generates provenance data. We anchor provenance data records into block chain transactions, which provide validation on provenance data and preserve user privacy at the same time. Once the provenance data is uploaded to the global block chain network, it is extremely challenging to tamper the provenance data. Besides, the provenance data uses hashed user identifiers prior to uploading so the blockchain nodes cannot link the operations to a particular user. The framework ensures that the privacy is preserved. We implemented the architecture on ownCloud, uploaded records to blockchain network, stored records in a provenance database and developed a prototype in form of a web service. [PENDING PUBLIC AFFAIRS APPROVAL]

10206-34, Session 6

New methods for enabling quantum computing with photonics *(Keynote Presentation)*

Michael L. Fanto, Air Force Research Lab. (United States)

No Abstract Available

10206-17, Session 7

Use of head-worn sensors to detect lapses in vigilance through the measurement of PERCLOS and cerebral blood flow velocity

Lindsey K. McIntire, R. Andy McKinley, Charles D. Goodyear, John P. McIntire, Air Force Research Lab. (United States)

The purpose of this study is to determine the ability of an eye-tracker to detect changes in vigilance performance compared to the common method of using cerebral blood flow velocities (CBFV). Sixteen subjects completed this study. Each participant performed a 40-minute vigilance task while wearing an eye-tracker and a transcranial doppler (TCD) on each of four separate days. The results indicate that percentage of eye closure (PERCLOS) measured by the eye-tracker increased as vigilance performance declined and right CBFV as measured by the TCD decreased as performance declined. The results indicate that PERCLOS (left eye r=-.72 right eye r=-.67) more strongly correlated with changes in performance when compared to CBFV (r=.54). We conclude that PERCLOS, as measured by a head-worn eye tracking system, may serve as a compelling alternative (or supplemental) indicator of impending or concurrent performance declines in operational settings where sustained attention or vigilance is required. Such head-worn or perhaps even off-body oculometric sensor systems could potentially overcome some of the practical disadvantages inherent with TCD data collection for operational purposes. If portability and discomfort challenges with TCD can be overcome, both TCD and eye tracking might be advantageously combined for even greater performance monitoring than can be offered by any single device.

10206-18, Session 7

Design and simulation of sensor networks for tracking WiFi users in outdoor urban environments

Christopher Thron, Khoi D. Tran, Texas A&M Univ.-Central Texas (United States); Douglas Smith, Air Force Research Lab. (United States); Daniel S. Benincasa, SUNY Polytechnic Institute (United States)

We present a proof-of-concept investigation into the use of sensor networks for tracking of WiFi users in outdoor urban envirnoments. Sensors are fixed, and are capable of measuring signal power from users' WiFi devices. We derive a maximum likelihood estimate for user location based on instantaneous sensor power measurements. The algorithm takes into account the effects of power control, and is self-calibrating in that the signal strength model used by the location algorithm is adjusted and improved as part of the operation of the network.

Simulation results to verify the system's performance are presented. The simulation scenario is based on a 1.5 km2 area of lower Manhattan, The self-calibration mechanism was verified for initial rms errors of 12 dB in the channel power estimates: rms errors were reduced to about 1dB within 300 track-hours.Under typical operating conditions, pedestrian location rms error is about 2 meters, with 95% accuracy within 4 meters; and vehicular location rms error is about 2.6 meters, with 95% accuracy within 5 meters. Distance errors are well-approximated by normal distributions.

The issue of optimal sensor placement in the sensor network is also addressed. We specify a linear programming algorithm for determining sensor placement for networks with reduced number of sensors. In our test case, the algorithm produces a network with 30% fewer sensors, with less than 10% performance degradation over the full network,

Finally, we discuss future research directions for improving the accuracy and capabilities of sensor network systems in urban environments.

Originator Reference Number: RIT-17-1218. Case Reviewer: Jeannie Masters Case Number: 88ABW-2017-0298 The material was assigned a clearance of CLEARED on 26 Jan 2017.

10206-19, Session 7

The virtual autonomous navigation environment: a high-fidelity modeling and simulation tool for the design and development of unmanned ground vehicles

Zachary T. Prevost, U.S. Army Engineer Research and Development Ctr. (United States)

Modeling and Simulation (M&S) play a critical role in the design and development of Unmanned Ground Vehicles (UGVs); however, many of the M&S tools used for UGVs have proven inadequate for predicting the behaviors of autonomous UGVs. The problem with many of these tools is that they are empirical or effects-driven, and they are incapable of recreating the complex situations a UGV might encounter in the real world. To better enable the design and development of autonomy algorithms and autonomous UGVs, the U.S. Army Engineer Research and Development Center (ERDC) has developed a high-fidelity, fully physics-driven M&S tools for simulating autonomous UGVs: The Virtual Autonomous Navigation Environment (VANE). The VANE was developed specifically to address the shortcomings found in empirical M&S tools. By being entirely physics-driven, the VANE can recreate the edge effects that arise from the complicated sensor-environment and vehicle-environment interactions that UGVs encounter in the real world. This way, the VANE allows developers to fully exercise their autonomy algorithms in simulation. The VANE uses an open architecture that allows users to easily plug in their own autonomy algorithms and vehicle models. The VANE has models for simulating the sensors commonly used for autonomous navigation, including cameras, LIDAR, and GPS, and uses a high-fidelity multi-body dynamics engine to simulate vehicle dynamics. A detailed overview of the VANE, including its architecture and its sensor, vehicle dynamics, and vehicle-terrain interaction models, will be presented. Additionally, the application of the VANE for autonomous convoy operations will be presented.

10206-20, Session 7

M and S supporting unmanned autonomous systems (UAxS) concept development and experimentation *(Invited Paper)*

James Sidoran, Air Force Research Lab. (United States); Frank Byrum, Spectrum (United States); Marco Biagini, Fabio Corona, NATO Modelling & Simulation Ctr. of Excellence (Italy); Olivia Fowler, Embry-Riddle Aeronautical Univ. (United States)

The development of the next generation of multi-domain unmanned semi and fully autonomous C4ISR systems involves a multitude of security concerns and interoperability challenges. Conceptual solutions to capability

shortfalls and gaps can be identified through Concept Development and Experimentation (CD&E) cycles. Modelling and Simulation (M&S) is a key tool in supporting unmanned autonomous systems (UAxS) CD&E activities and addressing associated security challenges. This paper serves to illustrate the application of M&S to UAxS development and highlight initiatives made by the North Atlantic Treaty Organization (NATO) M&S Centre of Excellence (CoE) to facilitate interoperability. The NATO M&S CoE collaborates with other NATO and Nations bodies in order to develop UAxS projects such as the Allied Command for Transformation Counter Unmanned Autonomous Systems (CUAxS) project or the work of Science and Technology Organization (STO) panels. Some initiatives, such as Simulated Interactive Robotics Initiative (SIRI) made the baseline for further developments and to study emerging technologies in M&S and robotics fields. Artificial Intelligence algorithm modelling, Robot Operating Systems (ROS), network operations, cyber security, interoperable languages and related data models are some of the main aspects considered in this paper. In particular, the implementation of interoperable languages like C-BML and NIEM MilOps are discussed in relation to a Command and Control - Simulation Interoperability (C2SIM) paradigm. All these technologies are used to build a conceptual architecture to support UAxS CD&E.In addition, other projects that the NATO M&S CoE is involved in, such as the NATO Urbanization Project could provide credible future operational environments and benefit UAxS project development, as dual application of UAxS technology in large urbanized areas.In conclusion, this paper contains a detailed overview regarding how applying Modelling and Simulation to support CD&E activities is a valid approach to develop and validate future capabilities requirements in general and next generation UAxS.

10206-22, Session 8

PCA characterization of photo-excited carrier population evolution in GaN computed via Monte Carlo simulations of the semiconductor bloch equations

Brent Kraczek, U.S. Army Research Lab. (United States)

Recent Monte Carlo simulations of the semiconductor Bloch equations of illuminated GaN have shown close agreement with experiments [1]. However, these calculations are characteristically noisy, and represent bulk, spatially uniform systems. High-fidelity surrogate models based on similar Monte Carlo calculations will likely be needed to extend these computations to structured optical components based on GaN, as well as enabling uncertainty quantification within such calculations.

We explore the evolution of these carrier populations through the use of principal components analysis (PCA), which can either be used as a surrogate model, or to inform non-linear surrogate models based on higher-order Gaussian process regression (GPR). In particular, we explore the character of the changes to carrier populations by examining the PCA results for sets of similar excitation states, with regard to total energy and E-field strength, excitation states throughout a single time-dependent evolution and the effects of Monte Carlo simulation parameters. We discuss the degree to which a distinction can be made between calculation parameters and noise, as well as the optimal number of degrees of freedom needed to represent the carrier excitation states. Finally, we estimate the ranges of exciting E-field and energy on which a single set of PCA can be extrapolated before a new domain must be used.

1. Shishehchi et al., J Appl. Phys. 114, 233106 (2013).

10206-23, Session 8

An integrated radar model solution for mission level performance and cost trades

John Hodge, Kerron Duncan, Rob Drupp, Dulce Castro, Madeline Zimmerman, Amelia Smith, Donald Barrett, Pat Dever, Rich Konapelsky, Northrop Grumman Electronic Systems (United States)

A fully integrated Mission-Level Radar model is in development as part of a multi-year effort under the Northrop Grumman Mission Systems (NGMS) sector's Model Based Engineering (MBE) initiative to digitally interconnect and unify previously separate performance and cost models. In 2016, an NGMS internal research and development (IR&D) funded multidisciplinary team integrated radio frequency (RF), power, control, size, weight, thermal and cost models together using ModelCenter for an Active Electronically Scanned Array (AESA) radar system. Each represented model was digitally connected with standard interfaces and unified to allow end-to-end mission system optimization and trade studies. The radar model was then linked to the Air Force's own mission modeling framework (AFSIM).

The team first had to identify the necessary models, and with the aid of subject matter experts (SMEs) understand and document the inputs, outputs, and behaviors of the component models. This agile development process and collaboration enabled rapid integration of disparate models and the validation of their combined system performance. This MBE framework will allow NGMS to design systems more efficiently and affordably, optimize architectures, and provide increased value to the customer. The model integrates detailed component models that validate cost and performance at the physics level with high-level models that provide visualization of a platform mission. This connectivity of component to mission models allows hardware & software design solutions to be better optimized to meet mission needs, creating cost-optimal solutions for the customer, while reducing design cycle time through risk mitigation and early validation of design decisions.

10206-24, Session 8

Building software for heterogeneous computers

Eric J. Kelmelis, EM Photonics, Inc. (United States)

The last several years have seen co-processing devices move from exotic to mainstream. While general-purpose microprocessors once had a monopoly on the computing field, they now share the space with massive vector processors such graphics processing units (GPUs) and Xeon Phis. Modern modeling and simulation software is struggling to adapt to this new reality. While there are numerous initiatives focused on building applications for these new hybrid computing environments, many are falling far short of expectations and are not reaching the performance potential promised by the available hardware. There are many reasons for this including the difficulty in programming these devices and the challenge in building software for a variety of distinct deployment scenarios. For instance, adapting a modeling and simulation tool that traditionally ran on a CPU-only system may require one version for such a platform, another version to run on NVIDIA GPUs, and still a different one for Xeon Phis. Building software for each of these can require different tools and techniques. Often, this work must also be redone when new generations of each device are released to account for the changes in load balancing driven by shifting performance characteristics. In this talk, we present three approaches to overcoming this challenge based on our current work. Specifically, we will discuss math libraries as way to encapsulate optimized functionality, cross-platform kernel compiling as a way to write a single computational function and build it for multiple devices, and dynamic task-based scheduling to address problem partitioning and data movement on heterogeneous computers.

10206-25, Session 8

improving developer productivity with C++ embedded domain specific languages

Stephen Kozacik, Aaron L. Paolini, James Bonnett, Evenie Chao, Paul Fox, Eric J. Kelmelis, EM Photonics, Inc. (United States)

Domain specific languages are a useful tool for productivity allowing domain experts to program using familiar concepts and vocabulary while benefiting from performance choices made by computing experts. Embedding the domain specific language into an existing language allows easy interoperability with non-domain-specific code and use of standard compilers and build systems. In C++, this is enabled through the template and preprocessor features. C++ embedded domain specific languages (EDSLs) allow the user to write simple, safe, performant, domain specific code that has access to all the low-level functionality that C and C++ offer as well as the diverse set of libraries available in the C/C++ ecosystem.

In this paper, we will discuss several tools available for building EDSLs in C++ and show examples of projects successfully leveraging EDSLs. Modern C++ has added many useful new features to the language which we have leveraged to further extend the capability of EDSLs.

At EM Photonics, we have used EDSLs to allow developers to transparently benefit from using high performance computing (HPC) hardware. We will show ways EDSLs combine with existing technologies and EM Photonics high performance tools and libraries to produce clean, short, high performance code in ways that were not previously possible.

10206-26, Session 8

Development of a GPU based synthetic infrared scene generation tool

Ozgur M. Polat, Yucel C. Ozer, Ozge Unel, ASELSAN A.S. (Turkey)

In this paper a real time GPU based synthetic infrared scene generator is presented. This scene generator is an end-to-end simulator for generating infrared scenes in image chain from object space to system detector output considering environmental and system effects. This scene generator has useful properties such as sub-pixel target handling, target signature generation, atmospheric background and cloud generation, terrain and sea surface generation, parametric sensor modelling for different kind of systems such as cooled, uncooled and scanning systems; capability of using measured system data and changing system parameters dynamically at runtime. This tool can be used for algorithm development, infrared/electro-optical system design and generating synthetic scenes for hardware in the loop systems. Also, this synthetic scene generation tool has a graphical user interface which includes sensor design and range performance calculation tools. An experimental validation procedure is applied in order to validate modelling of system components and scene effects. There are some additional capabilities of this scene generator under development such as laser based system simulation, distributed multi-sensor system simulation and a ray tracing tool.

10206-27, Session 8

A preliminary architecture for building communication software from traffic captures

Pedro Estrada Jr., The Univ. of Texas at El Paso (United States); Jaime Acosta, U.S. Army Research Lab. (United States)

Security analysts are tasked with identifying and mitigating network service vulnerabilities. A common problem associated with in-depth testing of network protocols is the availability of software that communicates across disparate protocols. Many times, the software required to communicate with these services is not publicly available. Developing this software is a time consuming undertaking that requires expertise and understanding of the protocol specification. The research project described here aims at developing a software package that is capable of automatically creating communication clients by using packet capture (pcap) and TShark dissectors. Currently, our focus is on protocols that operate at the upper layers of the network stack. The methodologies developed as part of this work will extend to complex lower layer protocols (e.g. Gateway Load Balancing Protocol (GLBP), Port Aggregation Protocol (PAgP), and Open Shortest Path First (OSPF) used by routing and switching equipment.

Thus far, we have architected a modular pipeline for our automatic traffic-based software generator. We start the transformation of captured network traffic by employing TShark to convert packets into a Packet Details Markup Language (PDML) file. The PDML file contains a parsed, textual, representation of the packet data. Then, we extract field data, types, along with inter and intra-packet dependencies. This information is then utilized to construct an XML file that encompasses the protocol state machine and field vocabulary. Finally, this XML is converted into executable code. Using our methodology, we have succeeded in automatically generating software that communicates with other hosts using ICMP, TCP, UDP, and HTTP protocols.

10206-28, Session 9

Simulated transient thermal infrared emissions of forest canopies during rainfall events

Jerrell R. Ballard Jr., William R. Hawkins, Stacy E. Howington, Raju V. Kala, U.S. Army Engineer Research and Development Ctr. (United States)

Most of the world's tropical forests are found in the equatorial zone around the world and cover less than 10% of the world's dry surface. In this environment, tropical rain forest environments are characterized by a warm climate, dense vegetation, and high amounts of near-daily rainfall.

As new sensor systems are developed, it is challenging to perform thorough physical testing of these systems due to limited availability of testing areas, high cost, and rapidly changing micro-meteorological conditions common in tropical forests. To address these challenges, virtual augmented testing and evaluation of sensor systems may be conducted in simulated environments. The complexity of the tropical forest presents unique modeling challenges for virtual sensor testing and evaluation. The basic physics of raindrops are well-described, but models for size distribution, wind driven velocity, and raindrop impact are scarce and are an active area of current hydrological and meteorological research.

We describe the development of a centimeter-scale resolution simulation framework for a theoretical tree canopy that includes rainfall deposition, evaporation, and thermal infrared emittance. Rainfall is simulated as discrete raindrops with specified rate. The individual droplets will either fall through the canopy and intersect the ground; adhere to a leaf; bounce or shatter on impact to a leaf resulting in smaller droplets are propagated through the canopy. Surface physical temperatures are individually determined by surface water evaporation, spatially varying within canopy wind velocities, solar radiation, and water vapor pressure. Results are validated by theoretical canopy gap models, reflectance models, and gross rainfall interception models.

10206-29, Session 9

Simplifying BRDF input data for optical signature modeling

Tomas Hallberg, Anna C. M. Pohl, FOI-Swedish Defence Research Agency (Sweden)

Scene simulations and modeling of optical material signature properties normally requires input of various parameterized measurement data of surface materials in order to achieve realistic scene object features. Some of the most important parameters are used in the model of the Bidirectional Reflectance Distribution Function (BRDF) and are determined by surface reflectance and scattering measurements. Reflectance measurements of the spectral Directional Hemispherical Reflectance (DHR) at various incident angles can normally be performed in most spectroscopy labs. In contrast, the BRDF of a surface at various incident angles is both a tedious process to measure or might not be available at all. However, the FWHM (Full Width

at Half Maximum) of the scattering distribution is one important input parameter that must be determined in order to use, e.g., the Sandford-Robertson BRDF model in signature simulation software for the infrared (IR) range.

We will present results showing a correlation between the degree of diffuse reflectance (DoDR), as obtained from using an integrating sphere equipped with a specular port plug, and the FWHM of the BRDF at a particular wavelength. Once this relationship is established for a particular integrating sphere it might in many cases not be necessary to measure the BRDF. This relationship was obtained from measurements on a number of different samples with various degree of surface roughness. We will also show how BRDF models used in signature simulation software are affected by using this relationship.

10206-30, Session 9

Non-Destructive Evaluation of Specialty Coating Degradation Using Terahertz Time-Domain Spectroscopy

Carley R. Nicoletti, John F. Federici, Laura Cramer, New Jersey Institute of Technology (United States); Alan Fletcher, Air Force Research Laboratory (United States); David Zimdars, Picometrix (United States); Zafar Iqbal, New Jersey Institute of Technology (United States)

Terahertz Time Domain reflection spectroscopy is utilized as a non-destructive test evaluation method to accurately determine the durability of paint. Accelerated aging techniques including temperature, UV light exposure and humidity, were performed continuously on multilayer paint samples. The exposed samples were measured using established testing methods as well as THz-TD techniques at various points throughout the degradation. Using an effective medium model for terahertz propagation in a paint sample combined with a non-linear least squares fitting method, the refractive index was extracted. The results obtained from the established techniques prove that the developed testing and data analysis methods using THz-TD evaluation are sensitive to the degradation changes of the paint layers.

10206-31, Session 9

Inverse modeling of diffuse reflectance spectra

R. Furstenberg, C. Kendziora, A. Shabaev, Y. Kim, R. A. McGill, S. G. Lambrakos, U.S. Naval Research Lab. (United States)

This study describes a parametric model of reflectance, based on the inverse analysis approach, for simulating the spectral response of detection procedures utilizing total internal reflectance spectroscopy (ATR). This model is purely phenomenological, but is optimal with respect to numbers of parameters. This model establishes ground-work for development of a prediction tool, which when given the constituent materials available, i.e., absorption coefficients of sorbent coating in contact with evanescent wave and analyte molecules absorbed within this coating, will enable optimal band-contrast matching of the composite system, i.e., sorbet coating and equilibrated analyte. The results of this study provide validation of the parametric model within reasonable error, for practical applications adopting ATR spectral response for detection of hazardous chemicals.

10207-1, Session 1

Information flow on social networks: from empirical data to situation understanding

Heather Roy, U.S. Army Research Lab. (United States); Tarek Abdelzaher, Univ. of Illinois at Urbana-Champaign (United States); Elizabeth K. Bowman, U.S. Army Research Lab. (United States); Md. Tanvir Al Amin, Univ. of Illinois at Urbana-Champaign (United States)

This paper describes characteristics of information flow on social channels, as a function of content type and relations among individual sources, distilled from analysis of Twitter data as well as human subject survey results. The working hypothesis is that individuals who propagate content on social media media act (e.g., decide whether to relay information or not) in accordance with their understanding of the content, as well as their own beliefs and trust relations. Hence, the resulting aggregate content propagation pattern encodes the collective content interpretation of the underlying group, as well as their relations. Analysis algorithms are described to recover such relations from the observed propagation patterns as well as improve our understanding of the content itself in a language agnostic manner simply from its propagation characteristics. An example is to measure the degree of community polarization around contentious topics, identify the factions involved, and recognize their individual views on issues. The analysis is independent of the language of discourse itself, making it valuable for multilingual media, where the number of languages used may render language-specific analysis less scalable.

10207-2, Session 1

From evolution to revolution: understanding mutability in large and disruptive human groups *(Invited Paper)*

Roger M. Whitaker, Cardiff Univ. (United Kingdom); Diane Felmlee, Pennsylvania State Univ. (United States); Alun D. Preece, Cardiff Univ. (United Kingdom); Dinesh Verma, IBM Thomas J. Watson Research Ctr. (United States); Grace-Rose Williams, Defence Science and Technology Lab. (United Kingdom)

Over the last 70 years there has been a major shift in the threats to global peace.

While the 1950's and 1960's were characterised by the cold war and the arms race, many security threats are now characterised by group behaviours that are disruptive, subversive or extreme. In many cases such groups are loosely and chaotically organised, but their ideals are sociologically and psychologically embedded in group members to the extent that the group represents a major threat. As a result, insights into how human groups form, emerge and change are critical, but surprisingly limited insights into the mutability of human groups exist. In this paper we argue that important clues to understand the mutability of groups come from examining the evolutionary origins of human behaviour. In particular, groups have been instrumental in human evolution, used as a basis to derive survival advantage, leaving all humans with a basic disposition to navigate the world through social networking and managing their presence in a group. From this analysis we present five critical features of social groups that govern mutability, relating to social norms, individual standing, status rivalry, ingroup bias and cooperation. We argue that understanding how these five dimensions interact and evolve can provide new insights into group mutation and evolution. Importantly, these features lend themselves to digital modelling, and therefore computational simulation can support causal explanations for group evolution and the discovery of latent factors, relevant to both internal group and external group modelling. Finally we consider the role of online social media in relation to understanding the mutability of groups. This can play an active role in supporting collective behaviour, and analysis of social media in the context of the five dimensions of group mutability provides a fresh basis to interpret the forces affecting groups.

10207-3, Session 1

Using soft-hard fusion for misinformation detection and pattern of life analysis in OSINT

Georgiy M. Levchuk, Aptima, Inc. (United States)

Today's battlefields are shifting to "denied areas," where the use of U.S. Military air and ground assets is limited. To succeed, the U.S. intelligence analysts increasingly rely on available open-source intelligence (OSINT). Multiple OSINT sources are available, including local news, blogs, online investigations, social media reports, etc.

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. Manual analysis of such data was always difficult in the past; with the increasing importance of social media as a primary source of information, manually analyzing these sources is infeasible due to its sheer volume. Analysts need tools for summarization and retrieval of information from OSINT sources, and these solutions must identify and resolve conflicting and deceptive information.

When combining multi-source data, it is critical to identify the claims from factual content. The reports in open source media often contain knowledge errors, manipulations and deceptions (e.g., due to propaganda) that are hard to identify due to ambiguity of linguistic expressions and uncertainty about identify and association of mentioned persons, organizations, locations, other physical objects, and events they are involved in. Information extraction tools only contribute to these challenges, as they produce high errors in extracting entities, relations and attributes from free-text data.

Fusing multiple text sources is further complicated by the presence of observer biases and misinformation. This will result in conflicts between the knowledge reported by different sources or in different documents. However, knowledge conflict detection alone is not enough: making a decision which of the pieces of knowledge in conflict is true and which is false requires further analysis. Many misinformation detection solutions are based on the hypothesis that true knowledge in OSINT is provided by many sources, and those sources must be trust-worthy. This means that source characterization credibility of the source (compared to other sources) and plausibility of the knowledge (compared to other pieces of knowledge must be evaluated). However, this makes the algorithms susceptible to bot armies, which would artificially inflate the frequencies of the knowledge reporting sources.

In this paper, we propose an alternative solution to source characterization and misinformation classification. We employ an assumption that true knowledge must be reported by independent sources. We compute the weight of dependency between the sources using the count of implicit linking between their relative posted media content. This is done by first extracting the "hard" data (imagery and video data) from OSINT sources (such as news media post, blog, or comment), identifying the original source of the media and its reposts, and finally using the times between the (re) posts to compute the posting correlation score.

10207-4, Session 1

Human-assisted machine information exploitation: a crowdsourced investigation of information-based problem solving

Sue E. Kase, Michelle Vanni, Marc Jackson, U.S. Army

Research Lab. (United States)

The Human-Assisted Machine Information Exploitation (HAMIE) investigation utilizes large-scale online data collection for developing models of information-based problem solving (IBPS) behavior in a simulated time-critical operational environment. These types of environments are characteristic of intelligence workflow processes conducted during human-geo-political unrest situations when the ability to make the best decision at the right time ensures strategic overmatch. The project takes a systems approach to Human Information Interaction (HII) by harnessing the expertise of crowds to model the interaction of the information consumer and the information required to solve a problem at different levels of system restrictiveness and decisional guidance. The design variables derived from Decision Support Systems (DSS) research represent the experimental conditions in this online single-player against-the-clock game where the player, acting in the role of an intelligence analyst, is tasked with a Commander's Critical Information Requirement (CCIR) in an information overload scenario. The player performs a sequence of three information processing tasks (annotation, relation identification, and link diagram construction) with the assistance of 'HAMIE the robot' who offers varying levels of information understanding dependent on question complexity. We provide preliminary results from a series of pilot studies conducted with Amazon Mechanical Turk participants on the Volunteer Science scientific research platform.

10207-5, Session 2

Physics-based and human-derived information fusion or hard-soft fusion for analysts

Erik Blasch, Air Force Research Lab. (United States)

Recent trends in physics-based and human-derived information fusion have amplified the capabilities of analysts; however with the big data opportunities there is a need for open architecture designs, methods of distributed team collaboration, and visualizations. In this paper, we explore recent trends in the information management, communications, information fusion, and multi-intelligence community to identify the needs, challenges, and focus areas for future developments. A driving effort would be in providing the analysts with applications, tools, and interfaces that afford effective and affordable solutions. Fusion at scale would be developed to allow analysts to access data, enter solutions, and store results for distributed decision making.

10207-6, Session 2

A technology path to tactical agent based modeling

Alex James, CUBRC, Inc. (United States); Timothy P. Hanratty, Eric Heilman, U.S. Army Research Lab. (United States)

Wargaming is a process of thinking of and visualizing events that could occur during a possible course of action. Over the past 200 years, wargaming has matured into a set of formalized processes. One area of growing interest is the application of agent-based modeling. Agent-based modeling and its additional supporting technologies has potential to introduce a third-generation wargaming capability to the Army, creating a positive overmatch decision-making capability. In its simplest form, agent-based modeling is a computational technique that helps the modeler understand and simulate how the "whole of a system" responds to change over time. It provides a decentralized method of looking at situations where individual agents are instantiated within an environment, interact with each other, and empowered to make their own decisions. However, this technology is not without its own risks and limitations. This paper explores a technology roadmap, identifying research topics that could realize agent-based modeling within a tactical wargaming context.

10207-7, Session 2

Implementing internet of things in a military command and control environment

Adrienne Raglin, Somiya Metu, Stephen Russell, Peter P. Budulas, U.S. Army Research Lab. (United States)

While the term Internet of Things (IoT) has been coined relatively recently, it has deep roots in multiple other areas of research including cyber-physical systems, pervasive and ubiquitous computing, embedded systems, mobile ad-hoc networks, wireless sensor networks, cellular networks, wearable computing, cloud computing, big data analytics, and intelligent agents. As the Internet of Things, these technologies have created a landscape of diverse heterogeneous capabilities and protocols that will require adaptive controls to effect linkages and changes that are useful to end users. In the context of military applications, it will be necessary to integrate disparate IoT devices into a common platform that necessarily must interoperate with proprietary military protocols, data structures, and systems. In this environment, IoT devices and data will not be homogeneous and provenance-controlled (i.e. single vendor/source/supplier owned). This paper presents a discussion of the challenges of integrating varied IoT devices and related software in a military environment. A review of contemporary commercial IoT protocols is given and as a practical example, a middleware implementation is proffered that provides transparent interoperability through a proactive message dissemination system. The implementation is described as a framework through which military applications can integrate and utilize commercial IoT in conjunction with existing military sensor networks and command and control (C2) systems.

10207-8, Session 3

Human/Autonomy Collaboration for Automated Generation of Intelligence Products

Phil DiBona, Jason Schlachter, Lockheed Martin Corp. (United States); Ugur Kuter, Robert Goldman, SIFT, LLC (United States)

Intelligence Analysis remains a manual process despite recent trends toward autonomy in information processing. Analysts need agile decision-support tools that can adapt to the evolving information needs of the mission, such as by allowing the analyst to pose novel analytic questions and to request automated monitoring for indicators & warnings on specific situations. Yet existing automation support tools fail to provide this because they are often inflexible and cannot customize their execution to meet complex or novel situations.

Lockheed Martin Advanced Technology Laboratories is conducting research into Proactive Human/Autonomy Collaboration that facilitates a unity of effort between the human and the autonomy, where the autonomy operates as a composable system, executing a workflow of algorithms to create an intelligence product for the human analyst. Traditional composable systems require analysts to tell the autonomy which algorithms/analytics are needed and how to orchestrate them into a workflow. Our approach alleviates this burden on the analysts by enabling the users to only provide a constrained English specification of what the intelligence product should be. Building upon planning research by Smart Information Flow Technologies, the autonomy discovers, decides, and generates a workflow of algorithms to create a product that achieves that English specification. Therefore, the human analyst can quickly and naturally communicate to the autonomy what information product is needed, rather than how to create it. Our system provides analysts with customized, flexible decision support autonomy that is tailored to the mission at hand with minimal impact to their workload.

10207-9, Session 3

The mixed reality of things: Emerging challenges for human-information interaction *(Invited Paper)*

Evan Suma Rosenberg, Univ. of Southern California (United States); Stephen M. Russell, U.S. Army Research Lab. (United States)

Virtual and mixed reality technology has advanced tremendously over the past several years. This nascent medium has the potential to transform how people communicate over distance, train for unfamiliar tasks, operate in challenging environments, and how they visualize, interact, and make decisions based on complex data. At the same time, the marketplace has experienced a proliferation of network-connected devices and generalized sensors that are becoming increasingly ubiquitous. As the "Internet of Things" expands to encompass a predicted 50 billion connected devices by 2020, the volume and complexity of information generated in pervasive and virtualized environments will continue to grow exponentially. The convergence of these trends demands a theoretically grounded research agenda that can address emerging challenges for human-information interaction (HII). Virtual and mixed reality environments can provide controlled settings where HII phenomena can be observed and measured, new theories developed, and novel algorithms and interaction techniques evaluated. In this paper, we describe the intersection of pervasive computing with virtual and mixed reality, identify current research gaps and opportunities to advance the fundamental understanding of HII, and discuss implications for the design and development of cyber-human systems for both military and civilian use.

10207-10, Session 3

Human-machine analytics for closed-loop sense-making in time-dominant cyber defense problems *(Invited Paper)*

Matthew Henry, Johns Hopkins Univ. Applied Physics Lab., LLC (United States)

Many problems facing tactical decision-makers are characterized by adversaries that act at speeds that defy human-centric system monitoring and response defense practices. These well-honed and ostensibly reliable practices, as well as the infrastructures that enable them, pervade many domains, including cyberspace. The argument that often prevails when considering the automation of defense in these domains is that, while technological systems, e.g., sensors and filters, are good at and suitable for simple, well-defined tasks, only human analysts and operators possess sufficiently nuanced understanding of problems to act appropriately under all, including unforeseeable, circumstances. While this point of view is well founded in accepted and verifiable truths, it does not account for a middle ground, which is that human-defined and monitored technological capabilities can extend well into the territory of more complex reasoning, thereby automating more nuanced sense-making and at the same dramatically increasing the speed at which it can be applied. The Snort Network Intrusion Detection and Prevention System and other platforms like it have provided an infrastructure in which analysts can start to build, experiment with, refine, and deploy such automated sense-making. One shortcoming of these platforms, however, is an over-reliance on rule-based sense-making, which tends to confound analyst knowledge of how bad actors behave and the means by which bad behaviors can be detected. Because bad behaviors are implied by their assumed indicators and warnings, but not explicitly described, these inferencing rules may not account for all the ways in which bad behavior might manifest itself or be detected. We propose an alternative technique, which enables an analyst to first describe bad behaviors explicitly using a state machine framework and then establishes the means by which measurements and alerts driven by Snort-based or other filters can be applied to estimate the current state of a bad actor's operation. This presents two opportunities, the first of which is to anticipate future actions of a bad actor for the purposes of deploying active counter-measures. The second is to evaluate and prioritize sets of new alerting rules to feed back to intrusion detection system management functions, thereby closing the sense-making loop. This paper will motivate the approach and describe its application in the cyber defense context.

10207-11, Session 3

Visualizing UAS-collected imagery using augmented reality

Damon M. Conover, U.S. Army Research Lab. (United States); Brittany Beidleman, Ryan McAlinden, The Univ. of Southern California (United States); Christoph C. Borel-Donohue, U.S. Army Research Lab. (United States)

One of the areas where augmented reality will have an impact is in the visualization of 3D data. 3D data has traditionally been viewed on a 2D screen, which has limited its utility. Augmented reality head-mounted displays, such as the Microsoft HoloLens, make it possible to view 3D data overlaid on the real world. This allows a user to view and interact with the data in ways similar to how they would interact with a physical 3D object, such as moving, rotating, or walking around it. A type of 3D data that is particularly useful for military applications is geo-specific 3D terrain data, and the visualization of this data is critical for training, mission planning, intelligence and improved situational awareness. Advances in Unmanned Aerial Systems (UAS), photogrammetry software, and rendering hardware have drastically reduced the technological and financial obstacles in collecting aerial imagery and in generating 3D terrain maps from that imagery. Because of this, there is an increased need to develop new tools for the exploitation of 3D data. We will demonstrate how the HoloLens can be used as a tool for visualizing 3D terrain data. We will describe: 1) how UAS-collected imagery is used to create 3D terrain maps, 2) how those maps are deployed to the HoloLens, 3) how a user can view and manipulate the maps, and 4) how multiple users can view the same virtual 3D object at the same time.

10207-12, Session 3

An approach to explainable deep learning using fuzzy inference *(Invited Paper)*

David Bonanno, U.S. Naval Research Lab. (United States)

Deep Learning has proven to be an effective method for making highly accurate predictions from complex data sources. Convolutional neural networks continue to dominate image classification problems and recursive neural networks have proven their utility in caption generation and language translations. While these approaches are powerful, they do not offer explanation for how the output is generated. Without understanding how deep learning arrives at a solution there is no guarantee that these networks will transition from controlled laboratory environments to fieldable systems. This paper presents an approach for incorporating such rule based methodology into neural networks by embedding fuzzy inference systems into deep learning networks.

10207-13, Session 4

Adaptation of interoperability standards for cross domain usage

Barbara Essendorfer, Christian Zaschke, Christian Kerth, Fraunhofer-Institut für Optronik, Systemtechnik und Bildauswertung (Germany)

As globalization affects most aspects of modern life, challenges of quick and flexible data sharing apply to many different domains. To protect a nation's

security for example, one has to look well beyond borders and understand economical, ecological and cultural as well as historical influences. Most of the time information is produced and stored digitally and one of the biggest challenges is to receive relevant readable information applicable to a specific problem out of a large data stock at the right time.

These challenges to enable data sharing across national, organizational and systems borders is known to other domains (e.g., ecology or medicine) as well. Solutions like specific standards have been worked on for the specific problems. The question is: what can the different domains learn from each other and do we have solutions when we need to interlink the information produced in these domains?

A known problem is to make civil security data available to the military domain and vice versa in collaborative operations. But what happens if an environmental crisis leads to the need to quickly cooperate with civil or military security in order to save lives? How can we achieve interoperability in such complex scenarios?

The paper introduces an approach to adapt standards from one domain for another and lines out problems that have to be overcome and limitations that may apply.

10207-14, Session 4

Quantity and unit extraction for scientific and technical intelligence analysis

Peter F. David, Decisive Analytics Corp. (United States)

Scientific and Technical (S&T) intelligence analysts consume huge amounts of data to understand how scientific progress and engineering efforts affect current and future military capabilities. One of the most important types of information to S&T analysts is the quantities discussed in their source material. Frequencies, ranges, size, weight, power, and numerous other properties and measurements describing the performance characteristics of systems and the engineering constraints that define them must be culled from source documents before quantified analysis can begin. Automating the process of finding and extracting the relevant quantities from a wide range of S&T documents is difficult because information about quantities and their units is often contained in unstructured text with ad hoc conventions used to convey their meaning. Currently, even simple tasks, such as searching for documents discussing RF frequencies in a band of interest, is a labor intensive and error prone process. This research addresses the challenges facing development of a document processing capability that extracts quantities and units from S&T data, and how Natural Language Processing algorithms can be used to overcome these challenges.

10207-15, Session 4

Big data, little security: Addressing security issues in your platform *(Invited Paper)*

Thomas Macklin, U.S. Naval Research Lab. (United States)

This paper describes some patterns for security problems that consistently emerge when analysts must work in a heterogeneous network environment, both with respect to cyber threats and data sensitivity. Use cases are drawn primarily from qualitative studies and interviews of developers, operators, and certifiers of military applications that use analytical tools to support battlefield operations. Specifically, the problems addressed involve system architecture, sensitivity of data aggregates, and security decisions in the human machine interface. When known valid techniques can be brought to bear to address these problems, recommendations are given on how security practices could be improved. In cases where there are known security gaps, questions are posed to the analytics community in order to inform the security community on how to best address these gaps.

10207-16, Session 4

Issues in multi-resolution multi-modal modeling of physiological signals

Andre Harrison, Michael Lee, Mark Dennison, U.S. Army Research Lab. (United States)

Multimodal processing of physiological signals can help to classify a person's state by using the information from the set of modalities to identify the context of the situation. Identification of the context may cause a reduction in the variability in training data that is typically present when only a single modality of sensing information is collected and trained on. However, physiological signals operate at different time scales and sensing systems often operate at different frequencies and with the increasing use of physiological sensing systems that enable pervasive sensing new complexities arise in synchronization and multiresolution modeling within and across modalities. At the same time tools are already being developed to support the integration and processing of these signals as a whole. In this paper we present a brief survey of multi-resolution approaches and discuss ways they may be useful capturing information across modalities and the software tools to use them.

10207-17, Session 5

Human-machine interaction to disambiguate entities in unstructured text and structured datasets

Kevin D. Ward, Jack H. Davenport, Decisive Analytics Corp. (United States)

Creating network graphs is a manual, time consuming process for an intelligence analyst. Beyond the traditional big data problem, individuals are often referred to by multiple names and shifting titles as they advance in their organizations over time which quickly makes simple string or phonetic comparison methods to search for entities insufficient. Conversely, automated methods for relationship extraction and entity disambiguation typically produce questionable results as ground truth with no way for users to vet results, correct mistakes or influence the algorithm's future results.

We present an Entity Disambiguation tool, DRADIS, which aims to bridge this gap between human-centric and machine-centric methods. DRADIS automatically extracts entities from multi-source datasets and models them as a complex set of attributes and relationships. Entities are disambiguated across the corpus using a hierarchical model executed in Spark allowing it to scale to operational sized data. Resolution results are presented to the analyst complete with sourcing information for each mention and relationship allowing analysts to quickly vet the correctness of results as well as correct resolution mistakes by splitting and merging clusters. Vetted results are used by the system to refine the underlying model for future runs allowing analysts to course correct the general model to better deal with their operational data. Providing analysts with the ability to validate and correct the model to produce a system they can trust enables them to better focus their time on producing higher quality analysis products.

10207-18, Session 5

Automated evaluation of service orient architecture systems: A case study *(Invited Paper)*

Hesham Fouad, Antonio Gilliam, Suleyman Guleyupoglu, U.S. Naval Research Lab. (United States); Stephen M. Russell, U.S. Army Research Lab. (United States)

The Service Oriented Architecture (SOA) model is fast gaining dominance in how software applications are built. They allow organizations to capitalize

on existing services and share data amongst distributed applications. The automatic evaluation of SOA systems poses a challenging problem due to three factors: technological complexity, organizational incompatibility, and integration into existing development pipelines. In this paper we describe our experience in developing and deploying an automated evaluation capability for the Marine Corps' Tactical Service Oriented Architecture (TSOA). We outline the technological, policy, and operational challenges we face and how we are addressing them.

10207-20, Session 5

RAPID: Real-time analytics platform for interactive data-mining in a decision support scenario

Michelle Vanni, Sue E. Kase, U.S. Army Research Lab. (United States); Shanika Karunasekara, The Univ. of Melbourne (Australia); Lucia Falzon, Defence Science and Technology Group (Australia); Aaron Harwood, The Univ. of Melbourne (Australia)

The Real-time Analytics Platform for Interactive Data-mining (RAPID), a collaboration of the University of Melbourne and the Australia Defense Science and Technology Group (DSTG), consumes streams of big data, performs analytics computations of various types, and produces high-quality knowledge for use by information analysts in industry and government. Considered a Data Transformation Center, RAPID is optimized to support user interactivity and is engineered to accommodate diverse data providers, with Twitter feeds currently being the most widely ingested. In the collection phase, users input initial topic seed words and the system autonomously identifies emerging keywords in the data streams. Arbitrarily complex Boolean filters support sophisticated sampling for accuracy refinement. At the same time, users direct the system with time-windowing parameters, thresholds, update intervals and sample rates, which, along with custom queries, strategically filter and track the incoming data. Apache Storm and Apache Kafka permit real-time streaming while offline processing is supported with RAPID's logging options. We present results of system inquiries within a decision-support scenario featuring a series of Commanders' Critical Information Requirements, which involve comparisons over time and the time-sequencing of events in online social interactions. These capabilities are particularly well-served by this technology, which will be demonstrated in the presentation.

10207-25, Session 5

Advanced text and video analytics for proactive decision making

Elizabeth K. Bowman, U.S. Army Research Lab. (United States); Ranjeev Mittu, U.S. Naval Research Lab. (United States); Matt Turek, Paul Tunison, Reed Porter, Kitware (United States); Steve Thomas, AFRL (United States); Vadas Gintautas, Peter Shargo, BAE Systems (United States); Jessica Lin, Qingzhe Li, Yifeng Gao, Xiaosheng Li, GMU (United States); Carolyn P Rose, Keith Maki, Chris Bogart, Samrihdi S Choudhari, Carnegie Mellon University (United States)

No Abstract Available

10207-21, Session 6

Requirements for value of information (VoI) calculation over mission specifications

James R. Michaelis, U.S. Army Research Lab. (United States)

Intelligence, Surveillance, and Reconnaissance (ISR) operations center on providing relevant situational understanding to military commanders and analysts to facilitate decision-making for execution of mission tasks. Continuing advances in digital systems, ranging from smart sensor arrays to social media, provide greater volumes of data from which information could be extracted - as reflected in both commercial and military settings. However, limitations exist in tactical-edge environments on the ability to disseminate digital materials to analysts and decision makers over networks. From a cognitive science perspective, information overload and distraction are additional challenges that emerge from large-scale data management.

This work investigates novel methods to calculate of Value of Information tied to digital materials (termed Information Objects) for consumer use, based on interpretation of encoded mission specifications. Followed by a short survey of related VoI calculation efforts, foundational work on calculation of VoI for digital materials via adoption of the Missions and Means Framework will be presented.

10207-22, Session 6

Determining the perceived value of information when combining supporting and conflicting data

John Richardson, U.S. Army Research Lab. (United States); Justine Caylor, Towson Univ. (United States); Mark R. Mittrick, Eric Heilman, Timothy P. Hanratty, U.S. Army Research Lab. (United States)

Modern military intelligence operations involves a deluge information from a large number of sources. A data ranking algorithm that enables the most valuable information to be reviewed first may improve timely and effective analysis. This ranking is termed the value of information (VoI) and its calculation is a current area of research within the US Army Research Laboratory (ARL). Researchers at ARL have designed a fuzzy associate memory (FAM) approach to calculating VoI. This calculation used the source reliability and information content, as defined in US Army Field Manual FM 5-0, of a report to determine VoI. In a recent experiment, ARL leveraged the subject matter expertise of US Army intelligence analysts to evaluate their perceived value of abstract intelligence reports, defined by a source reliability and information content. Furthermore, analysts were also presented with additional information that either supported or conflicted with the initial report and asked to judge any perceived change in value of the original report. These results allowed ARL to correlate the SME perceptions with the FAM model and additionally to construct a cognitive model of the ranking process and the amalgamation of supporting and conflicting information.

10207-24, Session 6

A research and experimentation framework for exploiting VoI-based methods within analyst workflows in tactical operations centers *(Invited Paper)*

Laurel C. Sadler, U.S. Army Research Lab. (United States)

In today's battlefield environment analysts are inundated with real-time data received from the tactical edge that must be evaluated and used for managing and modifying current missions as well as planning for future missions. This paper describes a framework which facilitates a Value of Information (VoI) based data analytics tool for information object (IO) analysis in a tactical and command and control (C2) environment, which reduces analyst work load by providing automated or analyst assisted applications. It allows the analyst to adjust parameters for data matching of the IOs that will be received and provides agents for further filtering or fusing of the incoming data. It allows for analyst enhancement and markup to be made to and/or comments to be attached to the incoming data IO which can then be re-disseminated utilizing the VoI based dissemination service. Before disseminating, the tool allows the analyst to modify the matching or VoI parameters of the outgoing IO which will subsequently adjust the value of the IO based on this new/additional information that has been added, possibly increasing the value from the original.

The end goal of the framework is to provide an easy to use, dynamically changing Command and Control decision aide that reduces the workload of analyst.

Conference 10208: Fiber Optic Sensors and Applications XIV

Tuesday - Wednesday 11–12 April 2017

Part of Proceedings of SPIE Vol. 10208 Fiber Optic Sensors and Applications XIV

10208-1, Session 1

Mars or Bust! 40 years of fiber optic sensor development *(Invited Paper)*

Eric Udd, Ingrid Scheel, Columbia Gorge Research LLC (United States)

This is a tutorial talk intended to fit a 40 to 45 minute time slot and providing an overview of aerospace applications of fiber optic sensors...with a thread linking early developments to current Mars exploration efforts.

10208-2, Session 1

Optical frequency domain reflectometry for aerospace applications

Stephen T. Kreger, Nur Aida Abdul Rahim, Matthew A. Davis, Noah B. Beaty, Robert Gamber, Luna Innovations Inc. (United States); James W. Jeans, Structural Design & Analysis Inc. (United States)

Optical Frequency Domain Reflectometry (OFDR) is the basis of an emerging distributed fiber optic sensing (DFOS) technique that provides an unprecedented combination of resolution and sensitivity. OFDR differs from traditional DFOS techniques in that, rather than providing low resolution (1 m) measurements of strain and/or temperature over long ranges (many kilometers), it provides very high resolution measurements (millimeters) over relatively short ranges (tens of meters up to a few kilometers). OFDR has therefore been associated with the new acronym HD-FOS: High Definition Fiber Optic Sensing. We will focus on aerospace applications that benefit from the sensitivity and resolution of HD-FOS, such as for defect detection, FEA model verification, and structural health monitoring. We describe how HD-FOS is finding use in aerospace applications spanning the full design chain, from coupon to full model testing. We also review progress strain and temperature response calibration and certification that is necessary to meet aerospace regulatory requirements. Finally, we examine the challenges of making sense of the tremendous amount a data produced by HD-FOS, including event triggering options, synchronizing data acquisition with control signals, and integrating the data output with established industry protocols and acquisition systems.

10208-3, Session 1

Concept, design, fabrication and characterization of an FBG-transducer for a scanning laser-based fiber-optic interrogator

Nader Kuhenuri Chami, Alexander W. Koch, Technische Univ. München (Germany)

The Hybrid Sensor Bus (HSB) is a space-borne temperature monitoring system for telecommunication satellites, where in the system combines electrical transducers and fiber-optical Fiber Bragg Grating (FBG) sensors. The tailored FBGs are to be mounted on a space-qualified interface for an improved performance and FBG protection.

Beside characterization and modelling of the FBG sensors in order to measure more accurate temperatures, mechanically induced stress on the FBG has to be efficiently decoupled as good as possible. For the initial verification of the derived shock and vibration requirements, different design approaches are modelled and simulated for best strain decoupling by implying Finite Element Analysis (FEA). Due to outgassing and radiation tolerance requirements, by the nature of the project, the selection of adhesives like epoxide, silicon, and grease based is restricted. The most promising design approaches and adhesives are defined in a series of configurations which will then be measured by a specially designed small-size thermal-vacuum chamber capable of accurate temperature stabilization.

Furthermore this paper addresses the results of a 4-point bending test which is carried out as verification for the transducer's strain decoupling performance. Additionally, the thermal-vacuum characterization and modelling results of these prototypes are discussed and lead to a detailed trade-off for the most important characteristics, as hysteresis, accuracy, and model deviation. An appropriate space-qualified FBG-transducer prototype for the Heinrich-Hertz in-orbit verification (IOV) mission could thus be provided.

10208-4, Session 1

Improvement of the extinction ratio performance of a fiber laser based rangefinder by using successive real-time statistical algorithms

Frederic J. L. Chiquet, SensUp (France); Nicolas Bertaux, Aix-Marseille Univ. (France) and Ctr. National de la Recherche Scientifique (France) and Institut Fresnel (France); Patrick Auffray, Emcores (France); Guillaume Canat, Marc Le Flohic, Keopsys SA (France)

Today, it is commonly agreed that mid-range range-finders (typical range: 10 km) based on fiber laser technology, constitute the best trade-off between performance and reliability. But to intend to compete with long-range devices and propose an alternative to bulk solid state laser systems, it is essential to increase significantly their extinction ratio (ER) compared to the state of the art.

In this paper we report on a fiber laser based range finder which achieves an extinction ratio of 45dB in an eye-safety burst mode. This range finder is a cost effective solution based on a bi-static architecture, equipped with our 130 μJ, 10 ns pulse fiber laser and 45 mm optical aperture receiver, reinforced with a specially designed compact electronics. Its intrinsic ER in single-pulse emission has been measured at 31 dB.

Built around a high performance FPGA, a 32 bits softcore microprocessor and a 1Gsps analog to digital converter (ADC), the new electronics monitors all the required functionalities to drive the laser, to perform the calculation and to communicate with user interface. The waveform is processed in real-time on the FPGA through a 2 steps algorithm: pulse accumulation and distance estimation.

Various distance estimators have been tested: maximum detection, correlation, optimized estimation.

Compare to the max search estimation, the correlation estimator gain is close to 4 dB. With the optimized estimator, it increases in performance at 5.5 dB.

With this optimized algorithmic approach together with pulse accumulation, we finally enhance the intrinsic performance of our rangefinder up to a factor 15, pushing its extinction ratio above 45 dB.

10208-5, Session 2

Shupe and elastooptic effects of a fiber sensing coil with practical quadruple winding

Serdar Ogut, Berk Osunluk, Ekmel Ozbay, Bilkent Univ. (Turkey)

Fiber Optic Gyroscopes (FOGs) are highly precise sensors for angular rotation measurement that are used for navigation, positioning, and stabilization. The precision limits of FOG are still being discussed widely. One of the main limits is the thermally induced bias error. Quadruple winding is widely used in FOGs to reduce the thermal sensitivity, and the reduction has been analyzed in the literature. In this work, we extend this analysis to practical quadruple winding in the context of the Shupe and elastooptical error characteristics. We reviewed the thermal sensitivity of FOG in detail and created a simulation environment by the Finite Element Method (FEM). The Shupe effect describes the bias shift due to a change in the temperature field through a fiber coil while the elastooptic effect is based on a change in the stress field. Although the elastooptic effect has a similar mechanism, its analysis needs a deeper modeling of the fiber coil. For this purpose, we created two different FEM simulations: A very detailed model of a single fiber and a model of the fiber coil as a whole. Elastooptical interactions are modeled by using these simulations and homogenization-dehomogenization processes. FEM simulations are validated by comparing the results with a laboratory FOG setup. Using the validated simulation environment, we report the changes in the Shupe and elastooptic error characteristics for practical quadruple winding patterns.

10208-6, Session 2

Fiber optic gyroscope coils: performance characterization

Mansoor Alam, Jan A. Khan, Lilja Gudmundsdottir, Nufern (United States)

The need for precision guidance of systems in tactical theaters is becoming increasingly more important. This need has renewed interest in Interferometric Fiber Optic Gyroscopes (IFOG) that are capable of delivering navigation grade performance. The challenges however, include satisfactory performance over a large and severe operating temperature range (-60oC to +90oC), low unit cost and relatively small footprint. Performance of the IFOG depends critically on the quality of the sensing element which is the optical fiber coil and many of the performance limiting issues of the IFOG can be traced back to coil quality. Although significant progress has been made in the fabrication of temperature insensitive coils with high optical reciprocity, more needs to be done.

In this paper, data is presented on the performance of similar size (inside diameter, outside diameter, height) freestanding coils that were wound in quadrupole winding pattern at low tension using different polarization maintaining fibers. Performance characteristics of the coils were measured under variables including (i) fiber geometry, (ii) fiber coating, (iii) winding epoxy, and (iv) epoxy curing cycles. Although each coil had the same footprint, they contained different lengths of fiber based on the fiber coating size. Coils were characterized as a function of temperature with respect to: (i) optical loss, (ii) polarization extinction ratio (PER), and coherence. The data suggests that high performance navigation grade coils can be realized over a large and severe temperature range with careful choice of fiber, winding epoxy and cure cycle.

10208-7, Session 2

An interferometric sensor based on visibility modulation

Liang Zhang, Yuanfu Lu, Yuming Dong, Guohua Jiao, Shenzhen Institutes of Advanced Technology (China)

We propose and demonstrate an interferometric sensor based on visibility modulation. A pulse train, generated by a mode-locked fiber laser, is launched into a two beam interferometer, in which a section of polarization maintain (PM) fiber is spliced into one arm as the sensing head. The optical path difference(OPD) of the interferometer are chosen to be close to m multiples of the fiber laser optical cavity length. Due to the interference between the two pulse trains in the two arms, respectively, an interferometric fringe can be obtained with free spectral range (FSR) related to the difference between OPD of interferometer and m multiples of the fiber laser optical cavity length. On the other hand, the birefringence of the PM fiber splits the pulse train in the sensing arm, yielding a visibility envelop in the interferometric fringe. Strain applied on the PM fiber changes its birefringence and is modulated into the shift of the visibility envelop. Due to the high intensity resolution of OSA, slight strain can be demodulated by measuring the visibility change in a given wavelength. Experimental result shows that the sensor can achieve resolution of up to 100 nano-strain. This demodulation scheme is immunity to the wavelength shift and power fluctuation of OSA, thus improving the accuracy of the sensor. The sensor may shows advantages in some applications which requires high accuracy. The temperature and twist response of the sensor are also demonstrated in this paper.

10208-8, Session 2

Fiber interferometers for traffic applications

Vladimír Va?inek, Jakub Jaros, David Hrub?, Jan Nedoma, Marcel Fajkus, V?B-Technical Univ. of Ostrava (Czech Republic)

This paper describes the innovative way for speed measurement of vehicles during traffic. The described system is based on the usage of optical fibers in M-Z interferometer and against the conventional sensors they offer a wider application potential, benefits of implementing solutions and due to the massive expansion of fiber optic cables along roads in the telecommunications needs the possibility of direct connection to the existing infrastructure. The theoretical part summarizes the principle of operation and potential usage not only for the vehicles speed measurements but for analysis of particular. The practical part contains a description of assembled prototypes of fiber optic sensor units, which operate on the principle of light interference and initial tests carried out of the proposed sensor system including evaluation.

M-Z interferometer is placed outside of the carriageway because of its high sensitivity to acoustic pressure and vibration. Two M-Z interferometers placed several meters between them make possible to measure the speed of moving vehicles. Analysis of sound and vibration enables the evaluation of vehicle types, e.g. personal cars, trucks, motorcycles, buses, etc. Typical sound and vibration spectra will be presented for particular cars together with the method of data mining. The interferometers are based on SM fibers, and operating wavelength is 1550 nm

10208-9, Session 3

Optical properties and high-temperature gas sensing exploration of nanostructured sapphire optical fiber

Hui Chen, Stevens Institute of Technology (United States); Zsolt L. Poole, Paul R. Ohodnicki, National Energy Technology Lab. (United States); Henry Du, Stevens Institute of Technology (United States)

Single crystal sapphire optical fiber is an excellent candidate for sensing in harsh environment due to its high-temperature structural and chemical stability and good light transmission over a large spectral window. We present an experimental study of nanostructured sapphire optical fiber (NSOF) with nanoporous anodized aluminum oxide (AAO) as its cladding for high temperature gas sensing. Optical properties such as numerical aperture (NA), fiber attenuation, and far-field beam profile of NSOF are examined. We investigate the feasibility of entrapping plasmonic nanoparticles (e.g. Ag and Pd) in AAO cladding of NSOF to enable gas sensing at elevated temperatures. Measurements under cyclic temperature and on-off gas flow conditions are also carried out. Parallel sensing experiments using unclad sapphire optical fibers with immobilized plasmonic nanoparticles are conducted for comparison with NSOF. Sensing performance will be discussed with respect to sensitivity and thermal stability of the nanoparticles.

10208-10, Session 3

Mechanical properties of nanostructured sapphire optical fiber

Kai Liu, Padmalatha Kakanuru, Kishore Pochiraju, Henry Du, Stevens Institute of Technology (United States)

Single crystal sapphire fiber is an excellent candidate for fiber-optic sensing in harsh environments owing to its superior optical, mechanical and thermal properties at elevated temperatures up to 1500ºC. We have carried out an experimental and theoretical investigation on the mechanical properties of nanostructured sapphire optical fiber (NSOF) cladded with nanoporous anodized aluminum oxide (AAO). The threshold thickness beyond which the integrity of AAO cladding will be compromised due to tensile stress as growth of AAO extends radially outward is determined. Bending tests are conducted to explore relationship of NSOF mechanical properties with AAO porosity and thickness as parameters. Bending simulations using Finite Element Method will be compared with our experimental results. Parallel bending tests are conducted using AAO-clad silica fiber for comparison. Numerical and analytical simulations are also conducted to reveal the stress development during aluminum conversion to AAO on fiber geometry. The knowledge established on mechanical properties of NSOF will be of critical importance in its design, production, and utilization for a variety of demanding applications such as sensing for energy generation and energy production systems.

10208-11, Session 3

Modified single crystal fibers for distributed sensing applications

Michael P. Buric, Paul R. Ohodnicki, National Energy Technology Lab. (United States); Bo Liu, Oak Ridge Institute for Science and Education (United States); Benjamin T. Chorpening, National Energy Technology Lab. (United States)

Single crystal fibers like those made from sapphire are capable of operating at higher temperatures than conventional silica-glass-based fibers. This work aims to construct single-crystal optical fiber sensors capable of providing environmental data in combustion, high-temperature chemical processing, or power generation applications where temperatures exceed 1000C and standard silica fibers cease to provide useful information. In many cases the functionalization of a single-crystal fiber with conventional sensing materials or structures can decrease the maximum operating temperature of the fiber-system. Here, we explore the functionalization of these fibers using methodologies intrinsic to the crystal growth process which do not severely reduce their operating temperature range. While operating a laser-heated pedestal growth system to produce single-crystal optical fibers from rod feedstock, we continuously vary parameters such as fiber diameter to produce novel single-crystal linear distributed-sensing devices. The spectral characteristics of those modified devices, along with sensing performance in a high-temperature harsh-environment are reported. Modifications that can be readily achieved during the crystal growth process are highlighted with respect to distributed interrogation methodologies for those devices.

10208-13, Session 3

Simultaneous transmission of the high-power phase sensitive OTDR, 100 Gbps dual polarisation QPSK, accurate time/frequency, and their mutual interference

Petr Münster, Brno Univ. of Technology (Czech Republic)

Currently, fibre networks are only way how to satisfy the ever growing needs for more bandwidth. Thanks to that the optical fibre can be found almost anywhere and new application and services can be transmitted thru the networks. Accurate time transfer, ultra-stable frequency transfer and fibre-optic sensors networks have been rather common. High speed data transmission, time and frequency transmission, and fibre-optic sensors must share the common fibre-optic infrastructure because it would not be economically feasible to build separate fibre networks. Each system has individual transmission requirements and is prone to another type of interference. Data transmission systems based on DP-QPSK use digital signal processing for signal recovering but it cannot fully compensate signal degradation due to polarization dependent loss and nonlinear effects which are the most dominant sources of signal degradation. Accurate time signals are slow and often OOK modulated, therefore may experience the degrading effects of chromatic dispersion. Ultra-stable frequency signals are not modulated at all – information transmitted is the frequency of photons and such signals are continuous wave, but they suffer from phase noise also environmentally introduced, e.g. by vibrations. For phase sensitive OTDR sensor systems the high power pulses is necessary to use which may cause interference with other signals. For this reason, parallel and simultaneous transmission in DWDM spectral grids of standard data, time, frequency, and sensing signals is rather new and unexplored area of research.

10208-14, Session 4

Long-distance distributed temperature measurement in double-ended configuration

Xiaoguang Sun, OFS (United States)

The maximum sensing distance in a Raman-based distributed temperature sensing (DTS) systems is limited by the weak backscattered anti-Stokes signals and the fact that the maximum input pump peak power is limited by onset of the stimulated Raman scattering (SRS) in the fiber. For a double-ended configuration the maximum sensing distance is even shorter since the sensing fiber length is doubled. We will propose a new measurement technique which can reduce the threshold of the SRS and allows long distance DTS with a low spatial resolution and high temperature accuracy.

10208-15, Session 4

Quantitative high sensitivity distributed fiber measurements using ΦOTDR with chirped pulses

Hugo F. Martins, FOCUS S.L. (Spain); Juan Pastor-Graells, Andres Garcia-Ruiz, Sonia Martín-López, Miguel González-Herráez, Univ. de Alcalá (Spain)

Phase-sensitive optical time domain reflectometry (?OTDR) is a distributed sensing technique which allows for the monitoring of distributed acoustic/vibration sensing along optical fibres. However, the traditional ?OTDR using pulses with constant phase and direct detection depends nonlinearly on a disturbance applied to the fiber and is therefore unable to accurately quantify its amplitude.

In this work, the theoretical and practical implications of the use of ?OTDR with linearly chirped pulses is discussed and stat-of-the-art results are presented. By providing a frequency to time mapping, this recent technique allows for the linear measurement of distributed refractive index variations with unprecedented sensitivities (Δn=10^-8) amongst distributed fibre sensors, while maintaining the high bandwidth of detection and long fiber sensing ranges.

As it is demonstrated, the technique readily allows for the distributed measurement of temperature and/or dynamic strain with resolutions of millikelvin and/or few n?, at kHz rates, using standard single-mode fibers. Owning to the high linearity of the measurement, vibrations reaching the fiber can be recognized by human earing, thus effectively using the fiber as distributed microphone with metric spatial resolution over tens of kilometres.

Furthermore, if combined with transducing elements that convert a physical magnitude into refractive index variations, the technique can be used to measure a variety of parameters, with important applications in high sensitivity distributed chemical sensing. As an example, the distributed measurement of acetylene concentration, discriminated by its absorption lines, is presented.

10208-16, Session 4

Deep learning based multi-threat classification for phase-OTDR fiber optic distributed acoustic sensing applications

Toygar Akgun, Metin Aktas, Mehmet U. Demircin, Duygu Buyukaydin, ASELSAN A.S. (Turkey)

This paper presents a deep learning based threat classification method aimed at use with a direct detection phase-OTDR based distributed acoustic sensing system. The proposed method uses a deep convolutional neural network trained with real sensor data that is manually labelled. Training and test data sets are obtained from the mentioned phase-OTDR based distributed acoustic sensing system. The collected data is pre-processed to filter out spurious signal fluctuations and enhance signal components that are mostly likely to be caused by meaningful external events. For this purpose, a novel signal conditioning method that can be an alternative to the conventional time-differencing is presented. On the event detection side, an adaptive thresholding based approach is used. The proposed classification method is tested experimentally using an ITU-T G.652 fiber optic cable buried at one meter depth inside an HDPE pipe with a diameter of 15 cm and no filling. During the tests four typically observed threat classes, namely, walking, manual digging, vehicle vibration and mechanical digging are applied at varying distances from the buried fiber optic cable. The results show that by applying the proposed signal conditioning, event detection and classification methods, threat classification accuracies above 80% can be achieved with the four mentioned threat classes at ranges of up to 30 km. Detailed analyses are conducted on the classification results to identify the classes that are most likely to be confused with each other and to observe the effects of the applied signal processing methods on the classification system performance.

10208-17, Session 4

Experimental characterization of optical fiber architectures for distributed sensing applications

Will Ray, Brad Stinson, Oak Ridge National Lab. (United States); Michael J. Messerly, Robert Mellors, Jay W. Dawson, Lawrence Livermore National Lab. (United States)

A series of measurements designed to quantify and characterize the performance of various realizations of a distributed fiber optic sensing system is reported. The focus of these investigations is an apples-to-apples comparison of the response of distinct fiber designs and cabling architectures when they are exposed to controlled continuous-wave and transient standoff acoustic sources. Multiple realizations are assessed simultaneously by daisy-chaining candidate fiber configurations in a linear array probed by a single Rayleigh-based interrogation unit. Commercial and in-house developed novel fiber architectures have been tested. Experiments have been performed in an acoustically isolated tabletop setup, as well as in laboratory and outdoor environments. Fiber-sensing performance has been assessed with respect to acoustic source directionality, proximity, frequency content and source strength. Our analysis reveals significant differences among candidate fiber-sensing architectures enabling quantification of the fiber transduction efficiency in various environments. Statistics of the response of nominally identical fibers within the same cable housing have also been analyzed. These results inform the selection of fibers and cabling for multiple sensing applications, as well as the interpretation of the responses received by interrogation systems.

10208-41, Session 4

Fiber optic sensors for distributed monitoring of soil and groundwater during in-situ thermal remediation

Hamid Alemohammad, Amir Azhari, Richard Liang, AOMS Technologies Inc. (Canada)

In-situ thermal remediation (ISTR) is an efficient contamination removal process using localized heat sources, called electrodes, inserted deep in the soil to heat up the soil to a target temperature (i.e, 100 degC to 700 degC). The heat causes the evaporation of hazardous substances and pollutants which are then extracted through a vacuum system. The success of the ISTR process is highly dependent on the accurate measurement of soil temperature distribution and groundwater depth. Environmental remediation is a process which occurs deep in the soil and groundwater saturated with highly corrosive chemical compounds such as volatile organic compounds (i.e., tetrachloroethylene, polychlorinated biphenyls, and methylene chloride). However, due to the severe conditions (high temperature, harsh chemicals, and the electromagnetic interference generated by electric heaters), the state-of-the-art electronic based temperature and pressure sensors fail or lose performance in such environments.

In this R&D work, a distributed fiber optic pressure and temperature sensor, based on fiber Bragg gratings (FBG), has been developed for the accurate and high-fidelity measurement of soil temperature and groundwater depth through hydrostatic pressure measurement. The prototypes have been successfully field tested in brownfields and federal superfund remediation sites and the results have been compared with electronic based transducers. In this research, several key challenges related to material compatibility of transducers, high-resolution and low pressure sensing, and temperature compensation for pressure monitoring have been addressed by capitalizing on AOMS core innovation on multi-parameter fiber optic sensors.

10208-18, Session 5

Adapting optical technology to dynamic energy prices: fiber-optic sensing in the contemporary oilfield *(Invited Paper)*

Daniel J. Stark, John L. Maida Jr., Neal G. Skinner, Halliburton Energy Services (United States)

The oil and gas industry is continually striving to produce more hydrocarbons and less waste such as water. Several sensing techniques using optical fiber, including distributed sensing, have been developed over the last three decades for all stages of well development, including production through abandonment. This paper reviews these optical sensing technologies, with particular emphasis on new applications and business drivers. Expected performance parameters of these new technologies are

discussed, including their accuracy, resolution, stability, and operational lifetime. Environmental conditions, such as high hydrostatic pressures, high temperatures, shock, vibration, crush, and chemical exposure are also given. These optical technologies are expected to provide safe, reliable, cost-effective, and unprecedented monitoring solutions.

10208-19, Session 5

The evolution of optical fiber cable design for sensor applications

Dean J. Yamasaki, AFL (United States)

Since its invention in the 1970's, optical fiber has provided a technology-based vehicle for performance improvement to legacy copper conductor based systems. Optical fiber based systems have enabled improvements in capabilities and functionality that are simply not possible with copper-only systems. Typically, optical fiber systems enable higher rates of data transfer over longer transmission distances. Telecommunications applications have demonstrated this benefit through improved capability for voice, data and video transmission.

Optical fiber applications have now expanded beyond telecommunications. Performance attributes such as temperature, pressure, acoustic and seismic parameters are being monitored and evaluated today. Application examples are present in Oil & Gas Exploration, Geothermal Monitoring, Nuclear Power Generation, and Fire Detection. The sensing environment typically exposes the optical fibers to much more extreme environments that are not prevalent in telecommunications. This includes high temperatures, high pressures, ionizing radiation and harsh chemical exposure that must be addressed in the cable design containing the fibers in order to extend the useful life of the fibers as much as practical.

While optical cable for sensing applications require some specialization, there are still basic cable design tenants that still apply to construct a cable that meets or exceeds the application environment. In many cases, design concepts proven in older copper based cables may be adapted to incorporate one or more optical fibers. Nevertheless, more extreme environments require the use of non-traditional materials not utilized in typical telecommunication applications. Also, some applications, due to their specialized nature, may drive one or more design aspects that are completely opposite of traditional optical cable designs.

The focus of this paper/presentation is to compare/contrast sensing applications with traditional telecom applications, review the more significant design considerations, and outline several current design challenges necessary to enable value-added reliable cable deployments.

10208-20, Session 5

In-situ Raman investigation of optical fiber glass structural changes at high temperature

Binod Bastola, Andreas Ruediger, Institut National de la Recherche Scientifique (Canada)

Temperature dependent Raman spectroscopy is used to study the changes of Ge-doped Si-fiber core glass structure with a 473 nm laser line. Raman spectra of a fiber core glass consists of symmetrically broadened modes that are associated with wagging, bending, stretching, ring etc. Holding a fiber at various temperatures between ambient temperature and 1000 degree Celsius alters the position, width and amplitude of some of the components that shows that the temperature response is influenced upon heating. Temperature dependent microscopic processes associated with the Fiber core are investigated by systematic observation of (a) integrated intensity (b) band width and (c) shift in peak position of various Raman bands as a function of temperature.

10208-22, Session 5

Optimization of optical fiber and cable for distributed acoustic sensing (DAS) and distributed strain sensing (DSS) applications: A real world study

Bruce Chow, Corning Incorporated (United States)

Fiber Optic Distributed Acoustic Sensing (DAS) and Distributed Strain Sensing (DSS) systems are gaining acceptance for intrusion sensing. DAS is effective at detecting the acoustic signature of intruders, equipment, vehicles, gunfire, etc. Both DAS and DSS are effective at detecting the presence of tunneling or geotechnic movement. These technologies convert an optical fiber cable into tens of thousands of virtual detection zones and are well suited for long distance perimeter, border sensing applications, and protection of high value assets. Because the optical fiber is the sensing element itself, the selection of the optical fiber as well as the cable design and deployment conditions are critical to the performance of the system. In many cases, standard cables for telecommunications applications are designed to isolate and protect the fibers from the external environment, and therefore are not well suited for sensing applications where strong coupling to external signals is required. Cable designs specifically created for sensing are shown to achieve a much higher level of sensitivity, performance, and reliability relative to standard telecom designs for both DAS and DSS technologies. A comparison of different cable designs and deployment conditions in a real world environment. The results are presented in this paper.

10208-23, Session 5

Applications of fiber optic sensors for heavy oil production

Christopher S. Baldwin, Weatherford International Ltd. (United States)

Fiber optic sensors have been finding applications in the downhole oil and gas industry for almost 30 years. One area in particular that has used the unique advantages of fiber optic sensing is thermal monitoring of steam-assisted gravity drainage (SAGD) wells. These wells use heated steam to dilute and reduce of the viscosity of bitumen in the reservoir. As the bitumen becomes less viscous, gravity drains the bitumen to a lower producing well where the hydrocarbon product can be brought to the surface, usually with the use of electrical submersible pumps. Multiplexed fiber Bragg grating (FBG) sensors have been successfully used to monitor the steam injection and production processes in SAGD wells.

This paper will discuss the development and applications of array temperature sensing (ATS) that is used for these applications. A Bragg grating-based pressure and temperature gauge has also been developed and successfully implemented for SAGD heavy-oil monitoring applications. The sensing systems have demonstrated long lifetimes and reliable operation for many years in very hostile, hydrogen-rich environments. These wells typically have temperatures exceeding 250°C and pressures nearing 1,000 psi. The applications are ideally suited for the capabilities of fiber optic sensing and harsh environments.

10208-24, Session 6

Ultrafast photonic systems for FBG sensing in detonation and shock wave experiments *(Invited Paper)*

George Rodriguez, Los Alamos National Lab. (United States)

Ultrafast high speed photonics are shown to provide the necessary temporal and spectral information required for understanding FBG response under impulsive loading from either high explosive detonation or an inert shock wave interaction. Demonstration of both, chirped and uniform, silica based FBGs are presented for sensing under harsh conditions that vary from thermal ignition in high explosives to inert tracking of high pressure shock waves. Ultrafast laser based chirped pulse methods are used to time-stretch and streak the spectral response of the FBG sensor to provide information about material response under loading. Coherent broadband pulses from a femtosecond modelocked fiber laser at 1550 nm are used to illuminate and interrogate the FBG at a repetition rate of 100 MHz. After reflecting off the FBG, chromatic dispersion is applied to time stretch the pulse and separate spectral channels for detection with a 35 GHz photoreceiver and recording with a 25 GHz digitizing oscilloscope. Results to be presented include pressure measurements in thermal ignition of high explosives, high explosive detonation burn, pressure wave tracking in weak inert shocks. The focus of the presentation is present the method and tools used for this approach to high speed FBG sensing.

10208-25, Session 6

Optimization of fiber Bragg grating parameters for sensing applications
(Invited Paper)

Devrez M. Karabacak, Fugro (Netherlands); John A. O'Dowd, Selwan K. Ibrahim, FAZ Technology Ltd. (Ireland); Johannes M. Singer, Fugro (Netherlands)

Fiber Bragg Gratings (FBGs) are increasingly being employed in a novel range of systems, especially in sensing applications. Some of the new generation of FBG-based sensors, especially those requiring high resolution sensing in harsh environments, impose physical challenges on Bragg gratings and their performance. Additionally, there is a growing list of Fiber Bragg Grating types and manufacturing techniques, each with its own strengths and weaknesses. With the new generation of fiber optic interrogation technologies reaching femtometer-level resolution in Bragg wavelength tracking, the achievable accuracy and stability of the sensing system is becoming limited by the performance of the employed Bragg grating itself. In many cases, correct selection and definition of the FBG parameters can result in defining the success of the sensing system.

Here, we explore the specifications of Bragg gratings that are most relevant to FBG-based sensors, propose their characterization and analysis methodologies and explore their effects for both static and dynamic sensing applications in combination with tunable laser based fiber optic interrogation techniques. Bragg gratings manufactured by several different techniques are compared to demonstrate their suitability for different types of sensing applications. Several application focused examples are also provided, in an effort to demonstrate the importance of the parameters for detection of strain, pressure, sound, vibration and tilt using fiber optic sensors.

10208-26, Session 6

Force and pressure sensing using fiber grating sensors

Ingrid Scheel, Eric Udd, Columbia Gorge Research LLC (United States)

Fiber grating sensors may be used to measure force and pressure in a variety of ways. This paper will overview past approaches and introduce a new method to measure force and pressure using fiber grating sensors.

10208-27, Session 6

Performance assessment of a fiber Bragg grating sensor network inside a hydro power dam using optical backscatter reflectometry

Christoph Monsberger, Ferdinand Klug, Werner Lienhart, Technische Univ. Graz (Austria)

In recent years, many existing hydro power plants were modified to operate in more efficient pump storage mode. As a result, the loading conditions for the dams have changed significantly and new monitoring concepts are required to provide an economical and safe operation. In 2013, we developed and installed a FBG (fiber Bragg grating) based monitoring system to fully automatically monitor movements of segment joints inside a hydro power dam. This system enables dynamic measurements with a high measurement resolution and gives information about the structural behavior of the dam that cannot be observed with traditional sensors.

In this paper, we report about detailed investigations of the developed FBG sensor network using an optical backscatter reflectometer. This distributed measurement device allows distributed strain sensing with a very high precision of about 1μm/m every 10 millimeters or even better. Consequently, an analysis of the strain profile between two anchoring points of a FBG sensor is possible. In addition to distributed sensing, the linear backscatter amplitude of a small part of the signal can be obtained in the frequency domain and the different wavelengths of the FBGs along the fiber can be determined. Thus, the results of a classical FBG interrogator can be verified.

In advance to the field application, we investigated the measurement system in the laboratory and calibrated the installed sensors with our fiber optic test facility. These laboratory studies and the field verification measurements prove the high potential of FBG sensors for long-term static and dynamic monitoring of dams.

10208-28, Session 6

In-situ study of pH-responsiveness of polyelectrolytes using long-period fiber gratings

Fan Yang, Stevens Institute of Technology (United States); Svetlana A. Sukhishvili, Texas A&M Univ. (United States); Henry Du, Fei Tian, Stevens Institute of Technology (United States)

Solution pH is one of the most critical parameters for chemical reactions which are important for clinical, environmental or manufacturing applications. The integration of pH-responsive polyelectrolyte via layer-by-layer assembly (LbL) with long period grating (LPG) has enabled the monitoring of the pH in real time with high sensitivity at minimized volume. We show that the pH-responsive profile of the LbL/LPG platform can be tailored to specific needs depending on the deposition parameters during the LbL process. By choosing different deposition pH, weak polyelectrolytes showed either linear responsiveness or responsiveness with a reversal point at pH 4.5 over the pH range of 2-11. The most sensitive area was related to both the pKa of the chosen polyelectrolyte in the coating and the deposition pH during the LbL process. The study provides important guide to optimize and improve the sensitivity in specific pH range by selection of polyelectrolytes and/or deposition parameters. The LbL/LPG platform affords a powerful tool to study the mechanisms of the responsiveness and physiochemical properties of the polyelectrolytes.

10208-29, Session 6

Design, implementation and characterization of an FBG-emulator for a scanning laser-based fiber-optic interrogator

Nader Kuhenuri Chami, Alexander W. Koch, Technische Univ. München (Germany)

The Hybrid Sensor Bus is a space-borne temperature monitoring system for telecommunication satellites combining electrical and fiber-optical Fiber Bragg Grating (FBG) sensors. Currently, there is no method available for testing the functionality and robustness of the system without setting up an actual sensor-network implying numerous FBG sensors in which each has to be heated/cooled individually.

As a verification method of the mentioned system, FBG reflection based scanning laser interrogator, an FBG-emulator is implemented to emulate the necessary FBG sensors. It is capable of immediate emulation of any given FBG spectrum, thus, any temperature. The concept provides advantages like emulating different kinds of FBGs with any peak shape, variable Bragg-wavelength lambda, maximal-reflectivity, spectral-width and degradation characteristics. Further, it facilitates an efficient evaluation of different interrogator peak-finding algorithms and the capability of emulating up to 10000 sample points per second is achieved.

In the present paper, different concepts will be discussed and evaluated yielding to the implementation of a Variable Optical Attenuator (VOA) as the main actuator of the emulator. The actuator choice is further restricted since the emulator has to work with light in unknown polarization state. In order to implement a fast opto-ceramic VOA, issues like temperature dependencies, up to 200V driving input and capacitive load have to be overcome. Furthermore, a self-calibration procedure mitigates problems like attenuation losses and long-term drift. Finally, measurement results of the combined interrogation module and the FBG emulator are presented.

10208-30, Session PWed

Influence of different encapsulation types and shapes of polydimethylsiloxane on the temperature sensitivity of the FBG

Jan Nedoma, Marcel Fajkus, Radek Martinek, Martin Novak, Ondrej Zboril, Jan Jargus, Karel Witas, Frantisek Perecar, Vladimír Vašinek, VŠB-Technical Univ. of Ostrava (Czech Republic)

Fiber Bragg grating (FBG) is formed by the periodic structure in the core of the optical fiber and is one of the widely-used types of fiber optic sensors. FBGs are primarily sensitive to strain and temperature. For sensory application is an important encapsulation of FBG to achieve maximum sensitivity to the desired measurand and ensure of protection against damage. Interesting way to encapsulate FBG is the use of elastomer polydimethylsiloxane (PDMS). Authors of this paper followed on previous research regarding encapsulation of FBG and analyzed the influence of different encapsulation types and shapes of PDMS on the temperature sensitivity of the FBG expressed pm/°C. During the study tested five different types of PDMS. Realization of encapsulation is composed of three parts: FBG insertion to a regular form with the liquid PDMS, curing in a temperature box with a constant temperature 100 °C ± 5 % and 24 hours relaxation. Analysis of temperature sensitivity was carried out after curing including relaxation time and it using the broadband source of light LED (Light-Emitting Diode) with central wavelength 1550 nm and the optical spectrum analyzer OSA 203.

10208-31, Session PWed

Impact of fixing materials on the frequency range and sensitivity of the fiber-optic interferometer

Jan Nedoma, Marcel Fajkus, Radek Martinek, Lukas Bednarek, Stanislav Zabka, David Hruby, Jakub Jaros, Vladimír Vašinek, VŠB-Technical Univ. of Ostrava (Czech Republic)

Fiber-optic sensors are one of the dynamically developing areas of photonics, which is today one of the key technologies. Here include even fiber optic interferometers, allowing very sensitive sensing, they are immune to electromagnetic interference and are entirely passive regarding electric power supply. This type of sensor is dependent on the phase shift, the principle of the function based on interference of light. Use are especially in areas that require high sensitivity and measurement accuracy. The fundamental problem of fiber optic interferometry is a proposal storing and fixing the measuring arm of the interferometer and its influence on the frequency range and sensitivity of the interferometer. The authors focused on this issue and analyzed different types of fixing materials. Used a total of 8 different fixation elements with the different composition. We defined the constant method of fixation and compared it with a reference measurement without fixation. For the analysis of the frequency characteristic of the prototype was used generator harmonic signal with fixed amplitude signal. Sensitivity verified using the size of the amplitude response. The signal processed by the application written in LabView development environment. The results clearly showed that it is necessary to pay attention to fixation materials in the design of the measuring arm of the interferometer for use in practical applications. In the frequency range, thanks to the fixing material increased the value of bandwidth about value 3020Hz against the reference measurements. The sensitivity of the interferometer has increased threefold. The results verified by retesting assembled prototype.

10208-32, Session PWed

Fiber optic sensor encapsulated in polydimethylsiloxane for monitoring heart pulse

Marcel Fajkus, Jan Nedoma, VŠB-Technical Univ. of Ostrava (Czech Republic); Radek Martinek, VŠB Technical Univ of Ostrava (Czech Republic); Jan Jargus, Vladimír Vašinek, VŠB-Technical Univ. of Ostrava (Czech Republic)

Technology FBG belongs to the most widespread fiber optic sensors. It used for measuring a large number of chemical and physical quantities. Immunity to electromagnetic interference, small size, high sensitivity and principle information encoding about the measured value to the spectral characteristics cause usability of FBG sensors in medicine for monitoring vital signs such as pulse frequency, blood pressure, temperature or respiration. An important factor in this area is the use of an inert material for the encapsulation of Bragg gratings. An interesting choice is the elastomer polydimethylsiloxane (PDMS). PDMS is optically clear, general inert, non-toxic and non-flammable. The material commonly used for biomedical and medical applications. Experimental results presented in this paper describe the creation of prototype FBG sensor for monitoring heart rate of human body. The sensor is realized by Bragg grating encapsulated into polydimethylsiloxane. The FBG sensor is part of the elastic contact strap which encircles the chest of the patient. This tension leads to a spectral shift of the reflected light from the FBG. The research based on the monitoring of 10 different test persons. We monitored various physical activities (resting, active motion). The following research will focus on the comparison to conventional sensors.

10208-33, Session PWed

Analysis of the impact of the deposition optical fibers on the measuring of deformation with a distributed system

Marcel Fajkus, Jan Nedoma, VŠB-Technical Univ. of Ostrava (Czech Republic); Radek Martinek, Jakub Jaros, David Hruby, Frantisek Perecar, VŠB Technical Univ of Ostrava (Czech Republic); Vladimír Vašinek, VŠB-Technical Univ. of Ostrava (Czech Republic)

The team of authors article analyzed the influence of the cover layer in combination with various types of cushioning material to measure deformation with distributed system Brillouin Optical Time Domain Reflectometry (BOTDR). This system is based on the principle of measuring stimulated Brillouin scattering, which is frequency dependent on the measured temperature and the mechanical stress of the optical fiber. Standard telecommunication optical fiber G.652.D was used for experiments to verify whether this widely used type of fibers initially intended for telecommunication transmissions is suitable for measuring the deformation with the distributed system BOTDR. Knowing the impact of encapsulation type optical fiber is important in the use and implementation in practical applications. The results clearly show that it is important to pay attention to the implementation type of optical fiber. Based on post-analysis, it was determined the most appropriate implementation of optical fiber for optimal sensitivity in practical applications

10208-34, Session PWed

Polarized and birefringence-dependent stimulated Brillouin scattering in single mode fiber

Shan Cao, Tsinghua Univ. (China); Min Zhang, Tsinghua Univ. (China) and Peking Univ. (China)

Based on the vector theory of stimulated Brillouin scattering (SBS), a simplified model has been concluded through valid assumptions. A mathematical method referred to as Stratonovich generator, which is efficient in handling with stochastic differential equations, is utilized to analyze the model theoretically. The solutions are identical with directly numerical integration. Quantitatively, the average alignment of pump and signal is presented and adds to the detailed explanation of birefringence and state of polarization (SOP) dependent average Brillouin gain. According to the analysis above, SOPs relevant to maximum (minimum) Brillouin gain differ in two main birefringence regime, with a crossing point indicating a value where the discrepancy disappears. In addition, the fluctuation of signal has been studied and there are conclusions about the fluctuation range of signal with abundant SOPs. Finally, statistics of the signal has been investigated, resulting in a Gaussian distribution in terms of a log-scaled variable, contributing to a broader perspective for estimating and processing SBS signal. The detailed demonstration contribute to further understanding of the effect of polarization and birefringence on Brillouin systems, which will help in the performance analysis of distributed sensing based on SBS.

10208-35, Session PWed

Research on an optimized optical fiber accelerometer for well logging

Duo Yi, Institute of Ocean Research, Peking Univ. (China); Xiaokang Qiu, Tsinghua Univ. (China); Lijuan Gu, Min Zhang, Institute of Ocean Research, Peking Univ. (China)

In the industrial and military fields such as oil well logging, coal mining, geologic/oceanic exploration, torpedo detection etc, it is necessary to collect the seismic wave signal and transfer into basic physical parameters, for example, displacement, velocity or acceleration, and finally conducting the data processing to demodulate the required information. When compared to the traditional piezoelectric sensor, the optical fiber accelerometer is considered as a more promising candidate for these kinds of applications due to its immunity to the electromagnetic interference, easy to form sensing network, high sensitivity, small size, low cost. In case of oil well logging, it can ensure high performance in harsh conditions (high temperature, high pressure and flammable environment). Among all types of optical fiber sensors, the optical fiber accelerometers based on phase modulation with Mach-Zehnder or Michelson structure are mostly appreciated and widely used. This work evaluates an optimized optical fiber accelerometer for oil well logging applications. The compliant cylinder of the accelerometer is optimized as composite materials which consist of polyphenylene sulfone and silica rubber. When compared to the traditional accelerometer with pure single material of compliant cylinder, the new accelerometer is capable to provide both higher phase sensitivity and wider 3dB frequency bandwidth. An integral parameter S is proposed to access the overall performance of the accelerometer probe with considering both phase sensitivity and resonance frequency. The effects of young's module of the substrate material and the additive material to the integral parameter S are discussed and the optimized proportional mixing are finally suggested.

10208-36, Session PWed

Mechanical behavior analysis of a new sensing composite structure which embedding an optical fiber

Duo Yi, Min Zhang, Lijuan Gu, Institute of Ocean Research, Peking Univ. (China); Kuanglu Yu, Beijing Jiaotong Univ. (China)

Smart sensing composite structure material which embedding an optical fiber sensor has received increasing interests in various fields of aerospace, industrial, defense and civil infrastructure. The embedded optical fiber sensor can provide numerous important parameters such as micro strain, micro vibration, stiffness, which are vital to the in situ structural health monitoring as well as the optimizations of conditions. In this study, a numerical study is conducted to evaluate the mechanical behavior of a composite structure material which consists of thermal spray coating, substrate as well as embedded optical fiber by finite element method. The net incident heat flux density and the forced convective heat transfer coefficient are used to initialize the numerical model. Then the thermal results are converted for the mechanical analysis, the stress level of the composite structure especially the embedded fiber are analyzed. The variations of refractive index of the embedded fiber due to the thermo-optic effect and elasto-optic effect are investigated. The results shows that the stress level of the embedded fiber (order of 107 Pa) is much lower than the threshold value of tensile strength, the variation of refractive index during thermal spray has an insignificant effect on the optical transmission, which ensures a good embedding quality of the optical fiber.

10208-37, Session PWed

Real-time phase demodulation and data administration of distributed optical fiber vibration sensing system

Mengzhe Qin, Xiangge He, Fei Liu, Xiaoping Zheng, Tsinghua Univ. (China); Min Zhang, Institute of Ocean Research, Peking Univ. (China)

Distributed optical fiber sensing system (DOFS) has been researched a lot as a vital security alarm system based on its priorities of low cost and long

distance. Due to the simple structure and high density sensing points, DOFS is also really competitive in on-site operation of petroleum monitoring.

As the representative of DOFS, phase-sensitive optical time domain reflectometry (?-OTDR) is widely studied and used because of the relatively high sensitivity, simple construction and the characteristic of multi-point detection. In ?-OTDR system, in order to get high upper limit of dynamic range and better demodulation results, heterodyne demodulation method is proposed. A high-quality ?-OTDR should have long distance, high resolution and high system sampling rate, which means if being applied in real-time detection, it will generate ultra large amounts of data. For the development of ?-OTDR, it is really important to make high-efficiency administration of the large data by algorithm optimization.

In this paper, the heterodyne demodulation algorithm of ?-OTDR system is clarified. Taking advantages of the efficient matrix operations of MATLAB and multithreading function of VC++, the algorithm is highly optimized and the processing rate reaches up to 100MB/s, realizing the real-time demodulation of the whole system. Based on this, the three-dimensional map (vibration intensity versus time and space) is further plotted in the detecting experiments, which proves the strong application value of our ?-OTDR system. The administration method also applies to the large-scale fiber-optic hydrophone array system, which will have great potential in fields of energy, transportation and security.

10208-38, Session PWed

The influence of temperature loading on the optical fiber passive components

Frantisek Perecar, Lukas Bednarek, Lukas Hajek, Jakub Jaros, Marcel Fajkus, Aleš Vanderka, Jan Nedoma, Vladimír Vašinek, VŠB-Technical Univ. of Ostrava (Czech Republic)

The paper discuss about aging of the passive optical couplers and the passive optical splitters in their burdened high temperature. The article focus on applied research and experimental development of resources for safety operation of optical networks in environment with higher temperature. It addresses issues of accelerated ageing of optical fiber components in their burdened with high temperature. How does temperature influence on optical network elements? It is necessary to specify the changes in the optical coupler and find out why these changes occur. This article is devoted experimental measurement of the impact of temperature loading on the SM optical FBT coupler with 8 branches. Optical passive component were exposed to temperature 95°C for 959 hours. Measurements are focused on the parameters of geometry of optical beam. Graphical and mathematical detect changes in the dissemination of energy coupler after single doses of temperature loading are useful to understand the phenomenon of accelerated ageing elements of optical networks in environments with an higher temperature.

10208-39, Session PWed

Various optical fiber fixing methods for mechanical stress measurements

Jakub Jaros, David Hrubý, Vladimír Vašinek, Frantisek Perecar, VŠB-Technical Univ. of Ostrava (Czech Republic); Marcel Fajkus, Jan Nedoma, Tomas Kajnar, VŠB-Technical Univ of Ostrava (Czech Republic)

The monitoring of building structures deformations and testing of construction materials resilience are very important processes in the development and production of given materials and structures. Undesirable or excessive deformations of materials are phenomena which are unacceptable in construction, especially in supporting structures. These issues are currently monitored by electromechanical sensor in most cases. It is a classic technique when the sensor measures the material stress at the point of its installation. This paper deals with the concrete deflection measurement using fiber optic distributed strain system. The own principle of the measurement evaluation is based on stimulated Brillouin scattering. This can be caused by passing the coherent light thru the optical fiber. The size of frequency change, which is evaluated, is a measure of applied mechanical stress fibers. Since the frequency shift is generated by two phenomena that do not affect the inside of the optical fiber, it applies that if the variation of mechanical stress fibers, the resulting frequency shift of stimulated scattering is dependent only on the temperature, if the variation is the temperature, the resulting frequency shift depends only on mechanical stress. In this paper, we explore the use of different types of optical fibers and the possibilities of their fixing. We mainly focus on standard telecommunication fibers, which are significantly cheaper than special fibers. Above all, we are focusing on the possibility of their attachment to the measured objects. This is the most important step of the whole process that most affects the functionality and accuracy of measurement.

10208-40, Session PWed

Masonry moisture measurement using the distributed temperature sensing system

David Hrubý, Jakub Jaros, Stanislav Kepak, Tomáš Kajnar, Vladimír Vašinek, VŠB-Technical Univ. of Ostrava (Czech Republic)

Distributed temperature sensing systems (DTS) are based on the principle of time-domain reflectometry where an optical fiber acts as a temperature sensor. DTS is capable of measuring the temperature along the optical fiber using the non-linear phenomenon referred as Raman scattering. The biggest advantage of such sensing system is the use of an optical fiber itself as a sensor which gives the benefits of electromagnetic interference immunity, low sensor cost, measurement distances up to 10 kilometers and the safe use in flammable and corrosive environments. Fiber optic DTS can be therefore used in the environments and processes in which the application of conventional sensors is impossible. This article discusses the use of DTS for the moisture measurement in the masonry. In structures with built-in optical fiber, the immediate detection and location of moisture are possible. To perform the measurements an experimental brick wall has been built and between each wall layer the optical fiber was placed. The wall was built in stainless steel tub with a drain valve and was placed on a mobile trolley. The dimensions of the wall were 106 x 96 x 30 cm. The actual measurements were carried out in two stages. In the first, the tub was filled with water and the temperature change associated with the gradual increase of moisture inside the wall was measured. This measurement lasted until the saturation which was the time when the wall has no more moisture to adopt. The second stage then examined the evolution of the temperature inside the wall during gradual desiccation until the time when the temperature inside the wall was uniform between all layers.

Conference 10209: Image Sensing Technologies: Materials, Devices, Systems, and Applications IV

Wednesday - Thursday 12–13 April 2017

Part of Proceedings of SPIE Vol. 10209 Image Sensing Technologies: Materials, Devices, Systems, and Applications IV

10209-1, Session 1

Advanced terahertz imaging with electromagnetic metamaterials *(Invited Paper)*

Willie J. Padilla, Duke Univ. (United States)

The utilization of metamaterials as spatial light modulators (SLMs) offers a new route to achieve reconfigurable single pixel imaging systems. Here we demonstrate a metamaterial SLM hat permits high speed imaging at terahertz frequencies using communications engineering techniques. Specifically we implement quadrature amplitude modulation (QAM) with our all-electronic metamaterial SLM, which enables a doubling of the imaging frame rate. A second independent technique of frequency diverse imaging uses a number of sub-carriers to permit parallelization of the imaging process, which results in an increase in imaging speed only limited by signal to noise. Our results are not limited to the terahertz band, but may be scaled to nearly any sub-optical range of the electromagnetic spectrum, and verify the potential of metamaterials to operate as reconfigurable multifunctional devices which will enable next generation imaging systems.

10209-2, Session 1

Highly efficient terahertz metasurface flat lenses *(Invited Paper)*

Hou-Tong Chen, Los Alamos National Lab. (United States)

Conventional optical lenses focus electromagnetic waves by imparting position-dependent phase delay through shaping their geometry. This poses difficulties in eliminating the geometric aberrations in high numerical aperture lenses, in addition to the fabrication challenges when operating at short wavelengths (e.g. visible light), and bulky devices operating at long wavelengths (e.g. microwaves). In contrast, metasurfaces realize full control of phase through tailoring the subwavelength resonant structures, allowing for the demonstration ultrathin flat lens, although the efficiency is still rather low using single-layer metasurfaces. Here we report the demonstration of high-performance flat lens in the terahertz frequency range using few-layer metasurfaces. The three-layer metasurface structure is capable of rotating the incident linear polarization by 90° with a very high efficiency over a bandwidth of two octaves. More importantly, the phase of the output light can be tuned over the entire 2ϖ range with subwavelength resolution through simply tailoring the structure geometry of the basic building blocks. Based on this success, we design, fabricate, and characterize a metasurface lens operating at 0.4 THz. With a lens diameter and focal length both 5 cm, we realize a high numerical aperture of 0.5 and diffraction-limited terahertz beam focusing. Terahertz time-domain spectroscopy measurements show that the metasurface lens is capable of achieving the same signal intensity as compared to a bulk TPX lens of the same size and focal length.

10209-3, Session 1

Plasmonic design based structures for THz antenna sources and detectors *(Invited Paper)*

Shriganesh S. Prabhu, Tata Institute of Fundamental Research (India)

We have developed different plasmonic structural designs for the confinement of incident excitation infra-red (800nm, 10fs) laser pulse on SI-GaAs surface. The SI-GaAs surface is modified so that incident radiation is less reflected and more absorbed in the substrate. Fabricating THz antenna structures on it increases the efficiency of the THz source. We have demonstrated this idea in its simplest form by increasing the overall surface area by fabricating trenches on the GaAs surface in the past. The new designs are expected to increase the THz source emission by at least a factor 2 to 4. We have also fabricated quasi-crystal pattern on SI-GaAs substrate to enhance the incident light confinement and checked THz emission from it. We will fabricate this structure on C-irradiated SI-GaAs. The simulated plasmonic structures will be fabricated on the SI-GaAs substrates as well as C-irradiated GaAs substrates. We have shown that our in-house fabricated THz Sources from C-irradiated SI-GaAs showed ~2 orders power increase. The detectors fabricated from these materials showed much better replica of the incident THz wave compared to the one detected using ZnTe. We will also present use of the C-irradiated substrates in the generation of Continuous Wave (CW) THz sources. These sources will be compared with the commercially available sources made of LT-GaAs.

10209-5, Session 2

THz metamaterials for imaging and sensing *(Invited Paper)*

Seongsin Margaret Kim, The Univ. of Alabama (United States)

The ability to design and engineer sub-wavelength metamaterial structures capable of manipulating the propagation of Terahertz waves and the manner in which they interact with matter is of great fundamental and practical interest. In this paper, we review our recent work on the design, simulation and implementation of metamaterial devices operating at the Terahertz frequencies for applications such as sensors and imaging. First we will discuss the design, simulation, and realization of THz metamaterials exhibiting plasmon-induced transparency (PIT) by hybridizing two double split ring resonators on either silicon or flexible polymer substrates. Then we will present recent work on stereo-metamaterials inspired by stereoisomers and engineered by using a spatially different arrangement of meta-atoms, and present results of the polarization changes in this structure can be useful for THz imaging system. Finally we will discuss our recent work on near field THz imaging and its application to biometamaterials.

10209-6, Session 2

Ultra-short pulses from quantum cascade lasers for terahertz time domain spectroscopy *(Invited Paper)*

Muhammad Anisuzzaman Talukder, Univ. of Leeds (United Kingdom)

Although the quantum cascade laser (QCL) is a promising compact semiconductor terahertz (THz) source, its success in creating ultra-short pulses is limited. THz short pulses have many applications, including in time domain spectroscopy. There have been demonstrations of short pulse (>1 ps) generation from THz QCLs based on active modelocking, although the stability of the pulses is limited. We show that THz QCLs can be modelocked passively using a two-section cavity, where the sections are independently controlled by bias voltages. While one of the sections produces gain, the other produces quantum coherent saturable absorption and helps to create ultra-short pulses.

10209-7, Session 2

Effective algorithm based on Fourier transform for the passive THz image quality enhancement *(Invited Paper)*

Vyacheslav A. Trofimov, Vladislav V. Trofimov, Ivan L. Shestakov, Roman G. Blednov, MV Lomonosov Moscow SU (Russian Federation)

We propose new approach for THz image quality enhancing using correlation function (convolution function) between Fourier transform of the image under consideration and Fourier transform of a standard image which can be enough complex. This method allows to see the person clothes details that it means multi-times increasing of the passive THz camera temperature resolution. It is very important to stress that a standard image choosing allows us to remove essentially spurious parts of the image.

10209-8, Session 3

Large dynamic range terahertz spectroscopy enabled by plasmonic nano-antenna arrays

Nezih T. Yardimci, Mona Jarrahi, Univ. of California, Los Angeles (United States)

We present a new generation of time-domain terahertz spectroscopy systems based on large-area plasmonic nano-antenna arrays that offer significantly large dynamic ranges and spectral bandwidths compared to the state of the art. We demonstrate a time-domain terahertz spectroscopy system with a record-high dynamic range of 107 dB over a spectral bandwidth of 5 THz. Such high-performance time-domain terahertz spectroscopy system would extend the potential use of terahertz technology for various imaging and sensing applications.

10209-9, Session 3

Terahertz direct detectors based on superconducting hot electron bolometers

Jian Chen, Shoulu Jiang, Lin Kang, Pei Heng Wu, Nanjing Univ. (China)

Superconducting niobium nitride (NbN) hot electron bolometers (HEBs) have been used widely in the astronomical observations with its low noise temperature [1] (a few times of the quantum noise limit) as heterodyne detectors. On the other hand, with high temperature coefficient of resistance (TCR) and low noise characteristics, NbN HEB can be considered as direct detectors. Combined with NbN material's quick response property (response time:~ps), NbN HEB direct detector can be used in quick terahertz (THz) imaging and weak THz ultrashort pulse signal detection. A direct detector system similar to the microwave stability system[2] in our lab has been constructed. The injected microwave is used to suppress the superconducting current and bias the HEB to an optimum bias point combined with the constant DC voltage source. The bias current changes corresponding to the incident THz signal power is read out by the dynamic signal analyzer. Compared to the thermal bias method which used the heating methods to heat the HEB to its critical temperature, the proposed method can enhance the direct detector's stability and decrease the consumption of the liquid helium, which is key for the long time observations in the astronomical field and so on. More importantly, we found that our method can enhance the TCR of the NbN HEB from 8.45/K with the thermal bias method to 961/K. We obtained the noise equivalent power (NEP) of 1.4?10-12 W/Hz1/2 at 4.2 K and 0.65 THz. This value is mainly limited by the read out circuit at this moment. The response time of 86 ps is obtained in the separate measurement. Further improvement of NEP can be realized with optimizing the read out circuit.

References

[1] Y. Jiang, B. B. Jin, W. W. Xu, L. Kang, J. Chen and P. H. Wu, Science China-Information Sciences 55 (1), 64-71 (2012).

[2] J. Chen, Y. Jiang, M. Liang, L. Kang, B. B. Jin, W. W. Xu and P. H. Wu, IEEE Transactions on Applied Superconductivity 21 (3), 667-670 (2011).

10209-10, Session 3

Design and performance analysis of ultra-massive multi-carrier multiple input multiple output communication in the terahertz band

Luke Zakrajsek, Dimitris A. Pados, Josep M. Jornet, Univ. at Buffalo (United States)

In this paper, Ultra-Massive Multi-Carrier (UMMC) MIMO communication, which relies on ultra-dense frequency-tunable active planar plasmonic nano-antenna arrays, is explored as a way to overcome the frequency-selective, very high path loss at Terahertz (THz) frequencies. An optimization framework is developed to determine the capacity of UMMC MIMO communications by taking into account both the capabilities of THz nano-antenna arrays in transmission and reception and the behavior of the THz channel in multi-path scenarios. The analytical models are validated by means of electromagnetic simulations and extensive numerical results are provided.

10209-11, Session 3

Superconducting terahertz emitters using high Tc superconducting Bi-2212 single crystals *(Invited Paper)*

Kazuo Kadowaki, Univ. of Tsukuba (Japan)

After discovery of coherent radiation at Terahertz frequencies from the mesa structure of high-Tc superconducting Bi2212 single crystals in 2007, much development has been made both for fundamental understandings and applications, especially dowards imaging, sensing, communications, etc. The advantages of this emitter lies in the emission mechanism, which relies purely on the ac Josephson effect, accordingly giving a monochromatic radiation with variable frequencies by varying the applied voltage in a very wide frequency range. The disadvantage comes from superconducting nature of the device, which requires coolin below the critical temperatue Tc. However, this issue is not serious because recent cryocooler technologies can provide a cooling engine with sufficient cooling power at the operating temperature range of 50-77 K with a few kg weight. Therefore, combining the emitter and the handy cryocooler results in the prototype devices covering 1 and 2 THz region with variable frequencies. Recently, we have succeeded in making devices having a power level of 50 micriwatt/mesa and frequencies up to 2.4 THz by improving device fabrication technology, in particular, Joule heat due to dc-current from the device. The most updated results will be shown in the presentation.

10209-12, Session 3

Coherent imaging at terahertz frequencies with diffraction tomographic digital holography *(Invited Paper)*

Martin S. Heimbeck, U.S. Army (United States)

Tomographic digital holography and coherent imaging are explored in the terahertz frequency region (between 0.230 and 0.740 THz) with highly coherent, frequency-tunable continuous wave sources. The long coherence

length of microwave sources suggests that interferometric imaging techniques such as Fresnel off-axis holography can achieve sub-micrometer depth resolution of surfaces and through materials and structures that are transmissive in the terahertz spectral region. Research in this area will provide an important non-destructive imaging tool for the rapidly expanding field of additive manufacturing and composite fabrication. Unfortunately, imaging optics as they are used in confocal imaging and optics in general adversely affect the performance of terahertz imagers as their aperture size if comparable to the wavelength, which artificially limits image resolution according to the diffraction limit and can cause undesirable coherence effects in the image. We report on imaging methods that minimize the use of optics and used signal processing techniques that form images digitally from recorded holograms. This approach is directly applicable to focal plane arrays in contrast to confocal imaging modalities. Furthermore, we investigate the improvement of the image reconstruction and material index mapping using multiple aspect angles and wavelength exposure.

10209-28, Session 3

Development of nanostructured antireflection coatings for infrared image sensing technologies

Gopal G. Pethuraja, Roger E. Welser, Ashok K. Sood, Magnolia Optical Technologies, Inc. (United States); Harry Efstathiadis, Pradeep Haldar, State Univ. of New York Polytechnic Institute (United States); Eric A. DeCuir Jr., Priyalal S. Wijewarnasuriya, U.S. Army Research Lab. (United States); Nibir K. Dhar, U.S. Army Night Vision & Electronic Sensors Directorate (United States)

Image sensing technologies and systems operating from ultraviolet (UV) to long-wave infrared (LWIR) spectrum are being developed for a variety of defense and commercial systems applications. Reflection loss of a significant portion of the incident signal limits the performance of image sensing systems. One of the critical technologies that will overcome this limitation and enhance the performance of image sensing systems is the development of advanced antireflection (AR) coatings. Magnolia is actively working on the development and advancement of ultra-high performance AR coatings for a wide variety of defense and commercial applications. Ultrahigh performance nanostructured AR coatings have been demonstrated for UV to LWIR spectral bands on various substrates. The AR coatings enhance the optical transmission through optical components and devices by significantly minimizing reflection losses, a substantial improvement over conventional thin-film AR coating technologies.

Nanostructured AR coatings are fabricated using a tunable self-assembly process on substrates that are transparent for a given spectrum of interest ranging from UV to LWIR. The nanostructured multi-layer structures have been designed, developed and optimized for various optical electronic applications. The optical properties of AR coated optical components and sensor substrates have been measured and fine-tuned to achieve a predicted high level of performance of the coatings. In this conference, we review our latest work on high quality nanostructure-based AR coatings, including recent efforts on the development of nanostructured AR coatings on IR substrates.

10209-30, Session PWed

Nanocrystalline diamond based optical sensing

Adam Khan, Ernie Schirmann, Priya Raman, AKHAN Semiconductor Inc. (United States); Robert D. Polak, AKHAN Semiconductor Inc. (United States) and Loyola Univ. Chicago (United States)

We study the practical and economical usage of Nanocyrstalline Diamond (NCD) as a first surface in an anti-reflective coating upon a traditional substrate. Using measured index of refraction and extinction coefficient values, we are able to develop multi-layer coating solutions intended for the different spectral regions such as the visible or infrared wavelengths. These provide comparable transmissivity and reflectivity performance to known solutions while providing enhanced mechanical properties such as improved breakage and scratch performance and resistance to impact from airborne particles. Additionally, low temperature diamond allows Complementary Metal Oxide Semiconductor (CMOS) device integration on optical substrates opening new opportunities for the next generation optical sensing technologies.

10209-31, Session PWed

Optical design of wide-angle lens for LWIR earth sensors

RongSheng Qiu, Wei Dou, JinYan Kan, Kun Yu, Shanghai Aerospace Control Technology Institute (China)

The earth sensors on the satellites measure the attitude by observing the discontinuity between earth radiance and cold space background. As IR detector technology advances, the earth sensor has evolved from traditional scanning sensor to static sensors with uncooled infrared FPA. In order to obtain high pointing accuracy of the earth center and avoid the influence of the cloud layer, the optical system should have the following characteristics such as: excellent f-theta linearity, high MTF at corresponding frequency, and high transmittance in the 14 to 16 μm range. In addition, this earth sensor is intended to be used on a LEO satellite, so the optical system must cover a wide FOV larger than 130°, and be as light and compact as possible.

This paper contains the full design process of a FOV lens used for LWIR earth sensors from paraxial power allocation calculation to analysis of lens performance including DOE shading effect and vignetting introduced by absorption difference at different field of view. The lens has a relative large image circle of 12mm, which is compatible with a 640?480 25μm uncooled FPA, and its full FOV is 160°. Its focal length is 4.177 and F number is 0.8. The f-theta distortion is less than 0.25%. By choosing chalcogenide glasses as lens material, the lens has a higher transmittance compare to Germanium lens. Also by analyzing the chromatic aberration of the lens, applying a DOE surface helps to improve the image quality, and pushes the modulated transfer function towards diffraction limitation.

10209-32, Session PWed

Detection and identification of foreign bodies in polymer parts for use in semiconductor manufacturing

Thomas Arnold, Raimund Leitner, Martin Kraft, Christina Hirschl, CTR Carinthian Tech Research AG (Austria)

This paper presents an approach enabling localization and identification of foreign bodies in polymer materials applying a combined approach of x-ray imaging, optical coherence tomography and mid-infrared spectroscopy. The reliable detection of even small foreign bodies in polymer materials and parts designated for use in semiconductor manufacturing and processing machines is essential. Foreign bodies can in particular be metals, burnt particles of the polymer of the work piece, or intact or degenerated foreign polymers. In either case, all surfaces of e.g. a handling equipment that (may) get in contact with the semiconductor material or process solutions have to be free of foreign bodies to ensure the integrity of the manufacturing process. Size, localization and material of a foreign body are main parameters that decide if a work piece has to be rejected. Current inspection systems may enable the localization of the foreign body, but are not capable of identifying the material and structure of the foreign body; many components with inclusions are therefore rejected as a precaution. This work aims towards the development of a combined sensor approach as part

of an automatic quality assurance procedure which can be integrated in the fabrication process. X-ray imaging is used to identify metal foreign bodies. Optical coherence tomography is used to measure the three-dimensional position and size of the foreign bodies. Mid-infrared spectroscopy is used to identify the composition of the foreign bodies if they are located on the surface. All three technologies together fulfill the requirements of the inspection task.

10209-33, Session PWed

Autonomous electromechanical system for gas leaks odor detection

Javier Andrey Moreno Guzmán, Univ. Tecnológica de Puebla (Mexico); Severino Muñoz-Aguirre, Antonio Barcelata-Pinzón, Benemérita Univ. Autónoma de Puebla (Mexico); Omar Mauricio Moreno-Guzman, Univ. Tecnológica de Puebla (Mexico); Ricardo Iván Álvarez-Tamayo, Instituto Nacional de Astrofísica Óptica y Electrónica (Mexico); Carlos Rangel-Romero, Juan Castillo-Mixcóatl, Georgina Beltrán-Pérez, Benemérita Univ. Autónoma de Puebla (Mexico)

It have been proposed different solutions to the problem of gas leak detection one being the use of mobile systems. An autonomous system equipped with a gas sensor (ethanol) and controlled by a microcontroller and an algorithm designed to follow the trace of smell in terms of concentration that existed in the place of taking the reading by the sensor built without considering brownouts only taken the arrangement proposed by the sensor, thus the location of the source is made and direct the system directly. In this paper the results of location system made in different workspaces, focusing primarily on the acquisition of sensor data with an analog-digital conversion 10 bits are presented whose resolution would be 4.8 mV per bit against the standard 19 mV commercial resolution. Experimental results and analytic explanation is showed below.

10209-34, Session PWed

Veiling glare index measurements using novel small footprint test system

Stephen D. Scopatz, Electro Optical Industries, Inc. (United States)

The image on a focal plane sensor is formed by incident radiation passing directly through the optics; although in some camera systems the light is scattered, reducing the contrast of and/or obscuring the image. Veiling Glare is the phenomena where the light entering an optical system is dispersed and partially washes out the sensor. This phenomenon can arise from many sources ranging from dirt on the lens, imperfections in the lens to poor stray light rejection in the camera body and the corrections can range from simply cleaning the system, rejecting a poor quality lens or redesigning the camera. Veiling Glare Index evaluations as described in the ISO 9358 standard are difficult measurements to make. Veiling Glare Index test set ups in the standard require a large space and/or a large integrating sphere. This paper will discuss the development of and results from a novel approach to the design and construction of a Veiling Glare Index test measurement system. The test equipment requires only 12.5% of the volume to perform the test compared to the large spheres described in the standard. The new design has additional benefits of 360° orientation of the off axis glancing light angles. The instrument has adjustable light levels and continuous monitoring of the black and white targets so the contrast level is known at the time the measurements are made. The paper will include images obtained with the system of both excellent and marginal units under test.

10209-35, Session PWed

Micro-ellipsometry imaging of biostructures aided by 1D reflection grating

Ching-Hsiang Chan, Academia Sinica (Taiwan); Yu-Da Chen, Mai I. Khaleel, Academia Sinica (Taiwan) and National Tsing Hua Univ. (Taiwan); Ming-Lin You, Pei-Kuen Wei, Academia Sinica (Taiwan); Yia-Chung Chang, Academia Sinica (Taiwan) and National Cheng Kung Univ. (Taiwan)

We performed experimental measurements and theoretical simulation based on an efficient half-space Green's function method to investigate the diffraction patterns of light scattered from the biological structure on 1D reflection grating made of metal and polymer.

The 1D grating provides higher-order reflected light, which can boost the image signal for off-specular reflection. This can facilitate the micro-ellipsometry imaging experiment when an incident angle of light is at a large angle, while the detection camera is placed at the upright position. The micro-ellipsometry images for s- and p-polarized reflectance and their phase difference (Rs, Rp, and ?) was taken by a modified Optrel MULTISKOP system with rotating compensator configuration for various angles of incidence and wavelengths ranging from 450nm to 750nm. By using an 80X objective lens, the pixel size for our image is around 164nm. We can further increase the magnification and the numerical aperture by using a substrate collocated with a homemade acrylic resin lens, and the pixel size can be reduced to 50 nm. Based on the above, we study the optical properties of metallic/dielectric nanostructures and nearby biological systems including bacteria, and cancer cells via an imaging micro-ellipsometer combined with detailed theoretical modeling. By using specular and off-specular micro-ellipsometry imaging, we can achieve sufficient sensitivity to collect signals from a small area (around 10?m X 10?m) and obtain a 3D image mapping of the morphology and dielectric properties of the biological system of interest.

10209-36, Session PWed

Method for absolute angle positioning by non-distortion laser speckles imaging technique

Yi-Yuh Hwang, Yu-Hsiang Wu, Chin-Der Hwang, National Chung-Shan Institute of Science and Technology (Taiwan)

In our research, we present a novel method for absolute angle positioning by non-distortion laser speckles imaging technique. On the surface of a circular plate, we can use a non-distortion speckles imaging device to get the non-distortion image of the 3D profile. When the plate is rotating, we can continuously measure the speckles images, with each shot overlaps with the previous one. After the plate rotates by 360 degree, a ring-shaped speckles image is formed with several small shots will be acquired. Since the speckles image is non-distortion, the image can be directly corresponded to the angle coordinate. After getting all the images needed, database which includes all the speckles images and their corresponding angle can be build up. To measure the angle of any position on the plate surface, we can first get a real-time speckles image of that position, and thereby get the absolute angle of it after comparison to the database. In our experiment, we use SAD (Sum of Absolute Difference) to analyze the images and measure the angular displacement of the plate. The result shows that the positioning accuracy can reach 0.5 second by this method. This technique could be used to develop speckles image absolute positioning encoder.

10209-37, Session PWed

Optimal design of dark field illumination optical system for the bacterial colony imaging and selection device

Jihong Zheng, Kangni Wang, daoping li, Lu Liu, Rongfu Zhang, Univ. of Shanghai for Science and Technology (China)

The optimization of dark field illumination optical system used in high throughput bacterial colony selection device is reported in this paper. It improves the contrast of image in the premise of uniform illumination. Three important factors including angular distribution of light radiation, number of LED circle array and distance between the target and the LED circle source were analyzed in the study, which affect illumination uniformity of dark field illumination. The simulation result shows that the good illumination uniformity is 93.16% when the angular distribution of light radiation is 75°, the number of LED circle array is 3 , and the distance between the target and the LED circle source is 61mm. In addition, Experimental system was set up in order to test designed dark field illumination, which matched with the device requirement and simulated results very well.

10209-38, Session PWed

Foveal scale space generation with the log-polar transform

Aaron D. Long, Ram M. Narayanan, Timothy J. Kane, The Pennsylvania State Univ. (United States); Terence F. Rice, Michael J. Tauber, U.S. Army Armament Research, Development and Engineering Ctr. (United States)

Identifying and tracking targets within a scene on an embedded platform is of interest to a number of civilian and military applications. Embedded processing requires efficient algorithms capable of running in real-time while maintaining the robustness of more computationally intense approaches. It is accepted that objects observed in a scene may appear at a number of scales, and this increases computational burden as the search must be performed simultaneously at all scales of interest. Past literature has indicated the log-polar transform as a method of interest in this regard due to its scale and rotation invariance. Restated somewhat, the log-polar transform is of interest due to the space-variant resolution of the transformation. This space-variant resolution allows the log-polar transform to compress a scene around a point into a representation of all scales of the scene at that point. Taking cues from the bi-foveated vision of raptors, this paper presents an implementation of this transform for deep-field and near-field tracking in an algorithm with feature detectors and descriptors specialized for the log-polar transform. Emphasis is placed on the implementation of the diffusion equation in the log-polar domain to reduce the number of full-resolution memory accesses and increase the support for a pipeline architecture.

10209-39, Session PWed

Characterization of monolayer tungsten diselenide based device under optical excitation

Avra S. Bandyopadhyay, Gustavo Saenz, Chandan Biswas, Anupama B. Kaul, The Univ. of Texas at El Paso (United States)

Two-dimensional (2D) materials are very promising with respect to their integration into optoelectronic devices. Monolayer tungsten diselenide (WSe2) is a direct-gap semiconductor with a bandgap of ~1.6eV, and is therefore a complement to other two-dimensional materials such as graphene, a gapless semimetal, and boron nitride, an insulator. The direct bandgap distinguishes monolayer WSe2 from its bulk and bilayer counterparts, which are both indirect gap materials with smaller bandgaps. This sizable direct bandgap in a two-dimensional layered material enables a host of new optical and electronic devices. In this work, a comprehensive analysis of the effect of optical excitation on the transport properties in monolayer WSe2 is studied. Monolayer WSe2 flakes from natural WSe2 crystals were transferred onto Si/SiO2 (270nm) substrates by mechanical exfoliation. The flakes were observed under an optical microscope. The flakes were further characterized with Raman and PL spectroscopy to verify the layer property. Finally, a photodetector based on mechanically exfoliated WSe2 was fabricated using photolithography with Molybdenum as metal contact and Silicon as back gate and the optoelectronic properties were measured in a wide range of temperatures, in the presence of light with varying intensities and wavelengths.

10209-40, Session PWed

Temperature dependency of photocurrent generation mechanism in black phosphorous

Gustavo Saenz, The Univ. of Texas at El Paso (United States); Dalal Fadil, Institut d'Electronique de Microélectronique et de Nanotechnologie (France); Anupama B. Kaul, The Univ. of Texas at El Paso (United States)

Two-dimensional (2D) black phosphorous (BP) is a novel material with exciting potential for implementation in a new generation of optoelectronics devices. Two-dimensional BP, an intrinsically p-type semiconductor with high mobility, has anisotropic properties given its crystal structure along the zigzag versus the armchair direction. In contrast to other semiconducting layered materials, such as transition metal chalcogenides (TMDs), the band gap in black phosphorous remains direct both in bulk as well as in its monolayer form. Also, as the number of layers is reduced, the band gap increases from ~0.3 eV in the bulk, to ~2 eV or more in monolayer, which is opposite to the effect observed in most TMDs. Black Phophorus exhibits a fast photoresponse, and can be operated in the near infrared regime, where the photodetection can be tuned with an external electric field. The photocurrent generation in black phosphorous is driven by photovoltaic, photoconductive, photothermoelectric, and photobolometric effect. In this work, two-terminal photodetector based on mechanically exfoliated multilayer black phosphorus was fabricated and the opto-electronical properties were measured in a wide range of temperatures from 6 K to 350 K, in the presence of light with varying intensities and wavelengths. The multilayer device, which allows a higher light absorption than its monolayer counterpart, exhibits a different dominant photocurrent generation mechanism depending on the temperature in which it is submitted. Here we present a comprehensive analysis of the opto-electronic properties of 2D black phosphorus and comment on its prospects for enabling high-performance photodetectors and other optoelectronic devices.

10209-41, Session PWed

Image processing based bio-sensing electric system cancer cells detection

Jenipher D. Gonzalez-Aponte, Univ. del Turabo (United States); Miguel A. Goenaga-Jimenez, Univ. de Puerto Rico Mayagüez (United States); Lisandro F. Cunci-Perez, Univ. del Turabo (United States)

Would it be beneficial to have a system that provides preliminary results of whether a patient has cancer? While several techniques were developed for the detection of cancer, pathological analysis has been the gold standard.

However, it may take a significant amount of time to provide definite results, which sometimes can be subjective to the Pathologist that did the analysis. In some cases, the results come back negative using an enormous amount of resources for the test. In other cases, the result may be positive after waiting for many weeks without the patient having started the treatment. This leaves the patient with a worse prognosis than if the treatment was started earlier. The use of image processing, together with fluorescence probes, can provide the diagnosis to the physician in just a few hours or less, which can be used to start an early treatment to improve the prognosis. The main purpose of this project is design and develop a system that will identify cancer cells from the image and quantify the amount of the pixels of the RGB spectrum around the cells using algorithms from image processing.

10209-42, Session PWed

Performance evaluation of the thick pinhole gamma rays diagnostic system

Hongwei Xie, Institute of Nuclear Physics and Chemistry (China); Jinchuan Chen, Qiang Yi, Faqiang Zhang, Linbo Li, INPC, CAEP (China)

The gamma-ray cameras based on the pinhole imaging principle are widely used in the study of the spatial intensity distribution of pulse radiation sources and the weak radiation sources. Meanwhile, it's a method of nondestructive detection with high spatial resolution. Due to the optical imaging with fluorescence collection efficiency over 1%, the gamma rays camera could be used to detect the single particle and provide a large dynamic range of over than 500X. In this paper, the relationships among various parameters of the gamma-rays crammer such as the modulation transfer function (MTF), the signal-noise ratio (SNR) and the detective quantum efficiency (DQE) are developed and studied experimentally on the cobalt radiation source. The spatial resolution of the modulation transfer function (MTF) at 10% intensity obtained from the experiment was about 1 lp/mm. Additional measurements were carried out to determine other parameters including the system quantum gain and the noise power spectrum (NPS), etc. Finally, based on the experimental data, the relationships were proposed among the radiation source intensity, the signal-noise ratio (SNR) and the modulation transfer function (MTF).

10209-43, Session PWed

Study Combination of Luminophore and Polydimethylsiloxane for Alternative Option of Passive Energy Lighting

Jan Jargus, Jan Nedoma, Marcel Fajkus, Martin Novak, Vladimír Va?inek, V?B-Technical Univ. of Ostrava (Czech Republic)

Polydimethylsiloxane belongs among polymeric organosilicon compounds which find utilization in many industries. Within telecommunication technologies, the primary use is in the field of encapsulation of electronic units, circuit boards, optical splice or optical cables. This article focuses on the use of polydimethylsiloxane (below PDMS) for its optical properties. We created test samples with a defined ratio of PDMS polymer and luminophore which can to radiate part of the absorbed energy in the form of light. LED (Light-Emitting Diode) with the wavelength range of 440 nm to 470 nm, which corresponds to a blue color in the visible spectrum, was used as the source of excitation energy. Used luminophore is Yttrium Aluminium Oxide: Cerium (Y3Al5O12:Ce). The output of the selected combination generates white light. The value of the chromaticity temperature determines the color of light. The output of article is a definition of the suitable ratio of PDMS and luminophore whose the emitted light has the range of chromaticity temperatures matching white light, for example, for passive energy lighting. A USB-650 Red Tide spectrometer and SpectraSuite software, which has chromaticity temperature and spectral characteristic as output, were used to finding the chromaticity temperature.

10209-44, Session PWed

Analytical and graphical techniques for solution of transistor circuit transfer functions

Bruce M. Lambert, The Aerospace Corp. (United States)

Modern Focal Plane Array (FPA) image sensors are highly-integrated, microelectronic processor chips comprising both analog and digital circuitry and are as complex as modern computer processor chips. A complete picture of how these devices operate requires a deep understanding of analog and digital microelectronic circuit analysis, and therefore, can be very intimidating to the engineer and/or project manager who is the end-user of the device in a system application. The overwhelming barrier to understanding how these devices work can be significantly lowered by analyzing the operation of individual sub-circuits that comprise the device. Here we will analyze a particular sub-circuit, the Source Follower (SF), which is used substantially in FPA designs as both a charge-to-voltage converter at the unit-cell (UC) input node as well as an all-purpose voltage buffering/level shifting element for driving subsequent circuit stages of low input impedance. The goal of this paper is to systematically analyze the Source Follower circuit using an equation-based approach. The analysis starts with the Sah equation which describes the d.c. electrical operation of all Field Effect Transistors (FETs). Reasonable simplifications to the Sah equation then yield a tractable solution to the problem requiring only algebraic manipulation and use of the quadratic formula. Novel graphical techniques will also be used along with the resultant algebraic expressions to provide an intuitive feel for the circuit operation. The systematic approach taken here can provide useful tools and techniques for a novice in the field of microelectronic circuits who is interested in gaining a deeper understanding of FPA operation and/or analog-digital mixed-signal microelectronic designs.

10209-45, Session PWed

Tests of irradiated silicon photomultipliers detectors for new high-energy space telescopes

Karine Lacombe, Institut de Recherche en Astrophysique et Planétologie (France); Thierry Gimenez, Ctr. National d'Études Spatiales (France); Baptiste Houret, Jürgen Knödlseder, Pascale Ramon, Institut de Recherche en Astrophysique et Planétologie (France); Cédric Virmontois, Ctr. National d'Études Spatiales (France)

Photon detection is a central element of any high-energy astronomy instrumentation. One classical setup that has proven successful in many missions is the combination of photomultiplier tubes (PMTs) with scintillators, converting incoming high-energy photons into visible light, which in turn is converted in an electrical impulse. Although being extremely sensitive and rapid, PMTs have the drawback of being bulky, fragile, and require a high-voltage power supply of up to several thousand volts. The silicon photomultipliers (SiPM) appear to be a promising alternative to PMTs in essentially all their applications. We have started a R&D program to assess the possibility of using SiPMs for space-based applications in the domain of high-energy astronomy. We presented first results of our characterization studies of SiPMs from 3 manufacturers. Each SiPM detector has been tested at low temperature and pressure to assess its performance in a representative space environment. For this purpose, we developed a dedicated vacuum chamber with a specific mechanical and thermal controlled system. Once we measured dark current, dark count rate and PDE, we make irradiation tests to understand the susceptibility of SiPM to radiation damage on two selected detectors. Finally, we plan to develop a low noise voltage power supply to ensure the stability of the SiPMs and to study their coupling to scintillators in parallel of the qualification of these SiPM.

10209-46, Session PWed

Effect of different buffer-layers on near-infrared response of GaAs photocathodes

Yijun Zhang, Cheng Feng, Nanjing Univ. of Science and Technology (China); Feng Shi, Science and Technology on Low-Light-Level Night Vision Lab. (China); Xiaohui Wang, Univ. of Science and Technology of China (China); Xinxin Liu, Xiang Zhang, Yuns-heng Qian, Nanjing Univ. of Science and Technology (China)

GaAs-based photocathodes have already found widespread application in modern night vision detectors. Enhancing the quantum efficiency of photocathodes in the near-infrared (NIR) waveband is especially critical to the detection efficiency at night. As we know, the favorable detectors can operate in the reflection-mode (r-mode) with the suitable optical geometry design, which helps to obtain higher quantum efficiency. In order to increase the NIR response, we propose two technical approaches by changing the structure of buffer-layer underneath the active-layer, wherein one is to produce a built-in electric field using the graded-composition structure, and the other is to produce a distributed Bragg reflector (DBR) using the superlattice structure.

The two r-mode GaAs photocathode samples were grown by molecular beam epitaxy. For the buffer-layer, one is of the 0.5-?m-thick AlxGa1-xAs layer with a graded aluminum composition of 0~0.9, and the other is of a DBR mirror containing 10 pairs of alternating AlAs and GaAs layers with the thickness ?/4. Besides, the 1-?m-thick GaAs active-layer is divided into four sections doped quasi-exponentially from 1E19 to 1E18 cm-3. The two different samples underwent the same preparation process including the surface cleaning and Cs-O activation. After activation, the quantum efficiency results show that the r-mode GaAs sample with the superlattice structure can obtain higher quantum efficiency than the one with the graded-composition structure at some NIR wavelength positions. The peak positions of quantum efficiency curve agree quite well with the dip positions in the reflectivity spectrum.

10209-47, Session PWed

Circular dichroism metamirrors with near-perfect extinction

Zuojia Wang, Zhejiang Univ. (China); Hui Jia, National Univ. of Defense Technology (China); Kan Yao, Northeastern Univ. (United States); Wenshan Cai, Georgia Institute of Technology (United States); Hongsheng Chen, Zhejiang Univ. (China); Yongmin Liu, Northeastern Univ. (United States)

In nature, the beetle Chrysina gloriosa derives its iridescence by selectively reflecting left-handed circularly polarized light only. In this talk, we propose and demonstrate the concept of circular dichroism (CD) metamirrors, which is an optical analogue of Chrysina gloriosa that enables selective, near-perfect reflection of designated circularly polarized light without reversing its handedness, yet complete absorption of the other polarization state. To achieve this functionality, Jones calculus is first employed to predict the required reflection matrix. The subsequent analyses in structural symmetry show that the necessary condition is to break both the n-fold rotational (n > 2) and mirror symmetries. On the basis of the transfer matrix method, a proof-of-concept CD metamirror utilizing an ultrathin, bilayer metamaterial is then designed and optimized in the midinfrared region. Simulation results show 94.7% reflectance and 99.3% absorption for left-handed circularly polarized and right-handed circularly polarized waves, respectively. Hence we can achieve selective perfect absorption for circularly polarized light, which is different from previous metamaterial-based absorber work. In addition, the device performance is insensitive to the incident angle and the offset between the two layers of metamaterials. Such an extremely high extinction ratio as well as the tolerance in geometry and illumination manifests promising applications in polarimetric imaging, CD spectroscopy, and quantum optical information processing. Furthermore, the planar metamirror is only quarter-wavelength thin, superior to chiral sculptured thin films with thickness larger than wavelength, and hence it is highly desirable for on-chip device integration.

10209-48, Session PWed

Dual-camera system for improving the magnification factor and having smooth optical zoom with distorted lens design

Yueh-Sheng Liu, Wei-Ting Lin, National Chiao Tung Univ. (Taiwan)

In recent years, some companies take a dual-camera system to achieve an optical zoom in the portable device without any mechanism to move optical elements. The solution comprises two apertures to perform a large zooming range: one with a wide-angle lens for lower magnification and the other with a telephoto lens for higher magnification. Nevertheless, this dual-camera system still needs to interpolate the digital zoomed image between the lower and higher magnification images, resulting in a discontinuous zoom. We propose a distorted dual-camera system with varying focal length for a smooth optical zoom. Besides, this optical system has a greater pixel count per field angle at the center of sensor than one at the periphery of sensor. Therefore, we sacrifice some resolution of the peripheral FOV to enhance the resolution of the center FOV for improving the capability of magnification. For example, using a 20 MP sensor and displaying a Full HD lossless zoomed image, the maximum magnification factor of 10.3 is achieved in our distorted lens system, but this factor of 3.2 in the distortion free lens system. In other words, we raise the capability of magnification up to 320%.

10209-51, Session PWed

Current calibration algorithm for bolometer-type uncooled infrared image sensor using pipeline signal processing technique

Sang-Hwan Kim, Byoung-Soo Choi, Jang-Kyoo Shin, Kyungpook National Univ. (Korea, Republic of); Jae-Hyun Park, Kyoung-Il Lee, Korea Electronics Technology Institute (Korea, Republic of)

Recently, bolometer-type uncooled infrared image sensor has been used in various fields, such as medical, military and commercial systems. Uncooled infrared image sensor using bolometer resistor has a wide detection range from the X-ray band up to a few millimeters band. In particular, many integration-type uncooled infrared image sensors have been proposed. But, bolometer resistor in the pixel which is fabricated by standard CMOS process has a deviation in the resistance. The deviation of the resistance in the 2-dimensional bolometer array is a serious problem in terms of fixed pattern noise (FPN). In this paper, we propose a pixel averaging current calibration algorithm for reducing fixed pattern noise due to the deviation of bolometer resistance. To reduce the fixed pattern noise, output current of each bolometer reference pixel is averaged by the averaging current calibration algorithm. The principle of algorithm is that average dark current of reference pixel array is subtracted by a dark current of each active pixel array. After that, the current difference with information of pixel deviation is converted to voltage signal through signal processing. To control the current difference of pixel deviation, a proper calibration current is required. Through this calibration algorithm, nano-ampere order dark currents with small deviations can be obtained. Sensor signal processing is based on a pipeline technique which results in parallel processing leading to very high operation. The proposed calibration algorithm has been implemented by a chip which is consisted of a bolometer active pixel array, a bolometer

reference pixel array, average current generators, line memories, buffer memories, current-to-voltage converters (IVCs), a digital-to-analog converters (DACs), and analog-to-digital converters (ADCs). Proposed bolometer-resistor pixel array and readout circuit has been simulated and fabricated by 0.35?m standard CMOS process.

10209-52, Session PWed

Panoramic vehicular imaging system

Teng-Yi Huang, Yu-Chen Wang, Chin-Jung Liao, National Chung-Shan Institute of Science and Technology (Taiwan)

The Panoramic Vehicular Imaging System (PaVIS) is the system of its kind providing a see-through solution for all confined members inside armored vehicles. The PaVIS, incorporating an around view monitoring system, panoramic cameras and an EO/IR payload, solves the limited vision problem for each one of the crew simultaneously, and significantly improves fighting efficiency.

The around view monitoring system provides nearby surrounding images and aerial photos to the driver that makes turning, backing and parking safe and easy.

Panoramic cameras provide 360?view within 500m to dismounted soldiers with in-situ video interchangeable among visible, IR and fused images. Dismounted soldiers can see the outside battlefield on any direction they observe by wearing head-mounted displays. If a danger appears, they can alert the commander immediately. When dismounted, already aware of the outside situation, they are better prepared to confront the assigned mission.

The PaVIS also assists the commander in making precise decision by 360?panoramic view, reports from dismounted soldiers, plus a variable zoom payload for long distance observation. Once an engagement is confirmed, the commander can guide the gunner to the right direction for shooting.

10209-53, Session PWed

Direct charge handling method for dead-time-less photon counting

Katsuyuki Takagi, Shizuoka Univ. (Japan); Akifumi Koike, ANSeeN Inc. (Japan); Toru Aoki, Shizuoka Univ. (Japan)

The charge from X-ray semiconductor detector is collected by CSA(Charge Sensitive Amplifier) to convert to voltage and digital code finally. CSA needs reset function because the ideal CSA is charge integrator and the charge from the detector is unipolar. And pulse shaper and/or dark current compensation is required to reduce dead-time by reset. We added CIC(Charge Injection Circuit) at the input of CSA to inject/extract the charge collected by CSA. The trigger to perform charge injection is the output voltage of CSA. When the voltage exceeds a threshold, CIC injects fixed charge into CSA to reduce collected charge. After that, check the output voltage again and repeat. Finally, the number of repeated is corresponding to the energy information of X-ray and CSA is reset at the same time. Proposed method doesn't require other reset functions and dead-time for reset because CSA is always working even while CIC injects. At the post process, we have to decode the number of repeated into energy value. As a side effect, we can compensate dark current of the detector in digital region because CSA is included in digital conversion loop.

To prove operating principals of our method, we simulated the loop behavior and constructed analog circuits (CSA, CIC and comparator). The simulation showed internal behavior, output digital code and system noise to compare the theoretical behavior. The experimental circuit showed that we can connect CIC and CSA, and our method actually works.

10209-54, Session PWed

Design and performance tests of a high volumetric figure of merit regenerative damper for vehicle suspension systems

Long Ren, Renwen Chen, Huakang Xia, Nanjing Univ. of Aeronautics and Astronautics (China)

Regenerative dampers for vehicle suspension systems that can harvest power at low frequencies efficiently are challenging to realise. To increase their energy harvesting efficiency, a type of high volumetric Figure of Merit magnetoelectric regenerative damper is proposed. To increase the magnetic linkage gradient of its coil in the moving direction and in its motion region, lumped parameter equivalent magnetic circuit model is adopted in its magnetic structural parameter optimisation. Finite element analysis is then used to verify the analytical model and theoretical results. Finally, 3 prototypes with different parametric combinations are manufactured and fabricated to do experiments. The experiments indicate that the optimised megnetoelectric regenerative damper can harvest vibration power of 16.3 watts and provide an adjustable damping coefficient that can reach 1605Ns/m when the damper in a relative velocity of 0.2m/s. The corresponding volumetric Figure of Merit can reach 8.3%, which is higher than most of the works presented in recent literatures. This type of regenerative damper can be used in vehicle suspension systems and meet their requirements. It also offers the opportunity to be applied in semi-active vehicle suspensions.

10209-13, Session 4

Imaging technology: A future perspective *(Keynote Presentation)*

Nibir K. Dhar, U.S. Army Night Vision & Electronic Sensors Directorate (United States)

No Abstract Available

10209-14, Session 4

Hemispherical focal plane arrays for wide field-of-view imaging

Kyle Renshaw, Zhao Ma, CREOL, The College of Optics and Photonics, Univ. of Central Florida (United States)

There are enormous optical advantages to use a curved image sensor in place of conventional flat focal plane arrays (FPA) because optical systems intrinsically want to focus to a curved focal surface. For this reason, biological imagers such as the human eye have evolved a curved image sensor (i.e. the retina) that enables use of a simple lens to achieve nearly diffraction-limited imaging over a wide FOV – all in a compact package. Today's digital imagers sample the curved focal surface using a flat FPA resulting in field-curvature aberrations that impose stringent limitations on the imager's FOV, F/#, resolution and image quality. Here, we introduce techniques to fabricate hemispherical focal plane arrays to enable the development of compact, wide FOV imaging systems. We have developed monolithically integratable flexible interconnects that can be integrated onto the backside of a planar, silicon FPA designed for hemispherical deformation. These interconnects provide: (1) backside signal routing between small regions of the FPA that were designed to be electrically isolated and (2) a flexible handle for the FPA before a through-wafer etch is performed to mechanically separate the electrically isolated regions of the FPA wafer. This process provides a fully interconnected, flexible FPA that can conform to a hemispherical surface for use in visible (all silicon) or infrared (hybrid) imagers.

10209-15, Session 4

C-RED One: An electron initiated avalanche photodiode SWIR camera for low noise high speed imaging

Philippe Feautrier, First Light Imaging S.A.S (France); Jean-Luc Gach, Thomas Carmignani, Fabien Clop, Timothée Greffe, Stéphane Lemarchand, Eric Stadler, First Light Imaging S.A.S. (France)

While in the visible Electron multiplying CCDs (EMCCDs) improved imaging techniques and permitted a leap especially in life science imaging, no important breakthrough has been made in the infrared imagery since the hybridization of III-V or II-VI semiconductors with low bandgap on CMOS read-out circuitry (ROICs). The EMCCD technology permitted wide readout bandwidths while maintaining ultra low readout noise. For instance our OCAM2 camera has to now the fastest readout speed combined with the lowest readout noise at the same time: it exhibits a readout rate in excess of 132 Mpixels/s while maintaining a readout noise down to 0.1 electron (Feautrier et al. 2010). No equivalent imagers to EMCCDs with embedded carrier amplification were existing up to now in the infrared, neither for short wave imaging (SWIR), nor for mid wave or long wave imaging (MWIR & LWIR).

During the last few years, HgCdTe avalanche photodiodes (APDs) have been demonstrated to be one of the most promising path to build focal plane arrays (FPA) for Infrared low flux and high speed applications such as active and hyper spectral imaging. Several groups (Beck 2001,2004,2006, Kinch 2004, Vaidyanathan 2004, Hall 2005, Reine 2006,2007, Perrais 2007, Rothman 2007) have reported multiplication gains of 100-1000 for low values of reverse bias, around 10V, associated with a quasi-deterministic multiplication yielding a close to conserved signal to noise ratio (SNR) by measuring an excess noise factor F from 1 to 1.2.

First light Imaging has decided to make this technology available to everybody with its C-RED One camera which is the first camera ever using an e-APD infrared array. Based on a 320x256, 2.5 um cutoff HgCdTe e-APD array deeply cooled to 80K with a high reliability pulse tube cryocooler (MTBF ~ 90 000 hrs), the camera can exhibit a huge readout speed of 3500 fps full frame while having a readout noise well below one electron, thanks to the APD gain in the range of 1 to 400. This ultra low noise will enable photon counting regime detection in the infrared. These unprecedented performances will open a new era for infrared imagery. In addition to the outstanding performances of the detector, First Light Imaging provides a fully integrated system that can be used in demanding environments and requires only an electric power supply and water cooling. No liquid nitrogen or vacuum pumping is needed for the camera operation allowing the continuous use of the camera in a remote environment without any human operator and allowing also a full remote control of the system. We will show the performances of this camera, its main features and compare them to other high performance cameras like EMCCDs in the visible and more classical cameras in the infrared.

10209-16, Session 4

Infrared (IR) activities of mercury cadmium telluride at Army Research Lab. (ARL) *(Invited Paper)*

Priyalal S. Wijewarnasuriya, U.S. Army Research Lab. (United States)

No Abstract Available

10209-17, Session 5

Laser doping processing for formation of pn-junction *(Invited Paper)*

Toru Aoki, Shizuoka Univ. (Japan) and ANSeeN Inc. (Japan); Katerina S. Zelenska, National Taras Shevchenko Univ. of Kyiv (Ukraine); Volodymyr A. Gnatyuk, Shizuoka Univ. (Japan) and V.E. Lashkaryov Institute of Semiconductor Physics (Ukraine); Junichi Nishizawa, Kento Tabata, Hidenori Mimura, Shizuoka Univ. (Japan); Akifumi Koike, Shizuoka Univ. (Japan) and ANSeeN Inc. (Japan)

Laser processing of the CdTe-In semiconductor-metal interface has been studied by irradiation through the CdTe crystal in water using nanosecond pulses with ?= 1064 nm. A thin In-doped CdTe layer adjoining to the In film was formed after direct laser impact on the CdTe-In interface. The fabricated In/CdTe/Au diode detectors with a p-n junction exhibited steep rectification and sensitivity to X/?-ray radiation. The simulation of laser-induced heating of the In film deposited on the CdTe crystal surface and irradiated through the CdTe in water was performed and temperature distribution in the three layer CdTe-In-Water structure at different moments after laser irradiation was calculated.

The main application of this laser doping is fabrication of high-energy radiation detector, but this method also effective for making solar-cells, sensors and so on. In this paper, we will show the detail data and discussion of mechanism of this laser doping process by using both results of irradiated by top (In-side) and back (through CdTe wafer) side.

10209-18, Session 5

Radio frequency sputtered (Al)_x N_y thin films for uncooled infrared detection

Nicholas P. Calvano, Phillip C. Chrostoski, Delaware State Univ (United States); Dennis Prather, Univ. of Delaware (United States); Murzy D. Jhabvala, NASA Goddard Space Flight Ctr. (United States); Mukti M. Rana, Delaware State Univ (United States)

A pyroelectric detector is a class of thermal detector for which there is a change in spontaneous polarization. Absorption of infrared radiation in the sensing layer of pyroelectric detector causes a change in temperature and hence changes in spontaneous polarization which finally generates a voltage. This work presents the deposition and characterization of ?Al?_x N_y thin films for using them as pyroelectric detector material. The pyroelectric detector design was done using Intellisuite Engineering Design Software and a thermal conductance of 4.57 ? 10-9 W/K was achieved. The detector design employed Al2O3 studs of 100 nm width and they had spider web shape. Capacitors of ?Al?_x N_y thin films with Au electrodes were designed using Intellisuite software. Capacitors of various sizes were fabricated. The diameter of the electrodes for capacitor was varied between 400 ?m to 1100 ?m with 100 ?m increment. The distances between two electrodes were varied between 400 ?m to 1100 ?m with 100 ?m increment as well. On a 3 inch diameter cleaned quartz wafer, 20 nm thick Ti adhesion layer was deposited followed by a 100 nm thick Au layer. On top of this Au layer, 100 nm ?Al?_x N_y thin film was deposited. Finally, 100 nm thick Au layer was deposited and lifted off by conventional photo lithography to form the electrodes of capacitors. All the layers were deposited by radio frequency sputtering at room temperature. Morphology and electro-optical properties for ?Al?_x N_y thin films are now being investigated in the laboratory and the results will be presented.

10209-19, Session 5

Optimization of mesa structured InGaAs based photodiode arrays

Halit Dolas, Kübra Çırçır, Serdar Kocaman, Middle East Technical Univ. (Turkey)

Short wavelength infrared (SWIR) spectrum is of interest across a wide range of studies spanning both defense and commercial applications such as surveillance, passive night vision, quality detection in importation, health/medicine applications and others. Among variety of semiconductor materials for SWIR detector production, lattice matched InP/In0.53Ga0.47As seems to give the high detector performance and relative low cost while providing opportunity to work in room temperature. In this work, optimization of lattice matched InP/In0.53Ga0.47As heterojunction p-i-n photodiodes working at low reverse bias regime (~-0.1V) is presented. Mesa-structured detectors are chosen due to their advantages for future multicolor/hyperspectral imaging applications and low cross talk. Various structures in order to get optimized epitaxial layers and absorbing layer doping density are studied numerically and experimentally. Epitaxial layers are grown using the in-house Molecular Beam Epitaxy (MBE) reactor and focal plane arrays (FPAs) as well as test detector pixels with different perimeter/area ratios are produced. I-V characteristics of test detectors are measured at room temperature and I-V-T characterization is also performed. Based on the results, bulk and surface dark current components are separated and a detailed dark current analysis is performed. R0A values, wavelength depended spectra, peak responsivity and peak detectivity values of the detectors are measured. Results are compared with the expected values and a good agreement is obtained.

10209-20, Session 6

Radiation tolerant image sensors using a CdS/CdTe photodiode and field emitter array *(Keynote Presentation)*

Hidenori Mimura, Tomoaki Masuzawa, Yoichiro Neo, Shizuoka Univ. (Japan); Masayoshi Nagao, National Institute of Advanced Industrial Science and Technology (Japan); Tamotsu Okamoto, National Institute of Technology, Kisarazu College (Japan); Masafumi Akiyoshi, Osaka Prefecture Univ. (Japan); Nobuhiro Sato, Ikuji Takagi, Yasuhito Gotoh, Kyoto Univ. (Japan)

Radiation tolerant image sensors are strongly demanded to collect crucial information inside the Fukishima Diich nuclear plants which was seriously damaged by the big Tsumami in 2011. However, semiconductor based image sensors such as CMOS and CCD have limited tolerance to radiation exposure. Image sensors used in nuclear facilities are conventional vacuum tubes using thermal cathodes, which have large size and high power consumption.

We have proposed and fabricated novel compact image sensors using a CdS/CdTe photodiode and field emitter array (FEA) for the application of radiation tolerant image sensors. The operation principle of the FEA-based image sensors is similar to that of conventional vidicon type vacuum tubes, but a thermal cathode is replaced with FEA. The advantage of the FEA-based image sensors is very compact and low power consumption as compared to the conventional vidicon type vacuum tubes. We will present recent results of the radiation tolerant compact image sensors using a CdS/CdTe photodiode and FEA.

10209-21, Session 6

Materials for microbolometers: vanadium oxide or silicon derivatives *(Invited Paper)*

Mukti M. Rana, Delaware State Univ. (United States)

Microbolometers are a class of uncooled infrared detectors whose resistance changes with temperature. Absorption of infrared radiation in the sensing layer causes the temperature to increase and hence induces a change in resistance in that layer.

Choice of sensing layer plays an important role for microbolometer's performance. The materials to be used for sensing layers of microbolometer must be capable of absorbing the infrared radiation, pose high temperature coefficient of resistance (TCR) and moderate resistivity as well as low noise.

Vanadium oxide and amorphous silicon are two of the materials which are primarily used as the bolometer sensing layers. Some other materials from silicon family include amorphous silicon germanium alloys, crystalline silicon germanium alloys and germanium silicon oxide. Both the materials - vanadium oxide or silicon derivatives have some unique advantages and disadvantages. Semiconducting phase of vanadium oxide provides low 1/f-noise which helps to achieve high signal to noise ratio while the high processing temperature makes this material incompatible with post complementary metal oxide semiconductor processing technology. Another disadvantage of this material is that its TCR is low as compared to the materials derived from silicon family. On the other hand, amorphous silicon and their alloys exhibit high temperature coefficient of resistance and higher 1/f-noise as compared to vanadium oxide alloys. Radio frequency sputtered thin films of germanium silicon oxide provide higher TCR than vanadium oxide than other materials mentioned here.

10209-22, Session 6

Calcium lead titanate thin films for pyroelectric detection

Phillip Chrostoski, Nicholas P. Calvano, Andrew Voshell, Mukti M. Rana, Delaware State Univ. (United States)

A pyroelectric detector is a class of thermal detector for which there is a change in spontaneous polarization. Absorption of infrared radiation in the sensing layer of pyroelectric detector causes a change in temperature and hence changes in spontaneous polarization which finally generates a voltage. This work presents the deposition and characterization of Calcium Lead Titanate thin films for using them as pyroelectric detector material. The pyroelectric detector design was done using Intellisuite Engineering Design Software and a thermal conductance of 4.57 ? 10-9 W/K was achieved. The detector design employed Al2O3 studs of 100 nm width and they had spider web shape. Capacitors of Calcium Lead Titanate thin films with Au electrodes were designed using Intellisuite software. Capacitors of various sizes were fabricated. The diameter of the electrodes for capacitor was varied between 400 ?m to 1100 ?m with 100 ?m increment. The distances between two electrodes were varied between 400 ?m to 1100 ?m with 100 ?m increment as well. On a 3 inch diameter cleaned quartz wafer, 20 nm thick Ti adhesion layer was deposited followed by a 100 nm thick Au layer. On top of this Au layer, 100 nm Calcium Lead Titanate thin films were deposited. Finally, 100 nm thick Au layer was deposited and lifted off by conventional photo lithography to form the electrodes of capacitors. All the layers were deposited by radio frequency sputtering at room temperature. Morphology and electro-optical properties for Calcium Lead Titanate thin films are now being investigated in the laboratory and the results will be presented.

10209-23, Session 6

Photon-counting x-ray imaging by CdTe detector *(Invited Paper)*

Toru Aoki, Shizuoka Univ. (Japan) and ANSeeN Inc. (Japan); Takaharu Okunoyama, ANSeeN Inc. (Japan); Hisashi Morii, Akifumi Koike, Shizuoka Univ. (Japan) and ANSeeN Inc. (Japan); Hidenori Mimura, Shizuoka Univ. (Japan)

CdTe photon counting type detector has good properties for practical nondestructive CT inspection system for example, room temperature operation, energy discrimination, high contrast imaging in hard X-ray and so on, but the maximum count rate is too low to practical use. We have also reported energy discriminated X-ray CT system by using 64pixel CdTe line sensor with 5-thresholds energy discrimination levels, and obtaining the effective-atomic number and electron density mapping cross-sectional image. These detectors can detect X-ray spectrum with using conventional X-ray source (tube), and make the photon counting X-ray CT (PC-XCT) system. The PC-XCT can reduce radioactive exposure and take high-contrasted images in the application of medicine, and material distinguished images in various applications. We developed high count rate (up to 600kcps with 10keV energy resolution within 50-250keV range) X-ray spectrometer, ANS-XDS0001 for practical application. The obtained spectra of X-ray tube shows same spectra shape is obtained up to 600kcps.

In this paper, we have developed the photon counting X-ray CT system for understand the energy discriminated tomogram with a faithful system to principle by using high count rate CdTe X-ray spectrometer using digital signal processing and new algorithm. We obtained projection data at 300kcps with full (2048 ch) energy spectrum by 200mS/point. A example of the taken image is a penetration image of mobile phone circuit board, and the color shows estimated effective-atomic number with has a high contrast property. We can change energy band for tomogram freely after taking the projection data for finding suitable threshold of energy for each materials.

10209-4, Session 7

Terahertz-wave generation using resonant-antenna-integrated uni-traveling-carrier photodiodes *(Invited Paper)*

Hiroshi Ito, Kitasato Univ. (Japan); Tadao Ishibashi, NTT Electronics Corp. (Japan)

Photomixing is a promising technique for generating continuous terahertz (THz) waves since it has superior features, such as extremely-wide frequency tunability, very narrow line-width, good frequency stability, and ability to transmit high-frequency signals through low-loss optical fibers. To make photomixer work more effectively, in the present study, antenna-integrated uni-traveling-carrier photodiodes (UTC-PDs) were developed. A UTC-PD has a unique mode of operation; namely only electrons are the active carriers that travel through the device. This feature provides several advantages over a conventional photodiode, such as higher operation speed, larger output saturation current, and lower operation voltage. To further increase the output power from a UTC-PD, use of a resonant antenna is effective. Two kinds of antennas, a slot antenna and a bowtie antenna with a resonant stub, were investigated. The characteristics of fabricated antenna-integrated UTC-PDs were compared with those of broadband (non-resonant) bowtie-antenna-integrated UTC-PD. The output powers of slot-antenna-integrated UTC-PDs were enhanced at frequencies from 350 to 850 GHz for a wide-slot device and from 900 GHz to 1.6 THz for a narrow-slot device with peak enhancement ratio of up to about 3.3. The slot antenna is thus suitable for increasing output power while maintaining relatively large bandwidth. Output power of a resonant-bowtie-antenna-integrated UTC-PD at frequencies from 400 to 700 GHz was also enhanced (with a peak enhancement ratio of about 3.1). The latter type UTC-PD exhibited fairly constant output power (within 3 dB) at frequencies from 300 to 650 GHz.

10209-24, Session 7

Materials and process development for the fabrication of far ultraviolet device-integrated filters for visible-blind Si sensors (Rising Researcher Presentation)

John Hennessy, April D. Jewell, Alexander G. Carver, Michael E. Hoenk, Shouleh Nikzad, Jet Propulsion Lab. (United States)

Traditional silicon photodetectors have poor sensitivity to far ultraviolet (FUV, ? < 200 nm) light due to the short absorption depth of FUV photons. This has been overcome at JPL by the use of molecular beam epitaxy to create 2D-doped surfaces that restore high internal UV quantum efficiency, although this high efficiency also extends to visible wavelengths. In many cases the detection of faint UV signals occurs in the presence of a large visible or solar background, and external filtration is therefore required to improve SNR at the cost of overall FUV throughput. In this work, we show that the direct-integration of metal-dielectric filters onto Si sensors can improve throughput 3X over external filter approaches, and yield devices with FUV QE greater than 50%, and rejection ratios of visible light greater than 10^3.

The performance of these filters at FUV wavelengths requires the use of non-absorbing optical dielectric materials. We have pursued the development of new atomic layer deposition processes for metal fluorides materials of MgF2, AIF3 and LiF. Using an anhydrous HF based approach, these films can be deposited at the low temperatures required for sensor integration and show good FUV optical properties. The performance of the complete multilayer filters on Si photodiodes and imaging sensors (EMCCD), and the design and fabrication challenges associated with this development will be discussed. This detector technology has potential applications in astronomy, planetary science, particle physics, and machine vision, and allows Si to compete in this space with wide bandgap based systems.

10209-25, Session 7

Performance and design differences between PMOS and NMOS CMOS imagers

James R. Janesick, Tom Elliott, James Andrews, John Tower, SRI International Sarnoff (United States)

Performance and design comparisons are reviewed for PMOS and NMOS CMOS imagers. Performance parameters measured and studied include pixel read noise, charge transfer efficiency, charge collection efficiency, readout speed, dark current and radiation damage tolerance. Focus is on pixel read noise given that PMOS can achieve lower noise than NMOS. For example, the technology inherently does not exhibit random telegraph noise (RTN) as NMOS does. This leaves flicker noise as the only fundamental limiting noise source for CMOS imagers. Further discussions will attempt to show where flicker noise is physically being generated and hopeful process fabrication remedies to reduce it below our current 1 h+ rms floor. The paper also discusses 'lessons learned' in converting NMOS designs to PMOS an effort that has generated some surprising difficulties. Also test set design considerations are reviewed for characterizing PMOS/NMOS imagers with minimum changes when switching between technologies. Lastly, test data generated by CMOS imagers whose designs are compatible to both NMOS and PMOS fabrication. For example, a new stitched PMOS/NMOS 4k x 4k x 10 um pixel CMOS sensor suited for spaceborne scientific applications is presented.

Conference 10210: Next-Generation Spectroscopic Technologies X

Monday - Tuesday 10–11 April 2017

Part of Proceedings of SPIE Vol. 10210 Next-Generation Spectroscopic Technologies X

10210-1, Session 1

Broadband mid-infrared and THz chemical detection with quantum cascade laser multi-heterodyne spectrometers *(Invited Paper)*

Jonas Westberg, Lukasz A. Sterczewski, Link Patrick, Gerard Wysocki, Princeton Univ. (United States)

Majority of chemical species of interest in security and safety applications (e.g. explosives) have complex molecular structures that produce unresolved rotational-vibrational spectroscopic signatures in the mid-infrared. This requires spectroscopic techniques that can provide broadband coverage in the mid-IR region to target broadband absorbers and high resolution to address small molecules that exhibit well-resolved spectral lines. On the other hand, many broadband mid-IR absorbers exhibit well-resolved rotational components in the THz spectral region. Thus, development of spectroscopic sensing technologies that can address both spectral regions is of great importance. Here we demonstrate recent progress towards broadband high-resolution spectroscopic sensing applications with Fabry-Perot quantum cascade lasers (QCLs) and frequency combs using multi-heterodyne spectroscopy (MHS) techniques.

In this paper, we will present spectroscopic sensing of large and small molecules in the mid-IR region using QCLs operating at ~8.5μm. An example high-resolution, broadband MHS of ammonia (small molecule) and isobutane (broadband absorber) at atmospheric pressure in the 1165-1190 cm^-1 range will be discussed. We have developed a balanced MHS system for mitigation of the laser intensity fluctuations. Absorption spectroscopy as well as dispersion spectroscopy with minimum fractional absorption down to ~10^-4/Hz1/2 and fast spectral acquisition capabilities down to 10 μs/spectrum range will be demonstrated. In order to mitigate the shortcomings of the limited chemical selectivity in the mid-IR, THz QCL based spectrometer is currently under development to provide spectral de-congestion and thus significantly improve chemical identification. Preliminary characterization of the performance of THZ QCL combs for the THz QCL-MHS will be presented.

10210-2, Session 1

Versatile, ultra-low sample volume gas analyzer using a rapid, broad-tuning ECQCL and a hollow fiber gas cell

Jason M. Kriesel, Camille Makarem, Opto-Knowledge Systems, Inc. (United States); Mark C. Phillips, James Moran, Pacific Northwest National Lab. (United States); Max L. Coleman, Lance E. Christensen, Jet Propulsion Lab. (United States); James F. Kelly, Opto-Knowledge Systems, Inc. (United States)

We will describe a versatile mid-infrared (Mid-IR) spectroscopy system developed to measure the concentration of a wide range of gases with an ultra-low sample size. The spectrometer combines a rapidly-swept external cavity quantum cascade laser (ECQCL) with a hollow fiber gas cell. The ECQCL has sufficient spectral resolution and reproducibility to measure gases with narrow features (e.g., ammonia, water, methane, etc.), and also the spectral tuning range needed to measure volatile organic compounds (VOCs), (e.g., acetone, aldehydes, ketones, sulfur compounds, etc.). In addition, the laser attains stable, repeatable scans at rates exceeding 100 Hz. The hollow fiber is a capillary tube having an internal reflective coating optimized for transmitting the Mid-IR laser beam to a detector. Sample gas introduced into the fiber (internal volume ~ 1 ml) interacts strongly with the laser beam, and despite relatively modest path lengths (L ~ 1 - 10 m), the requisite quantity of sample needed for sensitive measurements can be significantly less (e.g., nanomoles) than what is required using conventional IR laser spectroscopy systems. Example measurements will be presented including quantification of VOCs relevant for human breath analysis.

10210-3, Session 1

Laser speckle reduction techniques for mid-infrared microscopy and stand-off spectroscopy

Robert Furstenberg, Christopher A. Kendziora, Christopher J. Breshike, Michael R. Papantonakis, Viet K. Nguyen, R. Andrew McGill, U.S. Naval Research Lab. (United States)

Due to their high brightness, infrared (IR) lasers (such as tunable quantum cascade lasers, QCLs) are very attractive illumination sources in both stand-off spectroscopy and micro-spectroscopy. In fact, they are the enabling device for trace-level spectroscopy. However, due to their high coherence as laser beams, QCLs can cause speckle, especially when illuminating a rough surface. This is highly detrimental to the signal-to-noise ratio (SNR) of the collected spectra and can easily negate the gains from using a high brightness source. In most cases, speckle reduction is performed at the expense of optical power. In this paper, we examine several speckle reduction approaches and evaluate them for their ability to reduce speckle contrast while at the same time preserving a high optical throughput. We analyze multi-mode fibers, integrating spheres, and stationary and moving diffusers (both surface reflectance and volume diffusers) for their speckle reduction potential. Speckle-contrast is measured directly by acquiring beam profiles of the illumination beam or, indirectly, by observing speckle formation from illuminating a rough surface (e.g. Infragold® coated surface) with an IR micro-bolometer camera. We also report on a novel speckle-reducing device with increased optical throughput. We characterize speckle contrast reduction from spatial, temporal and wavelength averaging for both CW and pulsed QCLs. Examples of effect of speckle-reduction on hyperspectral images in both standoff and microscopy configurations are given.

10210-4, Session 1

High-fidelity infrared imaging of biological and polymeric materials using quantum cascade lasers

Kevin L. Yeh, Seth Kenkel, Rohit Bhargava, Univ. of Illinois at Urbana-Champaign (United States)

Infrared spectroscopic imaging is a promising analytical technique that can reveal important molecular information without the need for substantial sample processing. In conjunction with classification algorithms, these instruments can provide objective and automated evaluations to aid pathologists improve diagnostic accuracy. Quantum cascade lasers, with higher intensity and narrowband emission, allow for a discreet frequency approach enabling drastic increases in imaging speeds while maintaining competitive spatial and spectral resolution. Here we present new instrumentation incorporating enhanced imaging techniques for improving spectral and spatial quality. New optical designs minimize aberrations to achieve diffraction limited performance at all fingerprint-region wavelengths across the entire field of view. We evaluate the performance in terms of important spectral properties of biological and polymeric materials.

10210-5, Session 1

Scanning standoff TDLAS leak imaging and quantification

Richard T. Wainner, Michael B. Frish, Matthew C. Laderer, Nicholas F. Aubut, Physical Sciences Inc. (United States)

To reduce anthropogenic methane emissions that contribute to climate change, recent EPA regulations require optical gas imaging surveys of upstream natural gas infrastructure to identify sources of leakage. Current optical gas imaging tools, based on passive thermal infrared detection, visualize large leak sources, but are costly and require trained operators to gather and interpret gas images. Furthermore, available infrared imagers are relatively insensitive compared to active laser-based optical sensors and they are non-quantitative, i.e. they do not provide needed methane emission rate information. As a result, leak inspections with current imager technology at specific sites are infrequent and thus can fail to detect intermittent leaks, are insufficient to provide smaller leak detection, and do not provide leak flux information.

This paper describes R&D intended to create a lower-cost highly-sensitive quantitative natural gas leak survey and imaging tool that meets EPA imaging requirements and measures emission rate. This innovation combines active backscatter tunable diode laser absorption spectroscopy (TDLAS), passive optical imaging, novel operating techniques and advanced algorithms in a lightweight handheld tool. It provides quantitative images of path-integrated methane concentration, depicting methane plumes actively interrogated by the laser beam. Emission rates are calculated from the concentration map and supplemental wind vector information. Controlled indoor and outdoor leak imagery demonstrates the sensor utility for a number of different conceived deployment strategies.

10210-6, Session 2

Organic narrowband NIR-detectors

Bernhard Siegmund, Andreas Mischok, Robert Brückner, Ronny Timmreck, Karl Leo, Koen Vandewal, TU Dresden (Germany)

Organic materials offer fascinating properties for realizing optoelectronic devices such as organic light emitting diodes (OLEDs) and solar cells (OSCs). The performance of the latter is mainly determined by the low operating voltage with respect to the optical band gap and the limited absorption properties of organic materials in the near infrared (NIR) spectral region.

We utilize the weakly absorbing charge transfer state to fabricate a narrowband optical sensor in the NIR up to 1500 nm. With very high and competitive detectivities, we are not only entering the Indium-Gallium-Arsenide-dominated world but demonstrate an integrated spectroscopic sensor for accurate moisture detection.

10210-7, Session 2

Ultra-wide tunable light source with integrated spectrometer capabilities

Yonathan Dattner, Lior Blokshtein, Luxmux Technology Corp. (Canada)

Luxmux's Ultra Wide Tunable (UWT) SLED is a light source with integrated spectrometer capabilities. The UWT is a fiber-coupled solution that employs an optional single mode or polarization-maintaining (PM) fiber to deliver the optical signal. The device emits a narrow spectral output of only 1 nm (on average) full width at half maximum (FWHM) in the region of 1250 to 1750 nm. The average spectral density of the optical output is over 100 μW/nm. And, the light source is neatly confined into a palm-size (58 X 33 X 16mm) optical package. The driver offered by Luxmux provides the user full control over the optical package via a software interface as well as with an optional photodiode that can be embedded into the driver. This integration allows the user to move the peak of the emitted spectral output by steps as small as 0.1 nm within the 1250 to 1750 nm region, effectively generating a spectral scan. Additionally, the built-in photodiode can be used to acquire the reflected or transmitted signal at each point in the spectral scan. The power per wavelength thus obtained can then be plotted to represent the transmitted or reflected spectrum across the whole range of 1250 to 1750 nm. This process is completely automated using Luxmux's driver and can be initiated by a single push of a button within the software.

10210-8, Session 2

MIR hollow waveguide (HWG) isotope ratio analyzer for environmental applications

Zhenyou Wang, Yan Zhuang, Andrei Deev, Sheng Wu, Arrow Grand Technologies (United States)

A commercial MIR hollow waveguide (HWG) isotope ratio analyzer (IR2) was developed in Arrow Grand Technologies. The C13/C12 ratio was obtained by measuring the selected CO2 absorption peaks in the MIR region. Combined with a GC and a combustor, it has been successfully employed to measure C13/C12 ratios in oil industry. Here, we demonstrate three potential applications in environmental industry. The C13/C12 ratio and CO2 concentration for gas that is breathed out from soil samples was measured in real time with the analyzer. The concentration and the isotope ratio were found to change with the time. We also built another apparatus to convert Dissolved Inorganic Carbon (DIC) into CO2, and then measure the C13/C12 ratio with an accuracy of 0.5 per mil with a 5 min test time and 1 ml sample usage. Tap water, sea water, rainwater, mineral spring water, coca, and even beer were tested. Lastly, the C13/C12 ratio of CO2 exhaled by human beings was obtained 15 s after simply blowing the expiratory gas into a tube with an accuracy of 0.5 per mil. Recently, by combining the single path HWG with a 5-path HWG module, we are able to measure C13/C12 ratio at a wide CO2 concentration of 300 ppm-17,500 ppm. In summary, a commercial HWG isotope analyzer was demonstrated to be able to perform environmental studies with a high accuracy (~0.5 per mil), fast sampling rate (5 s- 5 min), low sample consumption (~1 ml), and wide CO2 concentration range (300 ppm-17,500 ppm).

10210-9, Session 2

Wireless data acquisition approaches for mobile spectrometry applications suited for the internet of things

Vassili Karanassios, Ryan Fitzgerald, Univ. of Waterloo (Canada)

In environmental monitoring and for mobile spectrometry applications, it would be ideal if there was a way to acquire data using wireless data acquisition while being able to connect mobile spectrometry chemical analysis systems to the internet of things. In this presentation, wireless data acquisition approaches using, for example, Bluetooth and Arduino approaches will be described in detail.

10210-10, Session 3

Intelligent MEMS spectral sensor for NIR applications *(Invited Paper)*

Uula Kantojärvi, Jarkko E. Antila, Jussi Mäkynen, Janne Suhonen, Spectral Engines Oy (Finland)

Near Infrared (NIR) spectrometers are widely used in many fields to measure material content, such as moisture, fat, protein, hydrocarbons, textiles, polymers and pharmaceutical ingredients. Some of industrial applications require highly miniaturized and robust NIR device to meet operators' expectations. In this paper we present a new portable wireless NIR reflection device that brings spectroscopy to pocket size. The NIR device is battery-powered and wireless that can be operated with a computer or mobile devices. Through cloud connectivity multiple spectral sensors can be operated simultaneously and seamlessly. Device is based on a diffuse reflectance measurement geometry. Device consists of a broadband illuminator and a tunable Microelectromechanical (MEMS) Fabry-Perot Interferometer with a single pixel extended InGaAs detector. The illumination and detection units with electronics are packaged to a cubic inch size with a weight of less than 15 grams. The operation wavelength ranges cover from 1350 nm to 2450 nm. We present the sensor design, it's building blocks, operation principle and easy-to-use algorithms to adapt the sensor to number of applications. In addition, we show how the algorithms are used to adapt the sensor to applications and how the sensor is powered with intelligence. We also present some practical NIR applications carried out with truly portable NIR device. Such miniature spectral sensors open up substantial new application and business opportunities by offering small footprint, high performance and intelligent connectivity.

10210-11, Session 3

Thermal stabilization of static single-mirror Fourier transform spectrometers

Michael Schardt, Christian Schwaller, Anton J. Tremmel, Alexander W. Koch, Technische Univ. München (Germany)

Fourier transform spectroscopy has become a standard method for spectral analysis of infrared light. With this method, an interferogram is created by two beam interference which is subsequently Fourier transformed. Most Fourier transform spectrometers used today provide the interferogram in the temporal domain. In contrast, static Fourier transform spectrometers generate interferograms in the spatial domain.

One example of this type of spectrometer is the static single-mirror Fourier transform spectrometer which offers a high etendue in combination with a simple, miniaturized optics design. As no moving parts are required, it also features a high vibration resistance and high measurement rates. However, it is susceptible to temperature variations.

In this publication, we therefore introduce and evaluate the main sources for temperature-induced errors in static single-mirror Fourier transform spectrometers: changes in the refractive index of the optical components used, variations of the detector sensitivity, and thermal expansion of the housing. As these errors manifest themselves in temperature-dependent wavenumber shifts and intensity shifts, they prevent static single-mirror Fourier transform spectrometers from delivering long-term stable spectra.

To eliminate these shifts, we additionally present a work concept for the thermal stabilization of the spectrometer. With this stabilization, static single-mirror Fourier transform spectrometers are made suitable for infrared process spectroscopy under harsh thermal environmental conditions. As the static single-mirror Fourier transform spectrometer uses the so-called source-doubling principle, many of the mentioned findings are transferable to other designs of static Fourier transform spectrometers based on the same principle.

10210-12, Session 3

Broadband mid-infrared silicon-on-insulator Fourier transform photonic IC spectrometer

Nicolas J. P. Gorius, Dat Tran, The Catholic Univ. of America (United States); Mark Lucente, Kyle Hoover, Nanohmics, Inc. (United States); Georges Nehmetallah, The Catholic Univ. of America (United States); Tilak Hewagama, Univ. of Maryland (United States); Shahid Aslam, Theodor Kostiuk, NASA Goddard Space Flight Ctr. (United States)

We present the design, simulation, and fabrication of a simplified proof-of-concept, real-time, broadband mid-infrared (2-6?m) Silicon–on-Insulator Photonic IC (PIC) spectrometer with low size, weight, and power suitable for remote sensing applications. The Fourier-transform spectrometer chip comprises an array of Mach-Zehnder interferometers (MZIs) of single-mode rib waveguides with high input coupling, no moving parts, and low power requirement. The path length difference between the two interferometer arms in each of the MZIs is fabricated with a linear progression across the array to obtain the interferogram.

All components of the spectrometer chip (splitters, combiners, and bends) will be analyzed and simulated by FDTD and beam propagation methods to evaluate the interferometer performance and to find the optimal parameters before fabrication. We present a series of simulations to assess the performance of different Y-branch junctions with respect to angle, and flatness of the junctions, and compare them with multimode interference power splitters. We also compare the performance between S-bends and 90o bends structures and find the optimal radius of curvature for 90o bend structure. We discuss the relation between the 90o bend radius of curvature, etching depth, width, and transmission efficiency of each MZI. We also analyze our tolerance to fabrication errors and present our mitigation strategy.

Finally, the proposed PIC spectrometer will be capable of acquiring a high-resolution (R up to 10,000) spectrum over 0.5 ?m bands between 2-6 ?m and could be considered for remote sensing applications where power, weight and volume are limited, including CubeSat and SmallSat applications.

10210-13, Session 3

Enhanced resolution infrared spectroscopic imaging by structured illumination

Seth Kenkel, Kevin L. Yeh, Rohit Bhargava, Univ. of Illinois at Urbana-Champaign (United States)

Infrared spectroscopic imaging is a useful technique for visualizing many biochemical and biophysical parameters of a material; however, the data storage, speed and costs of this technique limits its use in many biomedical fields. Confocal Fourier Transform Infrared (FTIR) imaging eliminates the need for expensive infrared cameras; however, acquisition speeds and signal strength are sacrificed for resolution. Structured illumination techniques can be used to compress the spatial information of a sample without loss of signal strength and offers improved acquisition speeds and reduced data size over confocal FTIR. Here we present a custom diffraction limited FTIR microscope using a Digital Micromirror Device (DMD) for compressing spatial image information. Improvements in acquisition speed and data quality for different compression and reconstruction techniques are discussed.

10210-14, Session 3

Femtosecond standoff LIBS studies of energetic materials

Venugopal Rao Soma, Abdul Kalam S., Lingamurthy N., Univ. of Hyderabad (India)

Any standoff detector for the effective detection of explosives/energetic molecules must meet two basic requirements: (a) capacity to detect the response generated from a tiny amount of material located at a distance of several meters (high sensitivity) and (2) the ability to provide easily distinguishable responses for different materials (high specificity). Raman spectroscopy and laser induced breakdown spectroscopy (LIBS)

are probably the only two analytical techniques which can surpass both the above requirements.The success of LIBS devices in Chadrayaan and ChemCam is an indication of the technique's maturity for various applications. Several hand-held LIBS based devices are now being supplied by various companies. However, there has been tardy progress in the detection of explosive molecules using the LIBS technique and in particular, employing femtosecond pulses. It has been demonstrated in various fields that femtosecond pulses have distinct advantages over the longer pulses. Herein we present some of our results from (a) LIBS measurements of different explosive molecules and efforts to discriminate them from others (b) design of standoff LIBS system for studying explosive molecules at trace levels. We have utilized ~50 femtosecond, 800 nm pulses for these measurements.

10210-15, Session 3

Ultra-compact MEMS FTIR spectrometer

Yasser M. Sabry, Si-Ware Systems (Egypt) and Ain-Shams Univ. (Egypt); Khaled Hassan, Momen Anwar, Mohamed Hamouda, Mostafa Medhat, Si-Ware Systems (Egypt); George A. Adib, Ain-Shams Univ. (Egypt); Rich Dumont, Si-Ware Systems (Egypt); Diaa Abdel Maguid Khalil, Si-Ware Systems (Egypt) and Ain-Shams Univ. (Egypt)

Portable and handheld spectrometers are being developed and commercialized in the late few years leveraging the rapidly-progressing technology and triggering new markets in the field of on-site spectroscopic analysis. Although handheld devices were commercialized for the near-infrared spectroscopy (NIRS), their size and cost stand as an obstacle against the deployment of the spectrometer as spectral sensing components needed for the smart phone industry and the IoT applications. In this work we report a chip-sized microelectromechanical system (MEMS)-based FTIR spectrometer. The core optical engine of the solution is built using a passive-alignment integration technique for a self-aligned MEMS chip; self-aligned microoptics and a single detector in a tiny package sized about 1 cm3. The MEMS chip is a monolithic, high-throughput scanning Michelson interferometer fabricated using deep reactive ion etching technology of silicon-on-insulator substrate. The micro-optical part is used for conditioning the input/output light to/from the MEMS and for further light direction to the detector. Thanks to the all-reflective design of the conditioning microoptics, the performance is free of chromatic aberration. Complemented by the excellent transmission properties of the silicon in the infrared region, the integrated solution allows very wide spectral range of operation. The reported sensor's spectral resolution is about 33 cm-1 and working in the range of 1350 nm to 2500 nm; upper limited by the extended InGaAs detector. The presented solution provides a low cost, low power, tiny size, wide wavelength range NIR spectral sensor that can be manufactured with extremely high volumes. All these features promise the compatibility of this technology with the forthcoming demand of smart portable and IoT devices.

10210-38, Session 3

Photo-induced force microscopy: nanoscale imaging with chemical recognition

Ryan Murdick, Molecular Vista, Inc. (United States)

Photo-induced Force Microscopy (PiFM) enables broadband spectroscopic probing of materials with nanoscale spatial resolution (< 10 nm). Combining AFM with optical illumination provides nanoscopic spatial resolution through the sharp tip (~10 nm) with the chemical recognition provided by optical spectroscopy. In PiFM, the response of the optically excited sample is probed directly in the near-field by reading out the time-integrated force between the tip and the sample. Because the magnitude of the force is dependent on the photo-induced polarizability of the sample, PiFM exhibits spectroscopic sensitivity. PiFM achieves very high spatial resolution even under ambient conditions, along with chemical recognition of a wide range of nano-materials, from semiconducting nanoparticles to polymer thin films to sensitive measurements of single molecules. The principles and the basic components of the PiFM will be presented with examples that highlight the nanoscale imaging and spectroscopic sensitivity inherent to the technique. Recent samples investigated with PiFM will be presented, including: polymer blends, nano-fibers, polypeptides, block copolymers, and 2D materials.

10210-16, Session 4

Time multiplexed spectral imaging of burning aluminum monoxide particles

Alvaro A. Cruz-Cabrera, Leland J. Sharp, Byron Demosthenous, Sandia National Labs. (United States); Jan S. Kasprzak, Feng Jin, Jolanta I. Soos, Sudhir B. Trivedi, Brimrose Corp. of America (United States)

Time multiplexed spectral images of burning aluminum particles from two experiments using a hyperspectral imaging system (HIS) coupled to a high speed video (HSV) camera were investigated. The first experiment looks at ignited aluminum particles generated by a welding torch that were continuously funneled into the imaging plane of the HIS-HSV system. The HIS was set to hop between two wavelengths at a rate of 300 frames per second (fps): 485.7 nm, the peak emission of aluminum monoxide, and 502.3nm, the bottom of the same emission peak. The second experiment images ignited AlO from the burn of an aluminized ammonium perchlorate solid propellant hoping between the wavelength of 486.3nm and 480.0nm at 2100 fps.

10210-17, Session 4

A hyperspectral scanning microscope system for phenomenology support

Paul G. Lucey, Jessica Norman, Univ. of Hawai'i at Manoa (United States); Sarah T. Crites, Japan Aerospace Exploration Agency (Japan)

Spectrum libraries are vital assets in analysis of hyperspectral data, especially in the context of signature based detection. As handheld HSI systems become widely available data obtained at short standoff ranges will begin to differ substantially from the conditions that traditionally hold in spectral systems that stock current spectrum libraries. In particular, some close range HSI systems will begin to detect individual particles of contaminants, or portions of materials that are typically unresolved. Recognizing this new era, at the University of Hawaii we have converted several hyperspectral imaging systems into scanning spectral microscopes. Most actively used at this time is an LWIR HSI scanner that collects data both in spectral emission and reflectance at a resolution of 30 microns for 1x4 cm samples. One active project is to compare the spectra of bulk materials measured in an FTIR, with the spectra of resolved individual particles in the 100 micron size range. An overview of the hardware will be presented, and data from our bulk vs. resolved particulate student will be shown.

10210-18, Session 4

Performance evaluation and modeling of a conformal filter (CF) based real-time standoff hazardous material detection sensor

Matthew P. Nelson, Shawna K. Tazik, Arjun Bangalore, Patrick J. Treado, ChemImage Corp. (United States)

Hyperspectral imaging (HSI) systems can provide detection and identification of a variety of targets in the presence of complex backgrounds. However, current generation sensors are typically large, costly to field, do not usually operate in real time and have limited sensitivity and specificity. Despite these shortcomings, HSI-based intelligence has proven to be a valuable tool, thus resulting in increased demand for this type of technology. By moving the next generation of HSI technology into a more adaptive configuration, and a smaller and more cost effective form factor, HSI technologies can help maintain a competitive advantage for the U.S. armed forces as well as local, state and federal law enforcement agencies.

Operating near the physical limits of HSI system capability is often necessary and very challenging, but is often enabled by rigorous modeling of detection performance. Specific performance envelopes we consistently strive to improve include: operating under low signal to background conditions; at higher and higher frame rates; and under less than ideal motion control scenarios. An adaptable, low cost, low footprint, standoff sensor architecture we have been maturing includes the use of conformal liquid crystal tunable filters. Conformal Filters (CFs) are electro-optically tunable, multivariate hyperspectral imaging spectrometers that produce optimized spectral passbands on demand, which can readily be re-configured, to discriminate targets from complex backgrounds.

This presentation will explore current generation CF standoff sensors, including recent testing results for a wide array of materials as well as performance modeling.

10210-19, Session 4

Compact LWIR sensors using spatial interferometric technology

Adam L. Bingham, Spectrum Photonics, Inc. (United States); Paul G. Lucey, Univ. of Hawai'i at Manoa (United States); Edward T. Knobbe, Spectrum Photonics, Inc. (United States)

Recent developments in reducing the cost and mass of hyperspectral sensors have enabled more widespread use for short range compositional imaging applications. HSI in the long wave infrared (LWIR) is of interest because it is sensitive to spectral phenomena not accessible to other wavelengths, and because of its inherent thermal imaging capability. At Spectrum Photonics we have pursued compact LWIR hyperspectral sensors both using microbolometer arrays and compact cryogenic detector cameras. Our microbolometer-based systems are principally aimed at short standoff applications, currently weigh 10-15 lbs and feature sizes approximately 20x20x10 cm, with sensitivity in the 1-2 microflick range, and imaging times on the order of 30 seconds. Our systems that employ cryogenic arrays are aimed at medium standoff ranges such as nadir looking missions from UAVs. Recent work with cooled sensors has focused on Strained Layer Superlattice (SLS) technology, as these detector arrays are undergoing rapid improvements, and have some advantages compared to HgCdTe detectors in terms of calibration stability. These sensors include full on-board processing sensor stabilization so are somewhat larger than the microbolometer systems, but could be adapted to much more compact form factors. We will review our recent progress in both these application areas.

10210-20, Session 4

Miniature infrared hyper-spectral imaging sensor for airborne applications

Michele Hinnrichs, Bradford R. Hinnrichs, Earl McCutcheon, Pacific Advanced Technology, Inc. (United States)

This paper is a follow-on paper to two previous paper presented at SPIE in 2012 and 2014 describing a design for a snapshot multi-spectral hyperspectral camera for CBRNE applications. An update on the final sensor development will be given. Under support by the US Army SBIR program and with support from ONR a hyper-spectral MWIR/LWIR camera was developed. The infrared hyperspectral cameras both use a 640 x 512, 15 micron pixel pitch with InSb for the MWIR and SLS for the LWIR focal plane array. The micro-optics (lenslet arrays) are configured in a 2 x 2 array giving 4 simultaneous different spectral images consisting of 256 x 256 pixels each. The lenslet array is translated using piezo motors to cover the full hyperspectral bands of 3 to 5 microns for the MWIR and 8 to 11 microns for the LWIR.

By multiplexing 4 simultaneous spectral images an entire hyperspectral data cube can be collected rapidly and thus eliminate or significantly reduce the temporal variation which reduces motion sensitivity between spectral images and enhances real-time image processing capability.

This paper will describe the design of the electro-optical system and how this is used to collect and perform spectral image processing in real-time using an embedded FPGA processor.

10210-21, Session 4

Push-broom imaging spectrometer based on planar lightwave circuit MZI array

Minyue Yang, Mingyu Li, Jian-Jun He, Zhejiang Univ. (China)

We propose a large aperture static imaging spectrometer (LASIS) based on planar lightwave circuit (PLC) MZI array. The imaging spectrometer works in the push-broom mode with the spectrum performed by interferometry. While the satellite/aircraft is orbiting, the same source, seen from the satellite/aircraft, moves across the aperture and enters different MZIs, while adjacent sources enter adjacent MZIs at the same time. The on-chip spectrometer consists of 256 input mode converters, followed by 256 MZIs with linearly increasing optical path delays and a detector array. Multiple chips are stick together to form the 2D image surface and receive light from the imaging lens. Two MZI arrays are proposed, one works in wavelength ranging from 500nm to 900nm with SiON(refractive index 1.6) waveguides and another ranging from 1100nm to 1700nm with SOI platform. To meet the requirements of imaging spectrometer applications, we choose large cross-section ridge waveguide to achieve polarization insensitive, maintain single mode propagation in broad spectrum and increase production tolerance. The SiON on-chip spectrometer has a spectral resolution of 80cm-1 with a footprint of 17?15mm2 and the SOI based on-chip spectrometer has a resolution of 38cm-1 with a size of 22?19mm2. The spectral and space resolution of the imaging spectrometer can be further improved by simply adding more MZIs. The on-chip waveguide MZI array based Fourier transform imaging spectrometer can provide a highly compact solution for remote sensing on unmanned aerial vehicles or satellites with advantages of small size, light weight, no moving parts and large input aperture.

10210-22, Session 4

Capturing spectral information from object and scene motion with polarization interferometry

Alex N. Hegyi, PARC, A Xerox Co. (United States)

A new method is introduced to obtain spectral information from object and scene motion, applicable to both spectral flow cytometry and hyperspectral imaging. Objects and scenes in motion are imaged onto a polarization interferometer consisting of a calcite Wollaston prism between parallel polarizers, with polarization axes at 45° with respect to the optical axes of the Wollaston prism. The polarization interferometer is placed in a conjugate focal plane of a flow cytometer detector, and due to the position-dependent optical path delay of the interferometer, interferograms are generated by particle flow. Fourier-transforming the interferograms with respect to time yields the optical spectrum of each particle. The polarization interferometer is also placed in front of a CMOS imaging array, and translation of the combined system with respect to a scene yields the interferogram of each scene point. A hyperspectral image of the scene is recovered by Fourier-transformation of these interferograms. The above two experiments demonstrate a means for obtaining spectral information from point particles and extended scenes that requires adding only a Wollaston prism and polarizing filters to existing optical systems. The method has applicability to situations where linear motion is already present, including flow cytometers, conveyor belt systems, fixed-wing aircraft, and satellites.

10210-23, Session 5

Recent advances in the smartphone-based points of need optical and luminescence biosensors *(Invited Paper)*

Aldo Roda, Martina Zangheri, Donato Calabria, Cristiana Caliceti, Patrizia Simoni, Mara Mirasoli, Univ. degli Studi di Bologna (Italy)

The proposed use of the smartphone as a portable bioanalytical devices has created an intense emotion and stimulates many researchers among the scientific community. Most of them take advance of the smartphone photocamera as a detector for optical or luminescence bioassay (1) but still require complex accessories for colorimetric or photoluminescence detection thus compromise the smartphone concept of simplicity.
The ideal smartphone-based biosensor should be almost reagent and instrumental-less, rapid and robust, with a detectability suitable for analytes of clinical interest. From one side, chemiluminescence detection offers high detectability and simplicity only requiring a mini-darkbox fabricated by 3D printing technology connected to the photocamera. We developed biosensor based on chemiluminescent lateral flow immunoassay, but this approach is limited by the addition of reagents for the reaction even if included in a microfluidic chip. To overcome this limitation, we exploited thermochemiluminescent labels (where light emission is generated by thermal decomposition of the label to generate a product in a singlet excited state) for the development of a paper-based bioassay using a mini dark box and a Li battery-powered mini-heater.

As an alternative, color-based biosensors using color detection by reflectance are the most popular but they still suffer of poor reproducibility related to inhomogeneity of color which limits the quantitative use. To overcome this problem, we proposed a smartphone paper-based approach in which reagents were selectively entrapped in different layer using polyelectrolytes to form a "wafer"-like structure film which enhances the stability of proteins and facilitate the reagent diffusion.

[1]Roda, A., et al.TrAC 79 (2016):317-325

10210-24, Session 5

Pharmaceutical applications using NIR technology in the cloud

Luiz Grossmann, Optionline LLC (United States); Marco A Borges, Optionline (Brazil)

New technologies such as Cloud Computing, IoT, Big Data and affordable NIR devices are redefining the way we deal with the major challenges in the pharmaceutical industry. Many new developments on the analytics side, such as the efforts to translate signals into useful intelligence stuff are now indicating new paths. However different those many market applications might look, they mostly relate to the same problem of properly identifying a chemical entity, therefore being able to distinguish between the good and the bad, the forbidden and the allowed, or the likelihood of the existence or non-existence of an active compound or contaminant in a particular sample through simple scan readings.

Easier said than done. An NIR signal is a very complex one. An NIR spectrum is basically a consequence of molecular vibrations in the sample, therefore influencing the light radiation that is reflected away from the sample. Usually the signal responses are not specific to a particular material, rather, each group´s responses add up, thus providing low specificity of a spectral reading. Signals are also heavily auto-correlated, making the signal decomposition a difficult task. A whole new science, aka Chemometrics, has emerged and is very focused in creating analytical tools for dealing with these complex data.

While a fool-proof identification of a chemical formulation using NIR is perhaps many years away, the convenience, mobility and affordability of presently available NIR technology can still address today´s problems today. By using spectral matching techniques, we can still assess what could likely be present in a sample, or perhaps what is unlikely to be there. This is closer to screening for something relevant than actually chemically analyzing the sample. A probability assessment is the outcome, and that means intelligence gathering. In other words, we are not trying to answer what is in there, but what could be in the sample. Being able to reduce the problem to a few possible items may be an important step for defining the best response.

Optionline´s approach has taken two separate paths in that direction. One is to build a reliable database of spectral signatures for thousands of relevant substances, mainly involving food, pharmaceutical and hazardous materials. Simultaneously, we are working on ways to provide online real time analysis for fast turnaround responses. That means utterly simplifying the readings and integrating a machine´s artificial intelligence to human intelligence. Usually a list of dozens of substances can be screened in just a few seconds if we know what to look for and compare them the same way. While a machine can reduce the scope from dozens of candidates to just a few, we count on human intelligence to take it from there. Of course we might be trading specificity and precision for intelligence and early warning.

Big data, IoT, NIR new technologies, when are all integrated, have more in common with sniffer dogs, among the oldest screening measures still employed. Being old or new does not matter. Usefulness is king.

10210-25, Session 5

Embry-Riddle Aeronautical University multispectral sensor laboratory: A model for distributed research and education

Sonya A. H. McMullen, Troy Henderson, David Ison, Embry-Riddle Aeronautical Univ. (United States)

The miniaturization of unmanned systems and spacecraft, computing and sensor technologies, has opened dramatic new opportunities in the areas of remote sensing and multi-sensor data fusion for a variety of applications. Remote sensing and data fusion historically have been the purview of large government organizations due to the high cost and complexity of developing, fielding, and operating such systems. However, miniaturized computers with high capacity processing capabilities, small and affordable sensors, and emerging commercially available platforms such as UAS and CubeSats to carry such sensors, the possible applications for such systems become vast. Embry-Riddle Aeronautical University (ERAU) developed an advanced sensor and data fusion laboratory to research sensor capabilities and their employment on a wide-range of autonomous, robotic, and transportation systems. This lab is unique in being a traditional campus laboratory for students and faculty to model and test sensors and scenarios, process multisensor data sets (both simulated and experimental), and analyze results and a "virtual" modeling, testing, and teaching capability reaching beyond the physical confines of the facility for use among ERAU Worldwide students and faculty located around the globe. Although other institutions have optical sensor laboratories, this is the first such lab to expand to multispectral sensors and data fusion. The initiative is a unique effort among Embry-Riddle faculty to develop a cross-campus research to facilitate faculty- and student-driven research. Specifically, the ERAU Worldwide Campus, with locations across the globe and delivering curricula online, will be leveraged to provide novel approaches to remote sensor experimentation and simulation.

10210-26, Session 5

Raman micro-spectroscopy as a non-destructive key analysis tool in current power semiconductor manufacturing

Martin De Biasio, Martin Kraft, CTR Carinthian Tech Research AG (Austria); Eduard Geier, Christoph Bergmann, Infineon Technologies Austria AG (Austria); Mercedes Cerezuela-Barreto, Dirk Lewke, Martin Schellenberger, Fraunhofer-Institut für Integrierte Systeme und Bauelementetechnologie IISB (Germany); Michael Rösner, Infineon Technologies Austria AG (Austria)

Raman spectroscopy (RS) measures inelastic light scattering at the molecular level of symmetric molecules non-invasively and non-destructive. RS is extremely information rich and is therefore a useful tool for chemical identification and the characterisation of the chemical structures of materials.

When monochromatic light is incident upon a sample this light will interact with the sample. In some manner it will be absorbed, reflected or scattered. For RS only the scattering information is of interest. Raman scattering changes the polarisation of the molecules, resulting in an energy difference between the incident light and the measured light. These characteristic Raman peaks allow the spectroscopic separation of different molecules or identical molecules in different crystalline forms.

The relative shift of Raman peaks can also be used to measure stress in semiconductor materials directly, non-destructively and quantitatively. The key purpose of this work was hence to investigate and validate RS as a reliable metrology tool for quantification of absolute stress levels on the two semiconductor materials silicon and silicon carbide under application conditions defined by the process. Measurements of silicon carbide were made on silicon carbide wafers; stress and material analyses of silicon were performed on: (i.) silicon wafers that had undergone different wafer thinning methods and (ii) along die sidewalls formed by mechanical and thermal laser separation. Our measurements demonstrate that micro-Raman spectroscopy is a feasible method for measuring stress and optimizing the thin wafer processes.

10210-27, Session 5

SERS measurements towards on-field detection of explosive molecules using a portable spectrometer

Venugopal Rao Soma, Chandu Byram, Bharathi M. S. S., Univ. of Hyderabad (India)

Surface-enhanced Raman scattering (SERS) based molecular analysis techniques exhibit highly attractive properties in terms of sensitivity, speed, cost, multiplexing and portability. SERS has been used successfully to resolve conjugated nitro explosives down to attomolar levels. However, the nanostructures/nanoparticles used for achieving such sensitivity are prepared by various chemical methods, which may lack reproducibility. Furthermore, each of these nanostructures prepared are good for sensing a particular molecule only. We have been working on preparing nanostructures/nanoparticles using the technique of laser ablation using ultrashort laser pulses over the last few years. We have been successful in preparing a a variety of nanostructures in Ag, Au, Ag-Au, Cu etc. and were successful in detecting different explosive molecules such as RDX, ANTA, TNT etc. down to nanomolar concentration levels. However, we had utilized a complicated, bulk micro-Raman spectrometer for these measurements. Herein we will present results from our efforts towards (a) realization of efficient SERS targets using laser ablation technique which are versatile (can detect several molecules), recyclable and robust (b) performing the measurements with a portable Raman spectrometer (few kgs in weight) which can be take to the field for measurements (c) demonstration of on-field detection of common explosive molecules. We will utilize the plasmonic metals of Ag, Au, Ag-Au and femtosecond laser pulses for ablation purposes. Our main focus would be to prepare efficient SERS substrates which can detect different explosive molecules and simultaneously perform the measurements with a portable Raman spectrometer.

10210-28, Session 6

Frequency-domain spectroscopy using high-power tunable THz-wave sources: towards THz sensing and detector sensitivity calibration *(Invited Paper)*

Yuma Takida, Hiroaki Minamide, RIKEN (Japan)

[Invited] The development of reliable high-power, frequency-tunable terahertz (THz)-wave sources is crucial for a wide variety of applications, such as spectroscopy, imaging, and sensing. In order to generate frequency-tunable THz waves at room temperature, one of the most promising methods is a wavelength conversion in nonlinear optical crystals. Here, we will present our recent results on high-power, widely-tunable, frequency-agile THz-wave sources based on nonlinear parametric processes in MgO:LiNbO3 crystals. By changing the noncollinear phase-matching condition in MgO:LiNbO3, the tunability of sub-nanosecond-pumped injection-seeded THz-wave parametric generators (is-TPGs) covers the 3.65-octave frequency range from 0.37 THz up to 4.65 THz. The monochromatic THz-wave output from is-TPGs is greater than 10 kW peak power with the linewidth of approximately 3 GHz and the stability of 1%. These is-TPG systems are reliable and promising high-power tunable THz-wave sources for frequency-domain spectroscopic measurements towards THz sensing and detector sensitivity calibration.

10210-29, Session 6

Grating-coupled surface plasmons on InSb: a versatile platform for terahertz plasmonic sensing

Diyar Talbayev, Tulane Univ. (United States); Jiangfeng Zhou, Univ. of South Florida (United States); Shuai Lin, Tulane Univ. (United States); Khagendra Bhattarai, Univ. of South Florida (United States)

Detection and identification of molecular materials based on their THz frequency vibrational resonances remains an open technological challenge. The need for such technology is illustrated by its potential uses in explosives detection (e.g., RDX) or identification of large biomolecules based on their THz-frequency vibrational fingerprints. The prevailing approaches to THz sensing often rely on a form of waveguide spectroscopy, either utilizing geometric waveguides, such as metallic parallel plate, or plasmonic waveguides made of structured metallic surfaces with sub-wavelength corrugation. The sensitivity of waveguide-based sensing devices is derived from the long (1 cm or longer) propagation and interaction distance of the THz wave with the analyte. We have demonstrated that thin InSb layers with metallic gratings can support high quality factor “true” surface plasmon (SP) resonances that can be used for THz plasmonic sensing. We find two strong SP absorption resonances in normal-incidence transmission and investigate their dispersion relations, dependence on InSb thickness, and the spatial distribution of the electric field. The sensitivity of this approach relies on the frequency shift of the SP resonance when the dielectric function changes in the immediate vicinity of the sensor, in the region of deeply sub-wavelength thickness. Our computational modeling indicates that the sensor sensitivity can exceed 0.25 THz per refractive index unit. One of the SP resonances also exhibits a splitting when tuned in resonance with a vibrational mode of an analyte, which could lead to new sensing modalities for the detection of THz vibrational features of the analyte.

10210-30, Session 6

Broadband terahertz circular polarization spectroscopy

Rolando Valdes Aguilar, The Ohio State Univ. (United States)

Light-matter interactions are fundamental in providing a deep understanding of materials. Even in the linear-response regime, the spectroscopic response of a material encodes in it many properties of the ground state as well as of its excitations. This knowledge has been critical in our understanding of novel quantum materials, and the further improvement and extensions of these methods will continue to be key in the understanding of these novel states of matter. Here we report, for the first time, the use of broadband circular polarization spectroscopy in the terahertz range of the electromagnetic spectrum. We take advantage of a novel design of a broadband quarter wave plate, based on the Fresnel rhomb concept, and use it in conjunction with a polarization modulation technique. This combination is able to provide direct information of the response of a material to circularly polarized THz radiation, a new capability shown here for the first time. As an example of the power of this technique we study the cyclotron resonance of a 2D electron gas from a AlGaaAs--GaAs quantum well. We demonstrate the unique advantages that this technique will bring in the study of novel quantum materials.

10210-31, Session 6

Lanthanide monopnictide nanoparticles within III-V semiconductors for photoconductive switches and other terahertz devices *(Invited Paper)*

Joshua M. Zide, Univ. of Delaware (United States)

In recent years, there has been interest in lanthanide monopnictide (Ln-V) nanoparticles (especially ErAs) embedded within III-V semiconductors for photoconductive switches and photomixers for terahertz generation and detection. Photoconductive switches based on ErAs:GaAs have proven quite effective, especially when compared to conventional materials such as low temperature-grown GaAs (LT-GaAs) or radiation-damaged silicon on sapphire. At the same time, the ability to pump a photoconductive switch with 1064nm or 1550nm fiber-coupled lasers rather than titanium-sapphire lasers represents a critical step to wider adoption of terahertz spectroscopy and related technologies.

Accordingly, we report on the growth and characterization of ErAs nanoparticles epitaxially embedded within GaBiXAs1-X. The incorporation of bismuth into III-V semiconductors has been shown to reduce the bandgap, and here, we demonstrate that such ErAs:GaBiAs nanocomposite materials have the requisite electrical and optical properties (i.e. appropriate bandgap, high dark resistance, high mobility, and short carrier lifetime) to be promising materials for photoconductive switches and photomixers operating at 1064nm and longer optical wavelengths. We will also discuss approaches to further extend this wavelength. Additionally, we will discuss our recent work on TbAs-containing materials in which the trap states associated with the nanoparticles can be saturated, providing carrier lifetimes that depend strongly on optical fluence. We believe these materials might provide a path to new terahertz device technologies.

10210-32, Session 6

THz spectroscopy of the atmosphere for climatology and meteorology applications

Peter C. Hargrave, Cardiff Univ. (United Kingdom)

We present a new satellite-based instrument concept that will enable global measurements of atmospheric temperature and humidity profiles with unprecedented resolution and accuracy, compared to currently planned missions. It will also provide global measurements of essential climate variables related to ice clouds, that will constrain global climate models.

The instrument is enabled by the use kinetic inductance detectors, arranged as superconducting filterbank spectrometers, operating between 100GHz and 850 GHz.

We present the science drivers, the current instrument concept and status, and predicted performance.

10210-33, Session 6

Role of disorder and recombination kinetics in the performance of CH3NH3PbI3 perovskite films *(Invited Paper)*

Elbert Chia, Chan Lao-o-vorakiat, Teddy Salim, Jeannette Kadro, M.-T. Khuc, R. Haselsberger, Liang Cheng, Huanxin Xia, Gagik G. Gurzadyan, H. B. Su, Yeng Ming Lam, Nanyang Technological Univ. (Singapore); R. A. Marcus, California Institute of Technology (United States); Maria-Elisabeth Michel-Beyerle, Nanyang Technological Univ. (Singapore)

Apart from broadband absorption of solar radiation, the performance of photovoltaic devices is governed by the density and mobility of photogenerated charge carriers. The latter parameters indicate how many free carriers move away from their origin, and how fast, before loss mechanisms such as carrier recombination occur. However, only lower bounds of these parameters are usually obtained. Here we independently determine both density and mobility of charge carriers in the organometallic halide perovskite film CH3NH3PbI3 by use of time-resolved terahertz (THz) spectroscopy (TRTS). Our data reveal the modification of the free carrier response by strong backscattering expected from these heavily disordered perovskite films. The results for different phases and different temperatures show a change of kinetics from two-body recombination at room temperature to three-body recombination at low temperatures. Our results suggest that perovskite-based solar cells can perform well even at low temperatures as long as the three-body recombination has not become predominant [1].

[1] C. La-o-vorakiat, T. Salim, J. Kadro, M-T Khuc, R. Haselsberger, L. Cheng, H. Xia, G. G. Gurzadyan, H. Su, Y. M. Lam, R. A. Marcus, M-E Michel-Beyerle, and Elbert E. M. Chia, Nat. Commun. 6, 7903 (2015).

10210-34, Session 6

Plasmonic enhanced THz-TDS system for identification of common explosives

Ekmel Ozbay, Bilkent Univ. (Turkey)

We present our work on identication of most commonly used explosives (C4, HMX, RDX, PETN, TNT and blackpowder) and some non-explosive samples (Lactose, Sucrose, PABA) using a nano-antenna coupled photo-conductive antenna (PCA) based terahertz time-domain spectroscopy system at 0.1-3.0 THz frequency range. 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 2x better when compared to the standard PCAs. Time-domain and frequency-domain pre-processings are applied to partly eliminate background noise, rejections, and water absorption lines due to humidity. We demonstrated that false alarm rate is found to be convincingly low using 5 principle components for these samples. We also demonstrated the capability of identifying possible explosive mixtures due to linearity in PC space.

10210-35, Session 6

Broadband nonlinear THz spectroscopy and its application *(Invited Paper)*

Masashi Yamaguchi, Rensselaer Polytechnic Institute (United States)

Recent development of bright THz source made it possible to explore the interaction of THz field and materials beyond the linear regime. For the purpose of THz spectroscopy, broader bandwidth is a desirable feature of the bright THz source. Laser-induced gas plasma source has intense and broad bandwidth covering entire THz gap region, and is suitable THz source of the nonlinear THz spectroscopy. In this presentation, frequency resolved THz z-scan spectroscopy and two-dimensional THz spectroscopy are discussed. Electronic and phononic contributions are resolved in broadband THz transmission spectra using gas-plasma source. The field dependence of the spectra shows the apparent existence of THz nonlinear contributions, and these contributions are attributed to the combinational mode of zone boundary LA phonons. Multiple of THz third order nonlinear contributions can be resolved by using co-linear configuration of two-dimensional spectroscopy. THz two-dimensional spectroscopy in collinear configuration was originally demonstrated by Kuehn et.al. [1] in higher frequency range than present study (>20 THz) using the electric filed over 1MV/cm. In InSb crystal, we have observed two-dimensional spectra with off-resonant excitation with much lower electric field in the order of 100 kV/cm in THz gap- region. The use of broadband nonlinear THz spectroscopy using laser-induced gas plasma provides a way to inspect and evaluate materials in more details.

[1]W. Kuehn, K. Reimann, M. Woerner, and T. Elsaesser, J. Chem. Phys. 130 (2009).

10210-37, Session PTue

Micro-Raman spectroscopy as a tool for the characterization of silicon carbide in power semiconductor material processing

Martin De Biasio, Martin Kraft, CTR Carinthian Tech Research AG (Austria); Bernhard Goller, Daniela Sternig, Michael Roesner, Infineon Technologies Austria AG (Austria)

Raman spectroscopy (RS) measures inelastic light scattering at the molecular level of symmetric molecules non-invasively and non-destructive. RS is extremely information rich and is therefore a useful tool for chemical identification and the characterisation of the chemical structures of materials.

Raman scattering changes the polarisation of the molecules, resulting in an energy difference between the incident light and the measured light. These characteristic Raman peaks allow the spectroscopic separation of different molecules or identical molecules in different crystalline forms. The relative shift of Raman peaks is also an indicator to measure stress in semiconductor materials directly, non-destructively and quantitatively. Silicon carbide is a wide band gap semi-conductor material that is used increasingly for high voltage power devices. It has a higher breakdown field strength and better thermal conductivity than silicon however its hardness makes wafer processing difficult. We measure the effects on the SiC wafer of (i) mechanical processing (i.e. grinding of the backside); (ii) chemical and thermal processing (i.e. doping and annealing). We used confocal microscopy to measure the surface roughness of ground wafers and micro-Raman spectroscopy to measure the stresses induced in the wafers by grinding. SiC wafers with different dopings were studied before and after annealing. Depth resolved micro-Raman spectroscopy was used to observe how doping and annealing affect: i) the damage and stresses induced on the crystalline structure of the samples ii.) the concentration of free electrical carriers. Our results show that standard mechanical, chemical and thermal processing techniques have effects on this semiconductor material that can be observed and characterized using confocal microscopy and high resolution micro Raman spectroscopy.

Conference 10211: Compressive Sensing VI: From Diverse Modalities to Big Data Analytics

Wednesday - Thursday 12–13 April 2017

Part of Proceedings of SPIE Vol. 10211 Compressive Sensing VI: From Diverse Modalities to Big Data Analytics

10211-1, Session 1

Visual tracking with L1-Grassmann manifold modeling

Raj J. Muchhala, Panos P. Markopoulos, Andreas Savakis, Rochester Institute of Technology (United States)

We propose a new approach to visual tracking based on L1-Grassmann manifolds for object and background subspace modeling. Grassmann manifolds are smooth surfaces where points represent subspaces defined by orthogonal mappings and distances between subspaces can be measured by principal angles. They promote high class discrimination due to their geometrical structuring and accounting for missing data through subspace spanning. They have been used for object class recognition and for object tracking using principal angle distance calculations. In this work, we construct subspaces for the tracked object and the background using principal-component analysis (PCA). However, due to noise and occlusions encountered in unconstrained settings, traditional L2-PCA may suffer from the presence of outliers. We address this problem by working with L1-Grassmann manifolds where L1-PCA is used for subspace generation. Kernelization is utilized to map points on the L1-Grassmann manifold to a Hilbert space where distances between subspaces are calculated. We employ a fast algorithm for L1-principal component construction that is based on combinatorial optimization. Image patches representing the object and background from a set of recent frames are considered for constructing the respective L1-subspaces. Candidate image patches in the new frame are used to construct candidate L1-subspaces that are compared with the object and background subspaces to determine the new object location. Then the object and background subspaces are updated and the process is repeated. Experimental results on standard videos illustrate the effectiveness of the proposed method.

10211-2, Session 1

Characterizing L1-Norm best-fit subspaces

Paul Brooks, Jose Dula, Virginia Commonwealth Univ. (United States)

Fitting affine objects to data is the basis of many tools and methodologies in statistics, machine learning, and signal processing. The L1-norm is often employed to produce subspaces exhibiting a robustness to outliers and faulty observations. The L1-norm best-fit subspace problem is naturally formulated as a nonlinear, nonconvex, and nondifferentiable optimization problem. The case when the subspace is a hyperplane can be solved to global optimality efficiently by solving a series of linear programs. The problem of finding the best-fit line has recently been shown to be NP-hard. We present necessary conditions for optimality for the best-fit subspace problem, and use them to characterize properties of optimal solutions. These conditions yield insights about L1 projection, explain why the best-fit hyperplane has a workable solution while the best-fit line is intractable, and suggest strategies for estimating best-fit subspaces.

10211-3, Session 1

L1-norm principal-component analysis in L2-norm-reduced-rank data subspaces

Panos P. Markopoulos, Rochester Institute of Technology (United States); Dimitris A. Pados, Michael Langberg, Univ. at Buffalo (United States); George N. Karystinos, Technical Univ. of Crete (Greece)

The K L1-norm principal components (L1-PCs) of a real-valued data matrix $mathbf X in mathbb R^{Dtimes N}$ (N data samples of D dimensions) can be calculated exactly with cost $mathcal O (N^{dK - K +1})$, where d is the constant rank of $mathbf X$. In contrast to standard L2-norm principal-component analysis (L2-PCA), L1-PCA has been shown to identify data subspaces that contain minimal, if any, portion of the outliers that may exist in $mathbf X$. At the same time, the cost of exact L1-PCA renders it, arguably, impractical when the rank of the analyzed data matrix is very high (case of "heavy" data). In this work, we propose an algorithm that seeks to combine the low computational cost of L2-PCA with the outlier resistance of L1-PCA. Specifically, we first project $mathbf X$ on an L-dimensional L2-norm subspace ($K < L < d$) calculated with low cost by means of standard singular-value decomposition (SVD). Then, we approximate the L1-PCs of $mathbf X$ by the exact L1-PCs of the rank-L projected data, calculated with reduced cost $mathcal O (N^{LK - K +1})$. Through detailed theoretical analysis, we derive formal bounds for the approximation-error of the proposed reduced-rank L1-PCs. In addition, we demonstrate the superiority of reduced-rank L1-PCs over standard L2-PCs in processing potentially faulty/corrupted datasets with experiments on data dimensionality reduction and disease diagnosis from genomic data.

10211-4, Session 2

Sparse image reconstruction of targets in multilayered dielectric medium using total variation minimization

Wenji Zhang, Ahmad Hoorfar, Villanova Univ. (United States)

A layered media represents a more realistic and accurate model than a homogeneous background medium in many radar imaging applications. In particular, during the past decade, the imaging of targets embedded in multilayered dielectric media has attracted growing interest in microwave remote sensing, nondestructive testing, ground penetrating radar and urban sensing. To achieve high imaging resolution in these applications, a long aperture is synthesized with an ultra-wideband transmitted signal. This becomes impractical and costly in many realistic situations, and it is therefore important to reduce the data volume in radar imaging, as it accelerates processing and, subsequently, allows prompt actionable intelligence. In recent years, to meet these objectives many research groups have applied Compressive Sensing (CS) to radar imaging, SAR-based GPR, and SAR and MIMO based TWRI to reconstruct a sparse radar image from far fewer non-adaptive measurements. The standard CS techniques, however, are mainly based on L1-norm minimization which is primarily effective in detecting the presence of targets as it cannot accurately reconstruct the target shape and/or differentiate closely-spaced targets from an extended target. In this paper we present a sparse image reconstruction approach for radar imaging through multilayered background media with total variation minimization (TVM). TVM minimizes the gradient of the image resulting in better edge preservation and shape reconstruction than the standard L1-minimization based CS. In our approach, which in general is applicable to both GPR and TWRI cases, the multilayered media Green's function is incorporated in the imaging algorithm to fully account for all the wave propagation effects, and it is efficiently evaluated with saddle point method. Numerical results are presented to show high quality focused image of the targets buried under multilayered media and better edge preservation and shape reconstruction than the standard L1-minimization based sparse radar imaging approach.

10211-5, Session 2

Sparse recovery for nonstationarity detection in radar measurements

Satyabrata Sen, Oak Ridge National Lab. (United States); Murat Akcakaya, Malia Kelsey, Univ. of Pittsburgh (United States); Arye Nehorai, Washington Univ. in St. Louis (United States)

Most existing radar algorithms are developed under the assumption that the environment (clutter) is stationary. However, in practice, the characteristics of the clutter can vary enormously depending on the radar operational scenarios. If unaccounted for, these nonstationary variabilities may drastically hinder the radar performance. It is essential that the radar systems dynamically detect changes in the environment, and adapt to these changes by learning the new statistical characteristics of the environment. In this paper, assuming that the occurrence of nonstationarities in the clutter are infrequent in usual radar operation environments, we employ sparse recovery for anomaly detection, specifically to identify the statistical changes in the clutter. We use Monte Carlo simulations and compare the sparse recovery based nonstationary detection with other anomaly detection methods.

10211-6, Session 2

Computational / compressive methods for LWIR image de-blurring

Michael DeWeert, Ian B. Murray, BAE Systems (United States)

When the point-spread function (PSF) of an imaging system is non-trivial (i.e., not a delta function), the collected image is always a compressive representation of reality. The broader the PSF, the more ill-posed is the problem of inferring the true scene from the collected image. We investigated the use of methods developed for computational imaging (CI) and compressive sensing (CS) to improve the quality of blurred images collected with long-wave infrared (LWIR) imaging systems. We compare the CS approach to Tikhonov-regularized Fourier Transform (FT) deconvolution. The CS approach was enabled by re-casting the PSF in a sum of separable components. We show that both approaches significantly improve the image quality, as quantified by the modulation transfer function (MTF) of the de-blurred images. In the cases studied, regularized FT and CS methods performed equally well, significantly improving the MTF for spatial frequencies from DC to the Nyquist frequency of the focal plane, with the greatest improvement at spatial frequencies of ? Nyquist. We discuss possible conditions under which CS might provide superior performance to FT for de-blurring.

In the course of our investigations, we also developed a noise-robust means for using slanted-edges of opportunity in LWIR images to provide superior estimates of the system PSF. The methods incorporated regularized integral-equation methods to estimated edge-spread functions, avoiding noisy numerical differentiation, and eliminating the need for edge-blurring median filtering. We discuss applications of the noise-robust PSF estimates to cases in which image blur is due to extrinsic factors, such as atmospheric scattering.

10211-7, Session 2

Computational imaging through a fiber-optic bundle

John Paul Dumas, Muhammad Asad Lodhi, Mark C. Pierce, Waheed U. Bajwa, Rutgers, The State Univ. of New Jersey (United States)

Compressive sensing (CS) has proven to be a viable method for reconstructing high-resolution signals using low-resolution measurements. Integrating CS principles into an optical system allows for higher-resolution imaging using lower-resolution sensor arrays. In contrast to prior works on CS-based imaging, our focus in this paper is on fiber-optic bundle imaging in which manufacturing constraints limit individual fiber spacing to ~2 ?m. This limitation essentially renders the fiber bundle as a low resolution sensor with relatively few pixels (fibers) per unit area. These fiber bundles are often used in minimally-invasive medical instruments for viewing tissue at the macro- and microscopic levels. While the compact nature and flexibility of fiber bundles allow for excellent tissue access in vivo, the limited pixel density within these components prevents imaging of fine tissue structure that is demanded in some medical situations.

Our hypothesis is that adapting existing CS principles to fiber bundle based optical systems will overcome the resolution limitation inherent in fiber bundle imaging. In a recent paper we examined the practical implementation of a highly parallel version of the single pixel camera by imaging synthetic objects. This paper reports an extension of the same architecture for fiber-bundle imaging and addresses some practical issues associated with imaging real physical objects. Additionally, we incorporate the real-world optical aberrations and alignment errors inherent in the system to reduce image reconstruction errors. Finally, our experimental platform explores image formation under both coherent and incoherent illumination, permitting a comparative analysis of both conditions.

10211-8, Session 2

Compressive full waveform LIDAR

Jun Ke, Weiyi Yang, Beijing Institute of Technology (China)

Full waveform LIDAR can record the complete reflected signal from a scene. Thus it is more suitable for collecting information from complex scenarios such as forest. To record the signal, high bandwidth detector, fast speed A/D converter, and large size memory disk are required. These devices or elements are costly, heavy, and need large space. To avoid these issues, a compressive full waveform LIDAR system is studied in this paper.

In such a LIDAR system, a temporally modulated laser, instead of a pulsed laser, is used as the source. Then a scene is illuminated by the modulated light. The reflected signal becomes the convolution between the source light and the original scene ranging profile. A set of measurements collected by a low bandwidth detector and a slow A/D device are used for reconstruction.

Random binary patterns are used to modulate the source in this paper. Full waveform data from NEON (National Ecological Observatory Network) are used for simulation study. The LIDAR system used to collect the data is Riegl LMS Q780. With compressive full waveform LIDAR, to achieve 0.15m ranging resolution, instead of 1G sample per second (SPS) A/D converter, a 100MSPS converter is assumed to make measurements. Additive Gaussian noise is added into the measurements. Then the full waveform signal is reconstructed using its sparsity in Curvelet domains. OMP and linear Bregman algorithms are used for reconstruction.

10211-10, Session 3

Adaptive sparse-binary waveform design for all-spectrum channelization

George Sklivanitis, Univ. at Buffalo (United States); Panos P. Markopoulos, Rochester Institute of Technology (United States); Stella N. Batalama, Dimitris A. Pados, Univ. at Buffalo (United States)

In recent years, adaptively optimized binary code waveforms attracted considerable attention with applications in physical layer security, data hiding, and cognitive radio networking. In this work, we introduce for the first time maximum-SINR, sparse-binary waveforms that modulate data information symbols from any finite alphabet and span the whole continuum of the available/device-accessible spectrum. We present an

optimal algorithm that designs the proposed sparse-binary waveforms by maximizing the signal-to-interference-plus-noise ratio (SINR) at the output of the maximum-SINR linear filter at the receiver. In addition, we propose a computationally-efficient, iterative design suboptimal algorithm. Simulation studies compare the proposed sparse-binary waveforms with their conventional non-sparse counterparts and demonstrate their superior SINR performance. The post-filtering SINR improvements attained by the proposed waveform design are also experimentally verified in a software-defined radio testbed of a single-input single-output (SISO) communication system operating in a multipath laboratory environment and in presence of colored interference.

10211-11, Session 3

Multiplication free neural network for cancer stem cell detection in H&E stained liver images

Ahmet Enis Çetin, Maen Mallah, Diaa Badawi, Bilkent Univ. (Turkey); Rengul Cetin-Atalay, Middle East Technical Univ. (Turkey)

Recently, it is shown that L1 norm based methods produce better results than L2 norm based results in many practical signal, image and video processing problems. This is because L1 based representations lead to sparse models. In recent signal, image and video processing algorithms, L1 norm is used as a regularization parameter or the solution is constrained to be in an L1 ball. In this paper, we will present an artificial neural network (ANN) based on a new vector operator which induces the L1 norm. Let a and b be two real numbers. The new operator is defined as follows: a?b=sign(axb)(|a|+|b|).

Another related operator is a?b=sign(axb)(max(|a|,|b|).

Vector products based on the above operators are defined as follows:

< x,y>=Sum_i x_i ? y_i .

The above vector product induces the L1 norm [1]. It is well-known that inner product computations are carried out in each artificial neuron. A computationally efficient (or energy efficient) neural network can be developed by replacing the inner product operation with the vector product defined above. Resulting ANNs do not need to perform any multiplications. As a result, they are not only computationally more efficient than ordinary ANNs but also energy efficient. This is an important advantage in big data sets. We tested the multiplication-free ANN to detect cancer stem cells in Hematoxilin & Eosin (H&E) stained liver tissue images. Kernels of such cells appear darker than other cell kernels in H&E stained liver images. We achieved a recognition accuracy of 94% in our data set. Reference: [1] C.E. Akbas, A. E. Cetin, Energy Efficient Cosine Similarity Measures According to a Convex Cost Function", to appear in Signal, Image and Video Processing, Springer 2017.

10211-12, Session 3

Artifact detection in electrodermal activity signals using sparse recovery

Malia Kelsey, Murat Akcakaya, Ervin Sejdic, Univ. of Pittsburgh (United States)

Electrodermal Activity (EDA) – a measure of sympathetic nervous system arousal - is one of the primary methods used in psychophysiology to study the autonomic nervous system. EDA is widely accepted as an indicator of arousal, as it has been shown to reveal when psychologically novel events occur. Many historical studies collect EDA data through laboratory experiments, however, recent developments in wireless biosensing have allowed for longer, out-of-lab studies to become more common. The transition to ambulatory collected data has introduced challenges with artifact, such as wearer motion, changes in temperature, and electrical interference, being identified as a true skin conductance responses (SCRs). Being unable to distinguish an artifact from an SCR may hindered the overall analysis of EDA data, therefore, the interest in developing automated systems that can be used to facilitate the identification of artifacts in EDA signals has increased in the recent years. The current state-of-the-art EDA analysis systems do not have the ability to distinguish between SCRs and artifacts and while other methods, such as SVM or sparse recovery, have been proposed and shown as viable methods to distinguish between SCRs and artifacts, these have yet to be incorporated into an automated system and require manual clean-up before further analysis can be completed. This manuscript presents a novel technique to automatically identify and remove artifacts using curve fitting and sparse recovery methods. Our method was evaluated using labeled data to determine the accuracy of artifact identification.

10211-13, Session 3

Superpixel sparse representation for target detection in hyperspectral imagery

Chunhua Dong, Masoud Naghedolfeizi, Dawit Aberra, Hao Qiu, Xiangyan Zeng, Fort Valley State Univ. (United States)

Sparse Representation (SR) is an effective classification method. Given a set of data vectors, SR aims at finding the sparsest representation of each data vector among the linear combinations of the bases in a given dictionary. In order to further improve the classification performance, the joint SR that incorporates interpixel correlation information of neighborhoods or patches has been proposed for image pixel classification. However, SR and joint SR demand significant amount of computational time and memory, especially when classifying a large number of pixels. To address this issue, we propose a superpixel sparse representation (SSR) algorithm for target detection in hyperspectral imagery. The SSR algorithm firstly clusters hyperspectral pixels into nearly uniform hyperspectral superpixels based on their spectral and spatial information. The sparse representations of the superpixels are then obtained by simultaneously decomposing superpixels over a given dictionary consisting of both target and background pixels. The class of a hyperspectral pixel is determined by a competition between its projections on target and background subspaces. One key advantage of the proposed superpixel representation algorithm with respect to pixelwise and patch-based sparse representation algorithms is that it reduces computational cost while still maintaining competitive classification performance. We demonstrate the effectiveness of the proposed SSR algorithm through experiments on target detection in the in-door and out-door scene data under daylight illumination as well as the remote sensing data. Experimental results show that SSR generally outperforms state of the art algorithms both quantitatively and qualitatively.

10211-21, Session 3

Defect classification in sparsity-based structural health monitoring

Andrew L. Golato, Villanova Univ. (United States); Fauzia Ahmad, Temple Univ. (United States); Sridhar Santhanam, Moeness G. Amin, Villanova Univ. (United States)

Use of guided waves has gained popularity in structural health monitoring (SHM) due to their ability to inspect large areas with little attenuation and to provide rich interactions with any defects present. When the structural member is a thin plate or shell-like structure, the propagating waves are Lamb waves, which are a complex but well understood type of guided wave. Sparse reconstruction approaches have recently been employed for defect localization in SHM under the assumption of point-like defects. However, most structural defects are not perfect points but tend to take specific forms, such as surface cracks, internal cracks, and delaminations. Knowledge of the 'type' (class) of defect is useful in the assessment phase of SHM. In this paper, we present a multi-modal sparsity-based defect classification scheme which, in addition to accurately localizing defects, properly labels

the types of defects present. The proposed approach takes advantage of the bias that certain defect types have toward specific wave modes. For example, some defects strongly interact with the antisymmetric modes, while others respond well to symmetric modes. In this work, we build model based dictionaries for the fundamental symmetric and antisymmetric wave modes. These dictionaries are then utilized in unison within a sparse reconstruction framework to properly localize and classify the defects present. Simulated data of extended surface and internal defects in a thin Aluminum plate are used to validate the proposed classification scheme.

10211-14, Session 4

Performance analysis of sparsity-based interpolation for DOA estimation with non-uniform arrays

Elie Bou Daher, Villanova Univ. (United States); Fauzia Ahmad, Temple Univ. (United States); Moeness G. Amin, Villanova Univ. (United States)

We recently proposed a sparsity-based interpolation technique to extend the usable portion of the difference coarrays corresponding to partially augmentable non-uniform arrays for direction-of-arrival (DOA) estimation. The degrees-of-freedom (DOFs) offered by partially augmentable non-uniform arrays cannot be fully utilized for subspace-based DOA estimation due to the presence of holes in the corresponding difference coarray. The proposed interpolation approach is first employed to fill the holes in the difference coarray, thereby increasing the available DOFs. MUSIC with spatial smoothing is then applied to the combined set of actual and interpolated measurements for direction finding. In this paper, we conduct an in-depth performance analysis of the sparsity-based interpolation technique using co-prime array structures. The performance of the interpolation scheme is also compared and contrasted with the multi-frequency approach for filling the holes in the coarray.

10211-15, Session 4

Optimum antenna placements for non-uniform arrays in interference-free environment

Xiangrong Wang, Moeness G. Amin, Villanova Univ. (United States)

Although the nominal array configuration is uniform, sparse arrays have recently emerged to play a fundamental role in sensing systems involving multi-antenna transmitters and receivers. Structured sparse and random arrays have been shown to offer high resolution direction finding and flexibility in beamforming design and specifications. In this paper, we consider optimum array configurations for adaptive beamforming in interference-free environment. Optimality is defined as the maximum output signal to noise ratio (SNR) in lieu of other metrics used for array configurations, such as super resolution and the Cramer-Rao Bound (CRB). The two measures of maximum output SNR and equal gains towards all sources incident on the array are considered for the optimum array design. As it is computationally exhaustive to enumerate all configurations and implement eigenvalue decomposition, we propose an iterative linear fractional programming method to maximize the relaxed spectral norm of the source correlation matrix. The paper compares the proposed optimum nonuniform array with uniform linear arrays and structured co-prime and nested arrays with the same number of physical antennas for adaptive beamforming in interference-free environments. It exhibits the performance gain achieved by optimum placements of the antennas on the available spatial grid points. Simulation examples also confirm that the array configuration plays a vital role in determining the adaptive beamforming performance in interference-free scenarios. The selected optimum subarrays achieve maximum performance preservations with a dramatically reduced computational and hardware cost.

10211-16, Session 4

A novel hybrid total variation minimization algorithm for compressed sensing

Hongyu Li, Univ. at Buffalo (United States); Yong Wang, Xidian Univ. (China); Dong Liang, Shenzhen Institutes of Advanced Technology (China); Leslie Ying, Univ. at Buffalo (United States)

Compressed sensing (CS) is a technology to acquire and reconstruct sparse signals below the Nyquist rate. For images, total variation of the signal is usually minimized to promote sparseness of the image in gradient. However, similar to all L1-minimization algorithms, total variation has the issue of penalizing large gradient, thus causing large errors on image edges. Many non-convex penalties have been proposed to address the issue of L1 minimization. For example, homotopic L0 minimization algorithms have shown success in reconstructing images from magnetic resonance imaging (MRI). Homotopic L0 minimization may suffer from local minimum which may not be sufficiently robust when the signal is not strictly sparse or the measurements are contaminated by noise. In this paper, we propose a hybrid total variation minimization algorithm to integrate the benefits of both L1 and homotopic L0 minimization algorithms for image recovery from reduced measurements. The algorithm minimizes the conventional total variation when the gradient is small, and minimizes the L0 of gradient when the gradient is large. The transition between L1 and L0 of the gradients is determined by an auto-adaptive threshold. The proposed algorithm has the benefits of L1 minimization being robust to noise/approximation errors, and also the benefits of L0 minimization requiring fewer measurements for recovery. Experimental results using MRI data are presented to demonstrate the proposed hybrid total variation minimization algorithm yields improved image quality over other existing methods in terms of the reconstruction accuracy.

10211-17, Session 4

Low-rank matrix recovery for dynamic events

Salman Asif, Univ. of California, Riverside (United States)

Low-rank matrix recovery problems arise in a variety of scientific and engineering applications. For instance, blind deconvolution in signal processing and communication, phase retrieval in computational imaging, and recommendation systems in machine learning.

In this paper, we present an algorithm for reconstructing a time-varying low-rank matrix from sequential measurements. We assume that the signal under observation evolves according to a dynamic model. In particular, we study video reconstruction in which adjacent frames are related to each other via a motion-based dynamic model. We present an algorithm for estimating video frames from dynamic measurements while simultaneously refining the motion parameters of the dynamic model.

We will discuss two applications of our proposed model and algorithm:

(1) Beyond diffraction imaging: Phase retrieval of a video signal, where we sequentially record coded, low-resolution intensity images of a complex-valued high-resolution video signal.

(2) Auto-calibration in MRI: Blind deconvolution of a video signal, where we sequentially record Fourier samples of video frames modulated by coil sensitivities.

We will first present how these problem can be posed as recovery of a time-varying rank-one matrix. Then we present our rank-one matrix recovery algorithm that includes motion estimation. We demonstrate the performance of our proposed method on real and synthetic data.

10211-9, Session 5

Real time network traffic monitoring for wireless local area networks based on compressed sensing

Mohammadreza Balouchestani, Indiana Univ.-Purdue Univ. Fort Wayne (United States)

A Wireless Local Area Network (WLAN) is a wireless computer network that can use either infrared or radio frequency technology to transmit and receive information over the air in order to link a set of computers using a wireless distribution method. WLANs have become popular for use in many application such as the home, school, computer laboratory, industrial automation, and office building. In order to improve the performance of a WLAN, we need to minimize network traffic, load of sampling-rate, and power consumption. Real Time Networking Traffic Monitoring (RTNTM) is an important parameter to improve the Quality of Service (QoS) for all users. In this paper, Compressed Sensing (CS) approach is applied to WLANs in order to minimize load of sampling-rate as well as network traffic. Then, a new RTNTM method for WLANs based on CS is established. The new RTNTM method has the following advantage:

- Manage and control bandwidth of each user and application.

- Graphically display routing metrics, network performance metrics in real time based on dynamic routing protocol.

The proposed RTNTM architecture allows reducing sampling-rate as well as network traffic. In addition, the proposed algorithm out-performs existing algorithms by improving QoS in WLANs.

10211-18, Session 5

Performance bounds for modal analysis using sparse linear arrays

Yuanxin Li, Ohio State Univ. (United States); Ali Pezeshki, Louis Scharf, Colorado State Univ. (United States); Yuejie Chi, Ohio State Univ. (United States)

We study the performance of modal analysis using sparse linear arrays (SLAs) such as nested and co-prime arrays, in both first-order and second-order measurement models. We treat sparse linear arrays as constructed from a subset of sensors in a dense uniform linear array (ULA), and characterize the performance loss of SLAs with respect to the ULA due to using much fewer sensors. In particular, we argue that, provided the same aperture, in order to achieve comparable performance in terms of Cramer-Rao Bound (CRB) for modal analysis, SLAs requires more snapshots, that are about the number of snapshots required by ULA times the compression ratio in the number of sensors. This is shown analytically for the case with one undamped mode, as well as empirically via extensive numerical experiments for more complex scenarios. Moreover, the misspecified CRB proposed by Richmond and Horowitz is also studied, where SLAs suffer more performance loss than their ULA counterpart.

10211-19, Session 5

A smoothing gradient-based algorithm for training max-product neural networks and its convergence analysis

Long Li, Hengyang Normal Univ. (China); Zhijun G. Qiao, The Univ. of Texas Rio Grande Valley (United States)

In this paper, a smoothing algorithm based on gradient method is proposed to train max-product neural network. The basic idea of this method stems from nondifferentiable optimization via smooth approximation. The main drawbacks when directly employing gradient method are the efficiency of numerical computation and theoretical analysis. To overcome these obstacles, a smoothing function is introduced to approximate the output of max-product neural network. The monotonicity of the cost function and the deterministic convergence of the smoothing algorithm are rigorously proved. Numerical examples for solving fuzzy relation equations are given to demonstrate the efficiency of the algorithm and to support the theoretical findings.

10211-20, Session 5

Role of positivity in blind deconvolution

Piya Pal, Heng Qiao, Univ. of California, San Diego (United States)

Blind deconvolution is an important problem arising in many engineering and scientific applications, ranging from imaging, communication to computer vision and machine learning. Classical techniques to solve this highly ill posed problem exploit statistical priors on the signals of interest. In recent times, there has been a renewed interest in deterministic approaches for blind deconvolution, whereby, using the novel idea of "lifting", the non-convex blind deconvolution problem can be cast as a semidefinite program. Using suitable subspace assumptions on the unknown signals, precise theoretical guarantees can be derived on the number of measurements needed to perform blind deconvolution. In this paper, we will address the problem of positive sparse blind deconvolution, where the signals of interest exhibit positivity (alongside sparsity) either naturally, or in appropriate transform domains. Important applications of positive blind deconvolution include image deconvolution and positive spike detection. We will show that positivity is a powerful constraint that can be exploited to cast the blind deconvolution problem in terms of a simple linear program that can be theoretically analyzed. We will explore the questions of uniqueness and identifiability, and develop conditions under which the linear program reveals the true positive sparse solution. Numerical results will demonstrate the superior performance of the proposed approach.

10211-22, Session 5

Real-time network traffic classification technique for wireless local area networks based on compressed sensing

Mohammadreza Balouchestani, Indiana Purdue Univ. Fort Wayne (United States)

Classification of network traffic in a Wireless Local Area Network (WLAN) is a strong tool that helps identify different applications and protocols that exist in a wireless network. Various actions, such as monitoring, discovery, control, and optimization can then be performed on the identified network traffic for improving the network performance. WLAN's Network traffic is the main component for network traffic measurement, network traffic control and simulation. Traffic classification technique is an essential tool for wireless networks in the complex applications such as local area networks, wireless local area networks, wireless personal area networks, wireless metropolitan area networks, and wide area networks. Network traffic classification is also an essential component in the products for Quality of Service (QoS) control in different wireless network systems and applications. Traditional traffic classification techniques rely on Shannon Nyquist Sampling (SNS) procedure which suffer from huge load of sampling and power consumption. This paper presents a Real-time Network Traffic Classification (RNTC) algorithm for WLANs based on Compressed Sensing (CS). The fundamental goal of this algorithm is to solve difficult wireless network management problems. The proposed architecture allows reducing False Detection Rate (FDR) to 25% and Packet Delay (PD) to 15 %. The proposed architecture is also increased accuracy to 10 % which provides good background for establishing high qualified wireless local area networks.

Conference 10212: Advanced Photon Counting Techniques XI

SPIE. DCS COMMERCIAL+SCIENTIFIC SENSING AND IMAGING

Wednesday - Thursday 12–13 April 2017

Part of Proceedings of SPIE Vol. 10212 Advanced Photon Counting Techniques XI

10212-1, Session 1

Calibration of a single-photon counting detectors without the need of input photon flux calibration *(Invited Paper)*

Thomas Gerrits, National Institute of Standards and Technology (United States)

Calibration of fiber-coupled single-photon detectors usually requires knowledge of the input photon flux inside the fiber and/or knowledge of the linearity of a reference power meter. Many approaches have been presented in the past to accurately measure the photon detection probability of a single photon detector [1-6]. Under certain assumptions, one can utilize waveguide-coupled single photon detectors and a series of photon-counting measurements and a single-photon source to calibrate the detection efficiency of a single photon detector without the need of a reference power meter and the knowledge of the incoming photon flux. Here, this method is presented. Furthermore, if a reference detector is used, the detection efficiency of all evanescently coupled waveguide detectors can be measured, and the measurement outcome does not depend on splicing or fiber connection losses within in the setup, i.e., the measurement is setup-independent. In addition, the method, when using a reference detector, can be utilized to measure and distinguish between the absorption of a waveguide-coupled single photon detector and its internal detection efficiency.

[1] A. J. Miller et al, Opt. Express 19, 9102–9110 (2011)

[2] I. Muller et al., Metrologia 51, S329 (2014).

[3] A. L. Migdall, Instrumentation and Measurement, IEEE Transactions on 50, 478–481 (2001).

[4] S. V. Polyakov, A. L. Migdall, Optics Express 15, 1390–1407 (2007).

[5] A. Avella et al., Optics Express 19, 23249–23257 (2011).

[6] T. Lunghi et al., Opt. Express 22, 18078-18092 (2014)

10212-2, Session 1

Photonic quantum information and quantum metrology *(Invited Paper)*

Shigeki Takeuchi, Kyoto Univ. (Japan)

Quantum information science has been attracting significant attention recently. It harnesses the intrinsic nature of quantum mechanics such as quantum superposition, the uncertainty principle, and quantum entanglement to realize novel functions. Recently, quantum metrology is emerging as another appealing application of quantum information science. In this talk, we will report our recent progresses on the development of novel quantum entangled-photon sources [1] and application to quantum measurements, including an entanglement enhanced microscope beating the standard quantum limit [2,3]. We will also report the application to quantum optical coherence tomography [4]. Here we report on the realization of 0.54 ?m resolution two-photon interference, which surpasses the current record resolution 0.75 ?m of low-coherence interference for OCT. In addition, the resolution for QOCT showed almost no change against the dispersion of a 1 mm thickness of water inserted in the optical path, whereas the resolution for OCT dramatically degrades.

[1] S. Takeuchi, Jpn. J. Appl. Phys. 53 (2014) 030101.

[2] T. Ono, R. Okamoto, and S. Takeuchi, Nature Communications 4 (2013) 2426.

[3] T. Nagata, R. Okamoto, J. L. O'Brien, K. Sasaki and S. Takeuchi, Science 316, (2007) 726.

[4] M. Okano, H. H. Lim, R. Okamoto, N. Nishizawa, S. Kurimura and S. Takeuchi, Sci. Rep. 5, (2015) 18042.

10212-3, Session 1

Nearly-noiseless quantum frequency bridge *(Invited Paper)*

Ivan A. Burenkov, Yu-Hsiang Cheng, Sergey V. Polyakov, National Institute of Standards and Technology (United States)

We demonstrate an efficient, phase-preserving and inherently ultra-low noise parametric frequency up-converter. We report conversion efficiency as high as 53% with no signs of saturation (i.e. theoretically this efficiency can reach 100%). Owing to a lower energy of pump photons, and employing large spectral separation between the input and the pump frequencies, the up-conversion results in about 100 background photons per hour. We note an unprecedented dynamic range of this arrangement: it is capable of handling photon fluxes of as few as 10 photons per minute and up to 10^16 photons per second with no adjustments needed. In addition, we demonstrated high fidelity phase preservation, with fringe visibility of ≈0.98. Thus, this up-converter can faithfully convert a broad range of non-classical and entangled states. It can also enhance the range of efficient low-darkcount detection, because the energy of the output photons is significantly higher than that of the input photons. To reach accuracy required for this measurement, we introduced a darkcount reduction algorithm for a transition edge sensor. To our knowledge, these noise measurements demonstrate a new level in faint light source intensity measurement, providing better accuracy in a 100 times shorter measurement (as compared to Hubble Space Telescope extremely deep field data).

10212-4, Session 2

Fundamental limits for single photon detection *(Keynote Presentation)*

Prem Kumar, Defense Advanced Research Projects Agency (United States)

No Abstract Available

10212-5, Session 2

Quantum avalanche detection science *(Invited Paper)*

Joe C. Campbell, Olivier Pfister, Andreas Beling, Univ. of Virginia (United States); Seth R. Bank, The Univ. of Texas at Austin (United States)

No Abstract Available

10212-6, Session 2

Photon detection with an ultra low noise and highly efficient amplification mechanism *(Invited Paper)*

Yu-Hwa Lo, Univ. of California, San Diego (United States)

No Abstract Available

10212-7, Session 2

Bio-inspired photon detection using chromophore/nanotube hybrids *(Invited Paper)*

François Léonard, Sandia National Labs. (United States)

The human eye is an exquisite optical system with the ability to detect individual photons at room temperature. However, the complexity of this system, optimized over millions of years, has been difficult to reproduce using synthetic techniques. Here we discuss a bio-inspired approach for photon detection based on chromophore/nanotube hybrids, where the chromophore plays a similar role to the retinal molecule in the human eye, and the signal transduction is provided by electronic transport in the carbon nanotube. In this presentation, I will present the concept and discuss our progress in realizing this type of photodetection mechanism.

10212-8, Session 3

Prospects and fundamental limitations of room temperature, non-avalanche, semiconductor photon-counting sensors *(Invited Paper)*

Jiaju Ma, Thayer School of Engineering at Dartmouth (United States); Seyed Amir Ghetmiri, Univ. of Arkansas (United States); Xiaoxin Wang, Thayer School of Engineering at Dartmouth (United States); Lei Ying, Univ. of Wisconsin-Madison (United States); Zhiyuan Wang, Wei Deng, Thayer School of Engineering at Dartmouth (United States); Yang Zhang, Rahul Kumar, Yang Wu, Univ. of Arkansas (United States); Zongfu Yu, Univ. of Wisconsin-Madison (United States); Shui-Qing Yu, Gregory J. Salamo, Univ. of Arkansas (United States); Eric R. Fossum, Jifeng Liu, Thayer School of Engineering at Dartmouth (United States)

This research investigates the fundamental limits and trade-space of quantum semiconductor photodetectors using the Schrödinger equation and the laws of thermodynamics.We envision that, to optimize the metrics of single photon detection, it is critical to maximize the optical absorption in the minimal volume and minimize the carrier transit process simultaneously. Integration of photon management with quantum charge transport/redistribution upon optical excitation can be engineered to maximize the quantum efficiency (QE) and data rate and minimize timing jitter at the same time. Due to the ultra-low capacitance of these quantum devices, even a single photoelectron transfer can induce a notable change in the voltage, enabling non-avalanche single photon detection at room temperature as has been recently demonstrated in Si quanta image sensors (QIS). In this research, uniform III-V quantum dots (QDs) and Si QIS are used as model systems to test the theory experimentally. Based on the fundamental understanding, we also propose proof-of-concept, photon-managed quantum capacitance photodetectors. Built upon the concepts of QIS and single electron transistor (SET), this novel device structure provides a model system to synergistically test the fundamental limits and tradespace predicted by the theory for semiconductor detectors.

This project is sponsored under DARPA/ARO's DETECT Program: Fundamental Limits of Quantum Semiconductor Photodetectors.

10212-9, Session 3

super.DETECT: Superconducting nanowire single-photon detector theory and development *(Invited Paper)*

Jason Allmaras, Jet Propulsion Lab. (United States); Lucy Archer, Karl K. Berggren, Massachusetts Institute of Technology (United States); Francesco Bellei, Andrew D. Beyer, Jet Propulsion Lab. (United States); Andrew E. Dane, Massachusetts Institute of Technology (United States); Peter Day, Jet Propulsion Lab. (United States); Alexander G. Kozorezov, Lancaster Univ. (United Kingdom); Leonid S. Levitov, Massachusetts Institute of Technology (United States); Francesco Marsili, Matthew D. Shaw, Jet Propulsion Lab. (United States); Emily A. Toomey, Qingyuan Zhao, Di Zhu, Massachusetts Institute of Technology (United States)

No Abstract Available

10212-10, Session 4

Superconducting nanowire single photon detectors based on amorphous superconductors *(Invited Paper)*

Boris Korzh, Misael Caloz, Univ. de Genève (Switzerland); Jelmer Renema, Univ. of Oxford (United Kingdom); Richard J. Warburton, Christian Schönenberger, Univ. Basel (Switzerland); Hugo Zbinden, Félix Bussières, Univ. de Genève (Switzerland)

Superconducting nanowire single photon detectors (SNSPD) made from amorphous superconductors have showed great promise for achieving high fabrication yields, due to the highly uniform nature of the films. We present progress on the development of SNSPD based on amorphous MoSi with a critical temperature of around 5 K, which is ideal for detector operation at temperatures of 1 – 2.5 K, accessible with widely available cryogenic systems. First generation devices have achieved a saturated internal efficiency from visible to near-infrared wavelengths, which is the first requirement for high overall system efficiency. The broadband response has allowed us to make a robust study the energy-current relation in these devices, which defines the current required for a saturated internal detection efficiency for a given incident photon energy. Contrary to previous studies with other material systems, we find a nonlinear energy-current relation, which is an important insight into the detection mechanism in SNSPDs. The latest generation devices have been embedded into an micro-cavity structure in order to increase the system detection efficiency, which has increased to over 65% at 1550 nm. The efficiency is believed to be limited by fabrication imperfections and we present ongoing progress towards improving this characteristic as well as the yield of the devices. Efforts are also being made towards increasing the maximum operating temperature of the devices.

10212-11, Session 4

Superconducting nanowire single photon detectors for infrared imaging and sensing *(Invited Paper)*

Robert H. Hadfield, Nathan R. Gemmell, Alessandro Casaburi, Univ. of Glasgow (United Kingdom)

Over the past decade, superconducting nanowire single photon detectors (SNSPDs) have emerged as a key enabling technology for advanced infrared photon counting applications. SNSPDs offer single photon sensitivity from visible to mid infrared wavelengths with high efficiency, low dark counts, short recovery times and low timing jitter. A challenge for the community is to scale up SNSPDs from single pixel devices to large area arrays. I will report progress on large area SNSPD fabrication and novel readout schemes. I will discuss the demands of emerging single photon imaging and sensing applications and recent demonstrations. I will also discuss progress in miniaturized closed cycle cooling systems for SNSPDs.

10212-26, Session PWed

Ultraviolet intensified CMOS camera for single photon detection

Yun-sheng Qian, Xiaoyu Zhou, Hua Xu, Yan Wang, Nanjing Univ. of Science and Technology (China)

Ultraviolet detection technology has been widely focused and adopted in the fields of ultraviolet warning and corona detection for its significant value and practical meaning. The paper studied on the component structure of ultraviolet ICMOS, imaging driving and the photon counting algorithm. Firstly, the one inch and wide dynamic range CMOS chip with the coupling optical fiber panel are coupled to the ultraviolet image intensifier. The ultraviolet image intensifier adopts Te-Cs photocathode, which contributes to the solar blind performance, and the dual micro-channel plates (MCP) structure ensures the sufficient gain to achieve the single photon counting. Afterwards, in consideration of the ultraviolet detection demand, the drive circuit of the CMOS chip is designed and the corresponding program based on Verilog language is written. According to the characteristics of ultraviolet imaging, the histogram equalization method is applied to enhance the ultraviolet image and the connected components labeling way is utilized for the ultraviolet single photon counting. Moreover, one visible light video channel is reserved in the ultraviolet ICOMS camera, which can be used for the fusion of ultraviolet and visible images. Based upon the module, the ultraviolet optical lens and the deep cut-off solar blind filter are adopted to construct the ultraviolet detector. At last, the detection experiment of the single photon signal is carried out, and the test results are given and analyzed.

10212-27, Session PWed

Characterizing the Nash equilibria of three-player Bayesian quantum games

Neal Solmeyer, Radhakrishnan Balu, U.S. Army Research Lab. (United States)

Quantum games with incomplete information can be studied within a Bayesian framework. We analyze three-player Bayesian quantum games with a completely unrestricted space of strategy choices. We find and characterize the Nash equilibria of the games. The equilibria are found to have a phase diagram-like structure, depending on the amount of uncertainty and the degree of entanglement. In some cases the quantized version of a game to have an advantage over the classical version. Thus a deeper understanding of Bayesian quantum game theory could lead to novel quantum applications in a multi-agent setting.

10212-31, Session PWed

Software-defined network abstractions and configuration interfaces for building programmable quantum networks

Venkateswara R. Dasari, U.S. Army Research Lab. (United States); Ronald J. Sadlier, Oak Ridge National Lab. (United States); Nikolai Snow, U.S. Army Research Lab. (United States); Brian P. Williams, Travis S. Humble, Oak Ridge National Lab. (United States)

Unified control plane abstractions and interface definitions play a significant role in realizing a reliable network transport for quantum applications. A programmable protocol like OpenFlow for software-defined networking could be an ideal candidate for encoding the new abstractions in support of quantum networks and applications. In this project, we take leverage of new OpenFlow which supports various optical network labels to control optical networks and we encode new controller modules to support quantum networks and applications. Additionally, we also propose OpenFlow extensions to introduce network abstractions, to support new tables to hold quantum network and application attributes along with new table type patterns, and finally to introduce new match-action rules specific to quantum information being send over the network. We also show how the modified OpenFlow can be used to create a quantum memory agnostic programmable quantum network topology. We use numerical simulation of network behavior for both the quantum and classical channels that can be used to validate these specifications. We also report on work toward realizing these ideas in an experimental quantum optical network application.

10212-33, Session PWed

Markov chains based quantum walks

Chaobin Liu, Bowie State Univ. (United States); Radhakrishnan Balu, U.S. Army Research Lab. (United States); Salvador Elias Venegas-Andraca, Tecnológico de Monterrey (Mexico)

We analyze the probability distributions of the quantum walks induced from Markov chains by Szegedy. The first part of this talk is devoted to the quantum walks induced from finite Markov chains. It is shown that the probability distribution on the states of the underlying Markov chain is always convergent in the Cesaro sense. In particular, we deduce that the limiting distribution is uniform if the transition matrix is symmetric. In the cases of non-symmetric Markov chain, we exemplify that the limiting distribution of the quantum walk is not necessarily identical with the stationary distribution of the underlying irreducible Markov chain. The Szegedy scheme can be extended to an infinite state space (infinite Markov chains/random walks). In the second part, we formulate the quantum walks induced from a lazy random walk on the line. We then obtain the weak limit of the quantum walks. It is noted that the quantum walks appears to spread faster than its counterpart-quantum walks on the line driven by the Grover coin discussed in literature. The talk closes with an outlook on possible future directions.

10212-12, Session 5

Fully industrialised single photon avalanche diodes *(Invited Paper)*

Sara Pellegrini, Bruce R. Rae, STMicroelectronics (United Kingdom)

Single Photon Avalanche diodes (SPADs) were first realised more than five decades ago [1965, Haitz], and have now been industrialized for mass

production in the 130 nm CMOS technology node by STMicroelectronics (STM). The STM SPAD shows an excellent NIR photon detection probability (>5% at 850nm), with a dark count rate median of 200 cps at room temperature and a low breakdown voltage of 14.2V. The dead time of the SPAD is approximately 25 ns, leading to a maximum count rate of 40 Mcps.

Thanks to the 130 nm gate length of the CMOS technology used and the associated high digital gate density, features such as an embedded MCU have been included. While the low bias required by the SPAD allows for voltage generation to be done by on-chip charge pumps, the chip also includes the VCSEL driver with closed timing, resulting in a full system-on-chip. When packaged with a stand-alone VCSEL source a full time-of-flight system has been realised within a single module measuring just 4.8 x 2.8 x 1mm.

Our first generation time-of-flight system is capable of ranging up to 60 cm in 60 ms, and its most recent evolution can reach up to 200 cm in 30ms with millimetre accuracy. Ranging capabilities and accuracy are measured using a set of moving targets with reflectance of 5%, 17% and 88% in a fully automated test bed.

To our knowledge this is the only CMOS SPAD-based mass market ranging device available today.

10212-13, Session 5

Single photon counting detectors with high efficiency and tailorable spectral response for space and terrestrial applications *(Invited Paper)*

Shouleh Nikzad, Jet Propulsion Lab. (United States) and California Institute of Technology (United States)

An abundance of atomic and molecular absorption lines exist in the ultraviolet spectral range rendering UV a powerful diagnostic probe. A UV probe might be focused on living cells, pointed to deep space to study the intergalactic medium or exo-solar planetary atmospheres, or it might be used as a tool in a criminal investigations. Lines and bands from H, C, O, N, S, OH and CO, absorption lines by CO2, H2O, NH3, N2, and UV reflectance spectra are key for the detection of many oxides, organics, and other compounds. UV spectroscopy is used for studying galaxies, stars, planets and their satellites such as Enceladus and Europa. Hubble space Telescope's UV spectrometer recently revealed further observations of Europa's plumes of water and the Cassini mission has shown similar measurements on Enceladus. These exciting discoveries will be further investigated, at least in the case of Europa, in a mission that is under design. In addition to space applications, UV is used in cancer detection, tissue delineation, wafer inspection, lithography, defense applications, and electrical safety inspection.

Many UV detection applications are challenging due to weak signals and strong visible and infrared backgrounds. In such cases, photon-counting detectors with tailorable response are required. Nanoscale engineering of detector materials enables powerful new UV detectors that are smaller, more efficient and reliable than previous generations of detectors based on cesiated photocathodes, such as microchannel plates and photomultiplier tubes. We will discuss our development of solid-state, photon counting UV/optical imaging detectors and will present our latest results.

10212-14, Session 5

Free-running InGaAs/InP single-photon avalanche diodes with 50 ps timing jitter *(Invited Paper)*

Gianluca Boso, Emna Amri, Boris Korzh, Hugo Zbinden, Univ. de Genève (Switzerland)

In recent years, many applications have been proposed that require detection of light signals in the near-infrared (NIR) range with single-photon sensitivity and time resolution below 100 ps; notably laser ranging, biomedical imaging, quantum key distribution (QKD) and quantum information and communication experiments. The current state of the art in terms of timing resolution in the NIR range is a jitter below 20 ps achieved by superconducting nanowire single-photon detector (SNSPD). A more practical and compact alternative that does not require cryogenic cooling is represented by InGaAs/InP single-photon avalanche diodes (SPADs). Indeed, gated-mode SPADs can achieve a timing resolution below 50 ps at relatively high excess biases (above 7 V). However, despite their good performance in terms of photon detection efficiency, dark count rate and timing resolution, standard InGaAs/InP SPADs are limited by their afterpulsing noise to gated-mode operation, thus precluding their use in many applications.

Negative-feedback avalanche diodes (NFADs) are a special structure of InGaAs/InP SPADs where a monolitically-integrated quenching resistor is used to reduce the afterpulsing noise contribution hence allowing free-running operation. Here, we present our recent results on the characterization of the timing response of different NFAD detectors for temperatures down to 143 K that demonstrate how NFADs can achieve timing jitter down to 50 ps in an extended range of operating conditions.

10212-15, Session 5

Progress in low light-level InAs detectors-towards Geiger-mode detection *(Invited Paper)*

Chee Hing Tan, The Univ. of Sheffield (United Kingdom)

InAs avalanche photodiodes (APDs) can be designed such that only electrons are allowed to initiate impact ionization, leading to lowest possible excess noise factor. Optimization of wet chemical etching and surface passivation produced mesa APDs with bulk dominated dark current and responsivity that are comparable and higher, respectively, than commercial InAs detector. Our InAs APDs also show high stability with fluctuation of ~0/.1% over 60 s. These InAs APDs can detect very weak signal down to ~35 photons per pulse. Fabrication of planar InAs by Be implantation produced planar APDs with bulk dominated dark current. Annealing at 550 C was necessary to remove implantation damage and to activate Be dopants. Due to minimal diffusion of Be, thick depletion of 8 micron was achieved. Since the avalanche gain increases exponentially with the thickness of avalanche region, Our planar APD achieved high gain > 300 to be obtained at 200 K. This is higher than previously reported values for InAs mesa APDs, suggesting that when combined with a low noise amplifier, photon counting is possible.

10212-16, Session 6

Ultra-high cell-density silicon photomultipliers with high detection efficiency *(Invited Paper)*

Fabio Acerbi, Gaetano Zappala, Alberto Gola, Alessandro Ferri, Veronica Regazzoni, Giovanni Paternoster, Claudio Piemonte, Nicola Zorzi, Fondazione Bruno Kessler (Italy)

Silicon Photomultiplier (SiPM) is an arrays of many Single-photon avalanche diodes (SPADs), all connected in parallel. Each SPAD is sensitive to single photons and the SiPM gives an output proportional to the number of detected photons. It is becoming more and more popular in different applications, from high-energy physics to spectroscopy, and it has been significantly improved over last years, decreasing the noise, increasing the cell fill-factor (FF), thus reaching very high photon-detection efficiency (PDE).

In FBK (Trento, Italy), we developed new SiPM technologies with high-density (HD) and, more recently, ultra-high-density (UHD) of cells (i.e.

density of SPADs). These technologies employ deep-trenches between cells, for electrical and optical isolation. HD and UHD SiPMs are formed by square SPADs with size from 30μm down to 5μm. The smallest-cell SiPM has about 40000 SPADs per squared millimeter. Such small SPAD dimensions gives a significantly high dynamic range to the SiPM.

In general, High-density SiPM have a lower correlated noise (including lower afterpulsing) and a faster recharge time (in the order of few nanoseconds), but they preserve a very good detection efficiency (despite the small SPAD dimension). The optimum cell size depends on the application, and the performance of all cell-size SiPM will be presented and compared.

10212-17, Session 6

Time-resolved CMOS SPAD arrays: architectures, applications and perspectives *(Invited Paper)*

Federica A. Villa, Rudi Lussana, Davide Portaluppi, Alberto Tosi, Franco Zappa, Politecnico di Milano (Italy)

Many applications require to acquire low-intensity images, very fast light signals, or depth-resolved 3D ranging maps. CMOS Single Photon Avalanche Diode (SPAD) arrays provide single photon sensitivity, with low time jitter on photon arrival time, at high frame rates, thus providing time-resolved single photon counting measurements. Examples of current applications are in the fields of quantum physics, diffuse optics, physiological parameters monitoring, LiDAR and 3D ranging. We will present the architecture and performance of SPAD-based single pixels and imaging arrays for both photon counting and photon timing applications, summarizing the present state-of-the-art and highlighting trade-offs. Scientific experiments and measurements performed employing a 32?32 SPAD camera developed at Politecnico di Milano will be described in detail. This camera has a 100 kfps maximum frame rate, very low Dark Count Rate (DCR = 120 cps at room temperature for each 30 μm diameter SPAD), about 55% peak Photon Detection Efficiency (PDE), 95 dB dynamic range when operated in photon counting at 100 fps, 312 ps resolution (280 ps rms overall precision) and 320 ns full scale range when operated in photon timing. Finally, we will discuss the architecture of innovative SPAD pixels conceived for time-of-flight 3D ranging in the automotive field. The smart pixel aims to be very flexible to work in different operating modes, allowing for instance simultaneous photon counting and timing, hardware/software gating or equivalent free-running and including a distributed programmable readout logic.

10212-18, Session 6

Asynchronous Geiger-mode APD cameras with free-running InGaAsP pixels

Mark Itzler, Gennaro Salzano, Mark Entwistle, Xudong Jiang, Mark Owens, Brian Piccione, Sam Wilton, Krystyna Slomkowski, Scott C. Roszko, Esther Wei, Princeton Lightwave, Inc. (United States)

We describe Geiger-mode avalanche photodiode (GmAPD) cameras designed with asynchronous free-running operation that supports single-photon direct detection and coherent detection 3D LiDAR imaging as well as free-running applications such as free-space optical communications and target acquisition and tracking. Each free-running pixel in the 32x32 focal plane array performs independent time-of-flight measurements with a selectable reset time between 0.1 and 10 ?s. Asynchronous reporting of time-of-flight and pixel location data allows continuous operation for arbitrarily long periods of time at sampling rates exceeding 0.7 Gsample/s. We report results for cameras optimized for operation using either 1.0 or 1.5 ?m LiDAR sources.

10212-19, Session 7

Experimental demonstration of quantum data locking *(Invited Paper)*

Daniel Lum, Univ. of Rochester (United States); Michael S. Allman, Thomas Gerrits, Varun B. Verma, National Institute of Standards and Technology (United States); Cosmo Lupo, Massachusetts Institute of Technology (United States); John C. Howell, Univ. of Rochester (United States); Seth Lloyd, Massachusetts Institute of Technology (United States); Sae Woo Nam, National Institute of Standards and Technology (United States)

Shannon proved that information-theoretic secure encryption, which eliminates any mutual information between a text and its ciphertext, is only possible if the encryption key used is used only once, is random, and is at least as long as the message itself. However, the phenomenon of quantum data locking shows us that an information theoretic secure encryption can be achieved with a key that is significantly shorter than the message itself if classical information is encoded onto quantum states. In addition to a demonstration by Y. Liu et. al. [Phys. Rev. A 94, 020301 (2016)], we present one of the first experimental demonstrations of quantum data locking as a quantum enigma machine [Phys. Rev. A 94, 022315 (2016)]. Per photon, our experimental demonstration encrypts a 6-bit packet, consisting of new secret key, message, and forward error correction bits, using an encryption key strictly less than 6 bits while, in principle, remaining information theoretically secure.

10212-20, Session 7

Large-scale programmable photonic circuits for quantum information processing and sensing *(Invited Paper)*

Dirk R. Englund, Nicholas C. Harris, Jacques Carolan, Mihika Prabhu, Darius Bundandar, Yichen Shen, Marin Soljacic, Massachusetts Institute of Technology (United States)

Photonic integrated circuits (PICs) have become increasingly important in classical communications applications over the past decades, including as transmitters and receivers in long-haul, metro and datacenter interconnects. Many of the same attributes that make PICs attractive for these applications — compactness, high bandwidth, and the ability to control large numbers of optical modes with high phase stability — also make them appealing for quantum information processing. This talk will review our recent progress in adapting one of the leading PIC architectures — silicon photonics — as a programmable platform for arbitrary linear optical transformations between sets of optical modes. We analyze this programmable PIC for mode transformations in optical quantum information processing schemes and show that the PIC's reconfigurability allows near-perfect cancellation of fabrication imperfections. Beyond quantum information processing, programmable PICs also appear to have some promising classical applications, including in machine learning. We then extend the spatial-mode transformation scheme to temporal modes through programmable dispersion and discuss new applications in quantum communications, in particular quantum data locking and quantum key distribution.

10212-21, Session 7

Single-pixel 3D imaging with time-resolved single photon counting *(Invited Paper)*

Matthew P. Edgar, Miles J. Padgett, Univ. of Glasgow (United Kingdom)

The availability of compact, low-cost, and high-speed MEMS based spatial light modulators has generated widespread interest in alternative sampling strategies for imaging systems utilising single-pixel detectors. The development of novel compressed sensing schemes for real-time computational imaging may have promising commercial applications for high-performance detectors, where the availability of focal plane arrays are expensive or otherwise limited. In this work I will discuss the research and development of a prototype time-of-flight imaging system investigated in partnership with Leonardo, which utilises a single high-sensitivity photon counting detector and fast-timing electronics to recover millimetre accuracy real-time 3D video. An evaluation of the overall performance and image quality will be provided comparing different sampling strategies and image reconstruction techniques.

10212-22, Session 7

Robust and time-saving strategy of CPPM single-photon collision avoidance LIDAR against dynamic crosstalk of varying intensity

Fan Zhang, Mali Gong, Xing Fu, Tsinghua Univ. (China)

With increasing number of vehicles equipped with light detection and ranging (LIDAR), crosstalk is identified as a critical and urgent issue in the range detection for active collision avoidance. Chaotic pulse position modulation (CPPM) applied in the transmitting pulse train has been shown to prevent crosstalk as well as range ambiguity. However, static and unified strategy on discrimination threshold and the number of accumulated pulse is not valid against crosstalk with varying number of sources and varying intensity of each source. This paper presents an adaptive algorithm to distinguish the target echo from crosstalk with dynamic and unknown level of intensity in the context of intelligent vehicles. New strategy is given based on receiver operating characteristics (ROC) curves that consider the detection requirements of the probability of detection and false alarm for the scenario with varying crosstalk. In the adaptive algorithm, the detected results are compared by the new strategy with both the number of accumulated pulses and the threshold being raised step by step, so that the target echo can be exactly identified from crosstalk with the dynamic and unknown level of intensity. The validity of the algorithm has been verified through the experiments with a single photon detector and the time correlated single photo counting (TCSPC) technique, demonstrating a marked drop in required shots for identifying the target compared with static and unified strategy.

10212-23, Session 8

Dead-time correction for TCSPC systems *(Invited Paper)*

Sebastian Isbaner, Narain V. S. Karedla, Daja Ruhlandt, Simon C. Stein, Anna M. Chizhik, Jörg Enderlein, Georg-August-Univ. Göttingen (Germany)

Dead-time artifacts can dramatically influence the shape of Time-Correlated Single Photon Counting (TCSPC) histograms such as fluorescence lifetime curves [1]. These artifacts occur at high count rates, which limit the acquisition speed in Fluorescence Lifetime Imaging Microscopy (FLIM). We present an algorithm that corrects the distortions of TCSPC histograms which are caused by constant electronics and/or detector dead-times [2]. We verified the algorithm with Monte-Carlo simulations and fluorescence lifetime measurements. Furthermore, we performed FLIM measurements on densely labeled cells at various excitation powers and corrected the lifetime and intensity values for each pixel.

Our correction method is not restricted to TCSPC measurements only, but can be applied to any periodic single-event counting or timing measurement. Since it corrects dead-time artifacts for both lifetime and intensity, the algorithm could be beneficial for example for lidar or time-resolved fluorescence anisotropy measurements.

[1] W. Becker, Advanced Time-Correlated Single Photon Counting Techniques (Springer, 2005).

[2] S. Isbaner, N. Karedla, D. Ruhlandt, S.C. Stein, A. Chizhik, I. Gregor, and J. Enderlein, Opt. Express 24, 9429-9445 (2016)

10212-24, Session 8

Time stamping of single optical photons with 10 ns resolution

Irakli Chakaberia, Andrei Nomerotski, Merlin Fisher-Levine, Brookhaven National Lab. (United States)

Good spatial and nanosecond-scale time resolution are key features for many applications, ranging from imaging mass spectrometry and covariance imaging to neutron time-of-flight imaging. Sensitivity to single optical photons further broadens the potential field of applications to include the fluorescent imaging and quantum informatics. In this work we discuss new results on the time-stamping of single optical photons by using TimepixCam.

TimepixCam is a novel optical imager comprising an array of 256?256, 55 microm^2, pixels which achieves 10 ns-scale-time resolution. It is based on a thin entrance window silicon sensor bump-bonded to a Timepix ASIC with a commercial readout. The sensor provides high quantum efficiency to register photons in the wavelength range of 400 - 1000 nm, and makes the camera sensitive to flashes of light in excess of about 1000 photons.

We present the first results of time-stamping single optical photons with a time resolution of 10 ns, by coupling TimepixCam with a fast image intensifier composed of a GaAs photocathode, chevron MCP and P47 phosphor. The intensifier preserves the good position and time resolution of TimepixCam, while making it sensitive to single photons. The presented results include the characterization of single photon detection using this setup, and the first proof of principle experiments in fluorescent imaging and quantum informatics employing TimepixCam. The fluorescent imaging experiments involved measurement of the lifetime of samples using the Time-Correlated Single Photon Counting (TCSPC) technique. We also demonstrate a time-tagging capability of entangled photon pairs using TimepixCam for quantum informatics applications.

10212-25, Session 8

X-ray backscatter sensing of defects in carbon fibre composite materials

Daniel O'Flynn, Chiaki Crews, Univ. College London (United Kingdom); Nicholas Fox, Axi-Tek Ltd. (United Kingdom); Brian P. Allen, QinetiQ Ltd. (United Kingdom); Mark Sammons, Stefano Bettelli, Axi-Tek Ltd. (United Kingdom); Robert D. Speller, Univ. College London (United Kingdom)

X-ray backscatter (XBS) provides a novel approach to the field of non-destructive testing in the aerospace industry. XBS measurements are conducted by collecting the scattered radiation from a sample illuminated by a well-defined X-ray beam; the technique enables objects to be scanned at the sub-surface level with single-sided access, and without the requirement for coupling with the sample. Single-sided access is of particular importance when the objects of interest are very large, such as aircraft components. Carbon fibre composite materials are increasingly being used as a structural material in aircraft, and there is a demand for techniques which are sensitive to the delaminations which can occur in composites as a result of large impact forces and cumulative usage fatigue. The XBS signal is greatly enhanced for plastics and lightweight materials, making it an ideal candidate for probing sub-surface damage/defects in carbon fibre composites. Here we present both Monte Carlo computer modelling and experimental data which demonstrate the capability of the XBS technique for defect detection. Monte Carlo data show, for example, that 1mm thick air cavities can be detected in the centre of a 20mm thick composite with a signal to noise ratio of 32. Results from the modelling were used to build a laboratory-based XBS system using a small, commercially available X-ray source. Experimental results for plastic and carbon fibre materials show a sensitivity to small-scale defects which can be quantified and characterised, demonstrating the potential for the application of X-ray backscatter in scanning aircraft components - either at the production stage or in service.

Conference 10213: Hyperspectral Imaging Sensors: Innovative Applications and Sensor Standards 2017

Wednesday 12 April 2017

Part of Proceedings of SPIE Vol. 10213 Hyperspectral Imaging Sensors: Innovative Applications and Sensor Standards 2017

10213-1, Session 1

Quantitative hyperspectral dark-field microscopy for label-free scatter imaging of biological tissues and tissue-mimicking phantoms

Jeeseong Hwang, Phillip P. Cheney, National Institute of Standards and Technology (United States); David M. McClatchy, Dartmouth College (United States); David W. Allen, Paul Lemaillet, Daniel V. Samarov, National Institute of Standards and Technology (United States); Hyun-Jin Kim, Dartmouth College (United States) and National Institute of Science and Technology (United States); Stephen C. Kanick, Brian W. Pogue, Dartmouth College (United States)

The diffuse reflectance spectroscopy based on point sources and detectors combined with a physics based model has enabled quantitative tissue optical measurements to correlate the measurement results with standard pathological and clinical interpretations. However, this point probe technique has a limitation in achieving real-time spatial information at a larger region of interest towards effective diagnosis and surgical treatments of diseased tissues where the spatial information of the tissue scattering properties is critical. We have developed a quantitative dark-field scatter imaging technique to measure the local scattering coefficient of biomedical scattering phantoms and human breast tissues. Performance of the microscope was validated by the wavelength-dependent back scattering signals from well-defined scatter phantoms along with the results from the Monte Carlo photon transport and macroscopic and mesoscopic scattering measurement modalities including double integrating sphere system and sub-diffuse spatial frequency domain imager. Our ongoing effort involves quantitative mapping of local scattering coefficients of breast tissue lumpectomies to enable label-free quantitative optical biopsy for the on-site detection of tumor margins.

10213-2, Session 1

Explosives hide and seek: hyperspectral image comparison of agricultural and forest species exposed to various explosive compounds

Paul Manley, Catherine Johnson, Zhaozheng Yin, Missouri Univ. of Science and Technology (United States); Mikhail Berezin, Washington Univ. in St. Louis (United States); Abduwasit Ghulam, St. Louis Univ. (United States); Joel G. Burken, Missouri Univ. of Science and Technology (United States)

Landmines endanger the lives of civilians and military personnel. Current detection methods are costly, slow, and dangerous, and require people to navigate through contaminated areas. A new method for rapid detection is imperative to hasten the reopening of lands that have been inaccessible for years: hyperspectral imagery (HSI). Landmines exposed to soil moisture and rain rust, eventually leaching out explosives into surrounding soil. The compounds then move through the soil matrix and into plant roots via bulk water movement. In plants, explosives cause vegetative stress detectable with HSI, which is quickly acquired, processed, and analyzed and may be useful in the search for landmines. To eventually scale up to the landscape level of detection, a greenhouse study will be implemented using plant species native to and grown in Cambodia, a country extremely affected by remnant landmines that have rendered thousands of acres useless. Corn, soybean, common bamboo, and teak are native to, or grown in Cambodia. Willow and poplar will be used because of their previous extensive use in explosives uptake studies. We will test a range of concentrations of three explosives to simulate in situ conditions of vegetation exposed to explosives. Plants will be imaged weekly with a Headwall Nano-Hyperspec. Images will be processed with Headwall software and analyzed with ENVI. Reflectance indices will be correlated to plant physiology and morphology metrics. This study aims to compare plant responses to various chemicals and concentrations to determine the efficacy of plants as phytoforensic tools in the fight against forgotten landmines.

10213-3, Session 1

The selectable hyperspectral airborne remote sensing kit (SHARK) used in UAS for precision agriculture

Rick E. Holasek, Corning Inc. (United States)

Hyperspectral imaging (HSI) has been used for over two decades in laboratory research, academic, environmental and defense applications. In more recent time, HSI has started wider range adoption in commercial applications in machine vision, conservation, resource exploration, and precision agriculture, to name just a few of the economically viable uses for the technology. Corning Incorporated has been developing and manufacturing HSI sensors, sensor systems, and sensor optical engines, as well as HSI sensor components such as gratings and slits for over a decade and a half. This depth of experience and technological breadth has allowed Corning to design and develop unique HSI spectrographs with an unprecedented combination of high performance, low cost and low Size, Weight, and Power (SWaP). The extremely low SWaP of Corning's HSI sensors and sensor systems enables their deployment using limited payload platforms such as small unmanned aerial vehicles (UAVs), including low cost multi-rotor copters.

This paper discusses use of the Corning patented monolithic Offner spectrograph design, the microHSITM, to build a highly compact visNIR HSI turn-key airborne remote sensing payload. This Selectable Hyperspectral Airborne Remote sensing Kit (SHARK) has industry leading SWaP (1.7 lbs) including an Inertial Navigation System (INS), data acquisition and storage subsystem, and battery. The competitive SWaP and low cost of the microHSITM sensor is starting to approach the price point of Multi Spectral Imaging (MSI) sensors. Specific designs of the Corning microHSITM SHARK visNIR turn-key system are presented along with salient performance characteristics, and recent microHSITM SHARK prototype test results.

10213-4, Session 1

Detection of cold stressed maize seedlings for high throughput phenotyping using hyperspectral imagery

Chuanqi Xie, Ce Yang, Nathan Springer, Cory Hirsch, Univ. of Minnesota (United States)

Hyperspectral image can provide hundreds of images at different wave bands covering the visible and near infrared regions, which is superior to traditional spectral and RGB techniques. Minnesota produced most of the

maize in the USA, while the temperature in Minnesota can change abruptly during spring. This study was carried out to use hyperspectral imaging technique to identify maize seedlings with cold stress prior to having visible phenotypes. A total of 90 samples were scanned by the hyperspectral camera at the wave range of 395-885 nm. Both spectral and spatial information were extracted from the corrected hyperspectral images. By spectral reflectance information, different classification models (support vector machine, Adaboost, etc) were established to identify the cold stressed samples. Then, the wavelengths which could play significant roles for the detection were selected using two-wavelength combination method. The classifiers were built again using the selected wavelengths. From the results, it can be found the selected wavelengths can even perform better than full wave range. Based on the spatial information, the corresponded gray images were selected, in which the stressed samples can be easily observed before visible phenotypes. The overall results indicated that hyperspectral imaging has the potential to classify cold stress symptoms in maize seedlings and thus help in selecting the corn genome lines with cold stress resistance.

10213-5, Session 1

A brief review and application of the lamp-plaque method for the calibration of compact hyperspectral imagers

David W. Allen, National Institute of Standards and Technology (United States); E. Terrence Slonecker, U.S. Geological Survey (United States); B. Carol Johnson, National Institute of Standards and Technology (United States)

Hyperspectral imagers (aka imaging spectrometers) are becoming more commonly used for a range of applications. Newer compact designs are facilitating use in environments ranging from the laboratory benchtop to unmanned aerial vehicles (UAVs). In many cases there is a need to compare results of different hyperspectral imagers at different places and times. This necessitates the need to relate the measurements to an absolute scale. Measurement units of radiance can be related to the signal output of the imager through spectral radiance responsivity. Of the several different methods that can be used to determine the spectral radiance responsivity, the lamp-plaque method provides a simple easy to understand setup. While simple in design, there are a number of details that need to be considered in order to reduce significant bias and error. This paper examines the practice, sources of error and illustrates the application using several commercial off-the-shelf hyperspectral imagers. The result of the exercise provides a calibration with estimated uncertainties specific to each imaging system. Additionally, characterization of the imager performance can be gauged by examination of products derived from the same method outlined.

10213-6, Session 1

Design and verification of an aberration-corrected free-form concave blaze grating with variable line spacing for hyperspectral imaging

Cheng-Hao Ko, National Taiwan Univ. of Science and Technology (Taiwan); Bang-Ji Wang, Jih-Run Tsai, National Space Organization (Taiwan); Yueh-Hsun Wu, Sheng-Yu Tsai, National Taiwan Univ. of Science and Technology (Taiwan); Shin-Fa Lin, Chiu-Der Hsiao, National Space Organization (Taiwan)

A flat-field aberration corrected concave blaze grating for 400-1100nm is designed and fabricated. The concave grating, which has a free-form profile with blaze grating pitch and variable line spacing, is fabricated using five-axis CNC machine with nanometer machining precision. An optical system is setup to measure the focused spot size, spectral resolution and diffraction efficiency to evaluate the performance of aberration-corrected concave grating. The blaze grating reaches a diffraction efficiency of 70%. The focused vertical spot size is 50μm, which indicates a 50μm spatial resolution at the image plane. The focused horizontal spot size is 300μm, which converts to a spectral resolution of 6nm. The design methodology can be applied to an Offner type hyperspectral imager with a free-form convex grating and variable line spacing to achieve high efficiency and high spatial and high spectral resolving power.

10213-7, Session 2

Toward experimentally accessible standards for differing hyperspectral imaging architectures

Michael K. Yetzbacher, U.S. Naval Research Lab. (United States)

The increasing number of hyperspectral imaging applications has led to increased demand for smaller, cheaper, more compact instruments. Industry and academia have responded with a large number of architectures that meet the size, weight power and cost requirements. Here, we argue that the range of measurement, (i.e. optical bandwidth and field of view) must be defined before any standard can be meaningful. Once a range of measurement is set, standards can be developed to compare instruments of differing types without resorting to theory. When comparing instruments of different architectures (e.g. Fourier transform vs. grating spectrometers), the data transform must also be considered. This defines two domains, the measurement domain and the analysis domain. The analysis domain is the same for every type of instrument. We suggest standards based on experimentally measureable or definable quantities, the measurement domain pixel sensitivity function, and the data processing transform. For linear processing transforms, the analysis domain pixel sensitivity function can always be defined. The analysis domain sensitivity function can form the basis for a variety of metrics meant to determine spectral integrity or image quality: sensitivity, selectivity, resolution, cross-talk and signal to noise ratio. We present modeling results from different types of system architectures and suggest reasonable parameters for comparisons that are agnostic to the type of instrument being studied. Using an experimentally observable basis and fair metrics of evaluation may reduce controversy over different imaging spectrometer architectures.

10213-8, Session 2

Application of deep learning to UAS based real-time hyperspectral imaging for precision agriculture

ZhiQiang Chen, Shimin Tang, Univ. of Missouri-Kansas City (United States)

The last-mile challenge that prevents the realization of a truly real-time system for image-based learning of agricultural field condition is to deal with the complexity of real scenes captured in images. Such complexity manifests in the forms of different modalities of seasonal changes, illumination and coloring variations, presence of irrelevant artifacts, and intra-class uncertainties in scales and shapes. Such complexity imposes great difficulty in designing an all-in-one feature extraction and selection method. Thanks to the availability of real-time 'snapshot' like hyperspectral camera, such challenge becomes solvable when combined modern big-enabled learning engines. This paper aims to address this challenge and proposes a deep learning framework that is built upon deep neural networks, big data, and modern computational power. The Caffe deep learning framework is adopted, and the trained classier is further implemented using the NVidia's Jetson TX1 platform. To obtain a relatively large training database, available hyperspectral images are

manually annotated and are subdivided and further subjected to geometric transformations to form a large-scale concrete damage pattern database (> 106 image patterns). Besides cross-validation, another database that is taken from a real farm is used to validate the real-time imaging and identification. Our preliminary result has shown the great effectiveness of the proposed framework and further accuracy evaluation results are being generated. Last we expect that our deep learning algorithms can be implemented for an in-flight drone (within the drone or in the cloud) towards realizing a real-time robotic platform for automated agricultural field imaging, detection, and mapping.

10213-9, Session 2

Rapid and non-destructive assessment of polyunsaturated fatty acids contents in Salmon using near-infrared hyperspectral imaging

Feifei Tao, Ogan Mba, Li Liu, Michael O. Ngadi, McGill Univ. (Canada)

Polyunsaturated fatty acids (PUFAs) in the diet are essential to the growth and proper nutrition of humans. Salmon is a rich source of varieties of PUFAs. The PUFAs contents can vary greatly in farmed salmon depending on different fish species or their feeding regimes. Currently, gas chromatography (GC) is the most common method for determining FAs contents. However, GC analysis is time-consuming, laborious, destructive to samples and requires use of hazard solvents, making it impossible to be applied in a real-time and non-destructive manner. In this work, the potential of near-infrared (NIR) hyperspectral imaging technique for quantifying the major PUFAs in farmed Salmon was investigated. A total of 78 Salmon fillets were obtained from different parts of Salmon from different local markets. For each sample, the hyperspectral image was collected with a pushbroom NIR (900-1700 nm) hyperspectral imaging system followed by measurement of its reference PUFAs contents using GC analyses. Mean, first, and second derivative spectra were extracted from the hyperspectral images for development of quantitative prediction models. Different chemometric methods were employed in this work and their prediction results were compared. The quantitative models with superior quantitative ability were applied pixel-wise to the hyperspectral images to produce chemical images for visualization the distributions of different PUFAs, respectively. The obtained results indicate that hyperspectral imaging is promising in predicting and visualizing PUFAs distribution in farmed Salmon in a rapid and non-destructive way.

10213-10, Session 2

Hyperspectral remote sensing of vegetation: knowledge gain and knowledge gap after 50 years of research

Prasad S. Thenkabail, U.S. Geological Survey (United States)

This presentation summarizes the advances made over 40+ years in understanding, modeling, and mapping terrestrial vegetation as reported in the new book on “Hyperspectral Remote Sensing of Vegetation” (Publisher:Taylor and Francis inc.). The advent of spaceborne hyperspectral sensors or imaging spectroscopy (e.g., NASA’s Hyperion, ESA’s PROBA, and upcoming Italy’s ASI’s Prisma, Germany’s DLR’s EnMAP, Japanese HIUSI, NASA’s HyspIRI) as well as the advances made in processing when handling large volumes of hyperspectral data have generated tremendous interest in advancing the hyperspectral applications’ knowledge base to large areas.

Advances made in using hyperspectral data, relative to broadband data, include: (a) significantly improved characterization and modeling of a wide array of biophysical and biochemical properties of vegetation, (b) ability to discriminate plant species and vegetation types with high degree of accuracy, (c) reducing uncertainties in determining net primary productivity or carbon assessments from terrestrial vegetation, (d) improved crop productivity and water productivity models, (e) ability to assess stress resulting from causes such as management practices, pests and disease, water deficit or water excess, and (f) establishing more sensitive wavebands and indices to study vegetation characteristics.

The presentation will discuss topics such as: (1) hyperspectral sensors and their characteristics, (2) methods of overcoming the Hughes phenomenon, (3) characterizing biophysical and biochemical properties, (4) advances made in using hyperspectral data in modeling evapotranspiration or actual water use by plants, (5) study of phenology, light use efficiency, and gross primary productivity, (5) improved accuracies in species identification and land cover classifications, and (6) applications in precision farming.

10213-11, Session 2

Classification of hyperspectral imagery using MapReduce on a NVIDIA graphics processing unit

Andres Ramirez, Maryam Rahnemoonfar, Texas A&M Univ. Corpus Christi (United States)

A hyperspectral image provides multidimensional figure rich in data consisting of hundreds of spectral dimensions. Analyzing the spectral and spatial information of such image with linear and non-linear algorithms will result in high computational time. In order to overcome this problem, this research presents a system using a MapReduce-Graphics Processing Unit (GPU) model that can help analyzing a hyperspectral image through the usage of parallel hardware and a parallel programming model, which will be simpler to handle compared to other low-level parallel programming models. Additionally, Hadoop was used as an open-source version of the MapReduce parallel programming model. This research compared classification accuracy results and timing results between the Hadoop and GPU system and tested it against the following test cases: the CPU and GPU test case, a CPU test case and a test case where no dimensional reduction was applied.

10213-12, Session 2

Large format high SNR SWIR HgCdTe/ Si FPA with multiple-choice gain for hyperspectral detection

Xiaoning Hu, Aibo Huang, Qingjun Liao, Lu Chen, Xin Chen, Hua Fan, Honglei Chen, Ruijun Ding, Li He, Dexin Sun, YinNian Liu, Shanghai Institute of Technical Physics (China)

This paper reports the development of 2000?256 format SWIR HgCdTe/ Si FPA with multiple-choice gain (i.e. multiple-choice charge handling capacity) for hyperspectral detection. The spectral resolution is about 8nm. To meet the demands of variable low flux detection within each spectral band in the short wave infrared range, low dark current, low noise, variable conversion gains and high SNR (Signal to Noise Ratio) of FPA are needed.

In this paper, we fabricate 512?512 pixel 30?m pitch SWIR HgCdTe diode array on Si by using a novel stress-release construction of HgCdTe chip on Si. Moreover, we design low noise, variable conversion gain and large dynamic range read-out integrated circuit (ROIC) and hybridized the ROIC on the HgCdTe diode array on Si substrate. There are 8-choice gains which can be set up locally according to the incident flux to meet high SNR detection demand. By high-accuracy splicing 4 512?512 HgCdTe/Si FPA we get mosaic 2000?256 FPA, and characterizations have been carried out and reveal that the array dark current densities on an order of 10-10A/ cm2, quantum efficiency exceeding 70%, and the operability of 99.5% at operating temperature of around 110K. The SNR of this FPA achieved 120 when illuminated under 5E4photons/pixel

10213-13, Session 3

The use of unmanned aircraft systems (UAS), multispectral sensors and GIS can greatly enhance environmental monitoring and mitigation

Paul Granado, Luis Robles, AerialZeus, LLC (United States)

This technical document contains the results of the 2016 aerial-mapping of the Off-site Mitigation Areas at the Willits-Bypass Project in Northern California. It also serves as an attachment to satisfy Year-2, vegetation performance monitoring requirements, for rehabilitated wetland mitigation areas managed for the conservation of Baker's meadowfoam (Limnanthes bakeri), an endangered and endemic species, in California. The combined use of GIS with Unmanned Aircraft Systems (UAS) and multispectral sensors offer unparalleled advantages in conducting environmental studies, due to UAS' practicality, deploy-ability, low cost of data-acquisition and efficiency when accessing difficult areas, such as wetlands. In addition, using multispectral sensors in UAS-based platforms allow to conduct studies about the precise distribution, classification, and plant identification, through spectral signatures, which can be used to assess various physical and biological parameters. Aerial mapping was conducted on May 16 through May 20, 2016 in a parcel known as 'Frost', Mendocino County, California by using a multispectral camera (450-840 nm, 4 bands: blue, green, red, near infra-red and red edge). In-situ measurements were performed for the establishment of the training samples, based on the description of geo-located polygons in different parts of the study area. The spatial analysis was based on a supervised classification by a nonparametric decision rule (feature space), which employed the information contained into the training samples. The classifier algorithm selected was the maximum likelihood for best precision and accuracy. This algorithm compares each pixel against all the spectral signatures established on the classification and sets the probability and ties the pixels to a specific class. The spectral separability of the classes was 96%. To validate such classification, historical information of BMF distribution and 105 random points were used. This methodology reached an accuracy of 78% and the Cohen´s Kappa coefficient was determined to be 0.7692, cataloging this result into the good agreement category. Likewise, BMF occupied 2.36% (0.92 acres) of the total area (39 acres). UAS-acquired multispectral imagery provides high quality resolution data, thus enabling great agility to cover wide areas for the precise distribution of plants. These technologies and specific geomatic methods, focused on the spectral properties, represent fundamental tools to carry out monitoring and mitigation programs, specially of endangered species.

10213-15, Session 3

Inline hyperspectral thickness determination of thin films using neural networks

Anton J. Tremmel, Roman Weiss, Michael Schardt, Alexander W. Koch, Technische Univ. München (Germany)

Thin film thickness determination usually is performed spot-wise. Inline observation not only of spots but form areas is a demand for new materials quality. Hyperspectral imagers are offering possibilities for spatially resolved spectroscopy in only one device. For using a hyperspectral imager for thin film measurements, an optical head with integrated incident light source was developed. Hence this setup combines the principles of reflectometry and hyperspectral imaging.

Thereby reflections of the measurement object are imaged onto the entrance slit of the imager. Layer thickness is calculated by comparing a dataset of simulated spectra with the measured data. For a single frame this operation has to be done for each laterally resolvable pixel. In order to generate two-dimensional surfaces from single frames, however the measurement target has to move uniformly.

Utilizing the maximum frame rate of the hyperspectral imager, the pixel-wise spectra comparing procedure cannot be performed using a standard computer, due to the processing load.

In this work a method using neural networks for calculating layer thickness is presented. After complete parametrization of the neural network by training, the network is reduced to a nonlinear equation. A measured spectrum as input for this equation corresponds to a specific layer thickness. This process is less demanding than the comparing algorithm.

By the use of the nonlinear equation as result of a trained neural network, thickness data can be determined with a measurement rate matching the maximum frame rate of the hyperspectral imager.

10213-16, Session 3

Feasibility of a standard for full quantification of spectral imager performance

Torbjørn Skauli, Norwegian Defence Research Establishment (Norway)

Specification of camera performance is well developed for conventional imaging, but there is a need for a standard to fully specify the performance of spectral image sensors. In particular, there is no standardized way to specify many aspects of imaging quality related to the spectral dimension. It is a characteristic of spectral imaging that the data exploitation normally starts by processing the spectral dimension, and not the spatial dimension. The integrity of the spectral signal is therefore an important aspect to specify fully. For this, it is necessary to go beyond the modulation transfer function used to specify conventional imagers and instead consider the properties of the point spread function, which leads to a metric of spatial coregistration. In an analogous way, it is possible to define a metric for spectral coregistration of different pixels, another important aspect of spectral imaging. Spectral and spatial coregistration may be sensitive to movement or temporal variation of the scene, depending strongly on the operating principle of the spectral sensor. A metric for this sensitivity can be derived from basic metrics for coregistration. Another characteristic of spectral imaging is that the wavelength range tends to be set by physical limits of image sensors and other components, leading to large differences in responsivity between bands. It is therefore preferable to specify the effective dynamic range of spectral image sensors using a metric that takes into account variations in spectral responsivity, possibly with reference to a particular illumination spectrum such as daylight for reflective-domain sensors. Combining characteristics specific to spectral imaging with traditional camera characteristics, the talk will outline a way to fully specify spectral image sensors.

10213-17, Session 3

Estimation of leaf nitrogen concentration on winter wheat by multispectral imaging

Vincent Leemans, Gembloux Agro-Bio Tech, Univ. de Liège (Belgium); Guillaume Marlier, Univ. de Liège (Belgium); Marie-France Destain, Gembloux Agro-Bio Tech, Univ. de Liège (Belgium); Benjamin Dumont, Univ. de Liège (Belgium); Benoît Mercatoris, Gembloux Agro-Bio Tech, Univ. de Liège (Belgium)

Precision agriculture can be considered as one of the solutions to optimize agricultural practice such as nitrogen fertilization. Nitrogen deficiency is a major limitation to crop production worldwide whereas excess leads to environmental pollution. In this context, some devices were developed as reflectance spot sensors for on-the-go applications to detect leaves nitrogen concentration deduced from chlorophyll concentration. However, such measurements suffer from interferences with the crop growth stage and the water content of plants. The aim of this contribution is to evaluate the nitrogen status in winter wheat by using multispectral imaging. The proposed system is composed of a CMOS camera and a set of filters ranged from 450 nm to 950 nm and mounted on a wheel which moves due to a stepper motor. To avoid the natural irradiance variability, a white reference is used to adjust the integration time. The segmentation of Photosynthetically Active Leaves is performed by using Bayes theorem to extract their mean reflectance. In order to introduce information related to the canopy architecture, i.e. the crop growth stage, textural attributes are also extracted from raw images at different wavelength ranges. Statistical methods such as Partial Least Square and Best Subset regressions are used to select the best reflectance and textural attributes to estimate nitrogen concentration. The tests were carried out on the AgricultureIsLife parcels of Gembloux Agro-Bio Tech, Université de Liège, Belgium, with variable nitrogen fertilization. Results show that multispectral imaging, compared with the Kjeldahl method (R? = 0.92), is promising to estimate the leaf nitrogen concentration.

10213-18, Session PWed

Discrimination of wheat and oat crops using field hyperspectral remote sensing

Allison Kaiser, Rocio Duchesne-Onoro, Univ. of Wisconsin-Whitewater (United States)

In this study we attempt to identify the most suitable spectral bands to discriminate among wheat and oat crops using field hyperspectral remote sensing. Discrimination of these crops using ordinary aerial or multispectral satellite imagery can be challenging. Even though multispectral images could have a high spatial resolution, their few wide spectral bands hinder crop discrimination. Therefore, both high spatial resolution and spectral resolution are necessary to accurately discriminate between visually similar crops. One field each of oats and spring wheat, each at least 10 acres in size, was selected in southeastern Wisconsin. Biweekly spectral readings were taken using a spectroradiometer during the growing season from May to September. In each field, seven 10 m x 10 m quadrants were randomly placed and in each quadrants five points were selected from which 20 radiometric readings were taken. Radiometric measurements taken at each sampling point were averaged to derive a single reflectance curve per sampling date, covering the spectral range of 300 nm to 2,500 nm. Each spectral curve was divided into hyperspectral bands each 3 nm wide. The Mann-Whitney U-test was used to estimate how separable the two crops were. Results show that selected regions of the visible light and infrared radiation spectrum have the potential to discriminate between these crops. Crop discrimination is one of the first steps to support crop monitoring and agricultural surveys efforts.

10213-19, Session PWed

Stability improvement of a 4 cable-driven parallel manipulator using a center of mass balance system

Iman Salafian, Blake Stewart, Matthew Newman, Art Zygielbaum, Benjamin Terry, Univ. of Nebraska-Lincoln (United States)

We are developing a four-cable-driven parallel manipulator (CDPMR) that consists of sophisticated spectrometers and imagers in order to acquire phenotypic and environmental data over an acre-sized crop field. To obtain accurate data and quality images from the spectrometers, the end effector must be stationary during sensing. One of the factors that reduce stability is the center of mass offset of the end effector which can cause a pendulum effect or undesired tilt angle. The purpose of this work is to develop a system and method for balancing the center of mass of a 12th-scale CDPMR in order to minimize vibration that can cause error in the acquired data. A simple method for balancing the end effector is needed in order to enable end users of the CDPMR to arbitrarily add and remove sensors and imagers from the end effector as their experiments may require. The Center of Mass Balancing System (CMBS) is developed in this study which consists of an adjustable system of weights and a gimbal for tilt mitigation. An electronic circuit board including an orientation sensor, wireless data communication, and load cells was designed to validate the CMBS. To measure improvements gained by the CMBS, several static and dynamic experiments are carried out. In the experiments, the dynamic vibrations due to the translational motion and static orientation were measured with and without CMBS use. The results show that the CMBS system improves the stability of the end-effector by decreasing the vibration and the static tilt angle.

10213-20, Session PWed

UAV remote sensing capability for precision agriculture, forestry and small natural reservation monitoring

Karel Pavelka, Jaroslav Sedina, ?VUT v Praze, Fakulta stavební (Czech Republic)

For ecologically valuable areas monitoring, precise agriculture and forestry, thematic maps or small GIS are needed. Nowadays, the satellite data has a sub meter geometric resolution and aerial data are provided in decimeters per pixel. Unfortunatelly both data types are often too expensive, designed for larger areas and usually non-operable in certain cases. Remotely Piloted Aircraft Systems (RPAS) data can be obtained on demand in a short time. RPAS have a geometrical resolution of centimeters and can be used for small areas. Data collection is environmentally friendly and low-cost from an economical point of view. Our contribution is focused on using eBee drone for mapping or monitoring national natural reserve which is not opened to public and partly pure inaccessible because its moorland nature. From last year, the laboratory is equipped with thermal imager, multispectral imager, NIR, NIR red-edge and VIS camera; these sensors are used in precise agriculture and forestry. RPAS thus can be used for logging localities management such as cleaning up check after the log. Individual trees can be separated in various ways. NDVI is useful and helps to detect the presence of any pests, but better results are given by multispectral camera. In 2016, we started with a specialized agriculture case study using eBee drone. During vegetation season flights with multispectral and thermal equipment on agricultural test area (grass, grain and corn field) were performed. Outputs from season 2016 were analyzed and first results from multispectral and thermal RPAS imaging based on RPAS data were introduced.

Conference 10214: Thermosense: Thermal Infrared Applications XXXIX

Monday - Thursday 10–13 April 2017

Part of Proceedings of SPIE Vol. 10214 Thermosense: Thermal Infrared Applications XXXIX

10214-2, Session 2

A 2016 update on standards and guidelines relevant to thermographers

Gregory B. McIntosh, Snell Infrared Canada (Canada); Roy Huff, Snell Infrared (United States)

Given the recent proliferation of low cost thermal imagers whose performance and capabilities vary significantly, it is important and appropriate that there be a widespread understanding of who, how, when, and where these imagers should properly be applied in order to obtain credible, scientific, and repeatable results. The best place to look for this understanding is through the knowledge and use of professional unbiased and peer-reviewed standards guidelines and protocols (“standards”).

There have been numerous “standards” developed over the past 40 years relevant to thermal imaging and thermographers within a wide variety of applications and disciplines. Common to most standards and guidelines are minimum performance requirements for the instrument, qualifications for the operator, guidelines for specific use, and limitations of how thermal imaging should be applied.

These documents cut across a wide variety of agencies, disciplines, and nations often without regard for or knowledge of other similar standards or requirements. Agencies include but are not limited to the American Society for Test Methods; American society for Non-Destructive Testing; Canadian Standards Association; International Standards Organization; National Master Specifications of Canada (NMS); National Institute of Standards (NIST); and National fire Prevention Association and the European Committee for Standardization (CEN).

This paper will present a synopsis and current status of the various national and international thermography “standards” developed for the building, electrical, industrial, medical, and non-destructive testing industries. Particular detail will be given to newer and/or re-written standards that have come to be in the past 7 years, or are currently in development.

10214-3, Session 3

Fire testing and infrared thermography of oak barrels filled with distilled spirits

Jaap de Vries, FM Global (United States)

Adequate fire protection of distilled spirits stored in oak barrels requires understanding the failure mode of these barrels, including quantifying the leak rate. In this study, the use of a custom-calibrated, long-wave microbolometer camera is demonstrated to seek new protection methods for rack-stored distilled spirits. Individual oak barrels ranging between 200 L and 500 L filled with 75%/25% ethanol/water were exposed to both propane gas fires and pure ethanol pool fires. The IR camera was used to see through the smoke and flames showing the location of the leaks. The increase in HRR due to the leaked content was measured using gas calorimetry of the combustion products. This study showed that barrels leaked at a rate of approximately 4-8 lpm, resulting in heat release rates ranging between 1.2 and 2.4 MW. These numbers are confirmed by the quantitative measurements of gaseous H2O and CO¬2 in the exhaust. Surface temperature of the exposed oak could reach temperatures up to 750ºC.

10214-4, Session 3

Flame filtering and perimeter localization of wildfires using aerial thermal imagery

Mario M. Valero Pérez, Univ. Politècnica de Catalunya (Spain); Steven Verstockt, Univ. Gent (Belgium); Oriol Rios, Elsa Pastor, Eulália Planas, Univ. Politècnica de Catalunya (Spain)

Airborne thermal infrared (TIR) imaging systems are being increasingly used for wildfire tactical monitoring since they show important advantages over spaceborne platforms and visible sensors while becoming much more affordable and much lighter than multispectral cameras. However, the analysis of aerial TIR images entails a number of difficulties which have thus far prevented monitoring tasks from being totally automated. One of these is the appearance of flame projections during the geo-correction of oblique images. Filtering these flame projections is essential in order to accurately estimate the geographical location of the fuel burning interface. Therefore, we present a methodology which solves this issue and allows the automatic localization of the fire front and the burned perimeter with high spatial and temporal resolution. The actively burning area is detected in TIR georeferenced images through a combination of intensity thresholding techniques, morphological processing and active contours (also called snakes). Subsequently, flame projections are filtered out by the temporal frequency analysis of the appropriate contour descriptors. Finally, fire perimeters are built and updated on-line, and rates of spread (ROS) are computed. The proposed algorithm was validated using different aerial TIR footages acquired during large-scale field experimental burns and results proved acceptably similar to the manually delineated ground truth. Therefore, this algorithm provides a valuable method to automatically acquire real-time information about the development of a forest fire, whose immediate availability is bound to have a great utility for fire services' decision makers. Furthermore, this information can be used to feed simulation tools based on data assimilation, which would enable the rapid emission of short-term accurate forecasts about the fire evolution.

10214-5, Session 3

Object localization in handheld thermal images for fire ground understanding

Florian Vandecasteele, Steven Verstockt, Bart Merci, Univ. Gent (Belgium)

Currently, the images retrieved with handheld devices during a fire are used in a passive way and no automatic feedback is generated. An automated understanding of the thermal images will change the firefighting from a knowledge based environment to a data and sensing driven community. The work presented in this paper is a first step into this direction and investigates the possibilities of object detection and classification in the thermal and visual domain. State-of-the-art multi-labeling convolutional neural network architectures are applied with transfer learning for object localization and recognition in monocular infrared images. The object localization module, represented in this paper, is one part of a larger architecture that helps in the understanding of real fires.

The localization of objects in real fire thermal images will be helpful in different ways. However it is important to remark that only items which irradiate infrared light could be detected. Firstly, an automated detection and reporting of the element that is burning could be generated (see Figure 1). This could be further used as input for modelling and forecasting of fires with CFD packages. Secondly, understanding the room configuration (i.e. each objects location) will help with the indoor localization in reduced visibility environments. Thirdly, object classification is already proven to increase scene recognition task (i.e., the classification into kitchen, cellar, living room). Finally, the object detection from monocular thermal images could also assist the autonomous firefighting robots. Within this paper, we address the problems arising for each task and give some solutions and ideas for further research, such as the linking of BIM information and the possibilities with handheld devices.

10214-6, Session 4

Advanced imaging in metallic additive manufacturing *(Invited Paper)*

Ralph B. Dinwiddie, Andrzej Nycz, Bradley S. Richardson, Mark W. Noakes, Brian Post, Frederick A. List III, Ryan R. Dehoff, Peter D. Lloyd, Lonnie J. Love, Niyanth Sridharan, Jacob Raplee, Narendran Raghavan, Oak Ridge National Lab. (United States); S. Suresh Babu, Oak Ridge National Lab. (United States) and Univ. of Tennessee (United States)

The Manufacturing Demonstration Facility (MDF) at Oak Ridge National Laboratory (ORNL) provides world-leading capabilities in manufacturing facilities that leverage previous and on-going government investments in materials science research and characterization. This facility is home to numerous systems for the production of components with complex shape using additive manufacturing techniques (a.k.a. 3D-Printing). The industrial grade printers in operation include systems that print in thermoplastics or metal alloys. The metal alloy printers include several powder-bed based systems which either employ e-beams or lasers as their heat source. Another metal alloy printer is a direct metal deposition system that injects metallic powder into a laser beam that melts and deposits the metal onto an existing substrate. Finally, there are several wire-fed 3D printers that use MIG or TIG arc welding or a laser as their heat sources. ORNL has partnered with manufacturers, materials suppliers, OEMs and universities to assist in improving the final part quality and to develop new materials for use in these devices. One method currently being used to study the additive manufacturing processes relies on the advanced imaging capabilities at ORNL. These include infrared (IR) imaging, high-speed IR imaging and high-speed video. Much can be learned from advanced imaging of these processes and ultimately imaging systems may be used routinely for in-situ online quality assurance and process control. At ORNL, a high performance multi-physics computational tool is also extensively used to understand the effect of scan strategy and input parameters on the solidification microstructure of the fabricated component. Spatio-temporal temperature data from simulation and infrared imaging can complement each other in the verification and validation of the part quality fabricated through additive manufacturing process. This paper discusses thermal imaging techniques, lessons learned, and general observations made during metallic additive manufacturing processes.

Research sponsored by the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Advanced Manufacturing Office, under contract DE-AC05-00OR22725 with UT-Battelle, LLC.

10214-7, Session 4

Measurement of process dynamics through coaxially aligned high speed NIR imaging in laser powder bed fusion additive manufacturing

Jason Fox, Brandon Lane, National Institute of Standards and Technology (United States); Brian Fisher, Carnegie Mellon Univ. (United States)

For process stability in laser powder bed fusion (LPBF) additive manufacturing (AM), control of melt pool dimensions is imperative. In order to control melt pool dimensions in real time, sampling frequencies in excess of 10 kHz may be required, which presents a challenge for many thermal and optical monitoring systems. The National Institute of Standards and Technology (NIST) is currently developing the Additive Manufacturing Metrology Testbed (AMMT), which replicates a metal based laser powder bed fusion AM process while providing open architecture for control, sensing, and calibration sources. The system is outfitted with a coaxially aligned, near-infrared (NIR) imaging system, capable of 50,000 frames per second. Similar monitoring systems incorporated into LPBF testbeds, or even some into commercial machines, but at lower available frame rates, which may limit observation of higher frequency events such as spatter or size fluctuations. This paper presents an investigation of the coaxial imaging systems of the AMMT to capture the process dynamics, and quantify the effects of dynamic fluctuations on melt pool size measurements. Additionally, melt pool size measurements collected in-situ are compared to ex-situ measurements, and results are discussed in terms of temporal bandwidth.

10214-8, Session 5

Micro-scale thermal imaging of CO2 absorption in the thermochemical energy storage of Li metal oxides at high temperature

Junko Morikawa, Hiroki Takasu, Massimiliano Zamengo, Yukitaka Kato, Tokyo Institute of Technology (Japan)

Li-Metal oxides (typical example; lithium ortho-silicate Li_4SiO_4) are regarded as a novel solid carbon dioxide CO_2 absorbent accompanied by an exothermic reaction. At temperatures above 700˚C the sorbent is regenerated with the release of the captured CO_2 in an endothermic reaction. As the reaction equilibrium of this reversible chemical reaction is controllable only by the partial pressure of CO_2, the system is regarded as a potential candidate of the chemical heat storage at high temperatures.

In this study, we applied our recent developed mobile type instrumentation of micro-scale infrared thermal imaging system to observe the heat of chemical reaction of Li_4SiO_4 and CO_2 at high temperature above 650 ˚C or higher. In order to quantify the micro-scale heat transfer and heat exchange in the chemical reaction, the superimpose signal processing system is setup to determine the precise temperature.

Under an ambient flow of carbon dioxide, a powder of Li_4SiO_4 with a diameter 50 micron started to shine caused by an exothermic chemical reaction heat above 600˚C. This phenomena was accelerated with increasing temperature up to 700˚C. At the same time, the reaction product lithium carbonate Li_2CO_3 started to become molten with endothermic phase change above 700˚C. The direct measurement of such multiple thermal phenomena at high temperatures is significant to promote an efficient design of chemical heat storage materials.

This is the first observation of the exothermic heat of the reaction of Li_4SiO_4 and CO_2 at around 700˚C by the thermal imaging method.

10214-9, Session 5

Thermal analysis of fused deposition modeling process using infrared imaging and finite element modelling

Xunfei Zhou, Sheng-Jen Hsieh, Texas A&M Univ. (United States)

Over the years, Fused Deposition Modeling (FDM) has become the most popular technique used in commercial 3D printers due to its cost effectiveness and ease of use for fabrication. Mechanical strength and dimensional accuracy are two key factors that impact the reliability of FDM products. However, solid-liquid-solid state changes of the material during the FDM process make the process difficult to monitor and model. In this

study, an experimental model was developed to use cost-effective infrared thermography-based imaging methods to acquire the temperature history of filaments at the interface of each layer and their corresponding cooling mechanism. A three-dimensional finite element model was constructed to simulate the same process using the element activate-deactivate feature and validated using the temporal and spatial temperature profile from the experimental model. The spatial temperature pattern showed a maximum of 10% difference between the experimental and numerical models and the temporal temperature pattern showed a maximum of 5% difference. This work suggests that numerical modeling of the FDM process is reliable and can facilitate better understanding of bead spreading and road-to-road bonding mechanics during fabrication.

10214-10, Session 5

Thermography for lithium-ion polymer batteries monitoring and lifetime prediction

Xunfei Zhou, Sheng-Jen Hsieh, Anav Malik, Texas A&M Univ. (United States)

Lithium-ion batteries have become indispensable in consumer devices due to their high energy density and long lifespan. However, abusive usage conditions, flawed manufacturing processes and aging can greatly influence battery performance or create safety concerns. Therefore, it is necessary to replace batteries before they fail or reach end of life. Traditionally, battery lifetime prediction is achieved by analyzing data from current, voltage and impedance sensors. However, these types of prognostics are expensive to implement and require direct contact. In this study, low-cost thermal infrared sensors were used to acquire thermographic images over the entire lifetime of small scale lithium-ion polymer batteries (>300 cycles). An infrared system (non-destructive) was use to take temperature readings from multiple batteries during charging and discharging cycles of 1C and thermal characteristics of the batteries were derived from the images. A time-dependent and spatially resolved temperature mapping was obtained and quantitatively analyzed. The mapping was used in combination with a clustering methodology to locate internal hot or cold spots. This approach will be utilized to correlate thermal characteristics of the batteries with their life cycles, and to propose cost-effective thermal infrared imaging applications in battery prognostic systems.

10214-11, Session 6

Thermographic image analysis for classification of ACL rupture disease, bone cancer, and feline hyperthyroid, with Gabor filters

Mehrdad Alvandipour, Scott E. Umbaugh, Deependra K. Mishra, Rohini Dahal, Norsang Lama, Southern Illinois Univ. Edwardsville (United States)

Thermography and pattern classification techniques are used to classify three different pathologies in veterinary images. Thermographic images of both normal and diseased animals were provided by the Long Island Veterinary Specialists (LIVS). The three pathologies are ACL rupture disease, bone cancer, and feline hyperthyroid. The diagnosis of these diseases usually involves MRI or other costly tests while the method that we propose uses thermographic images and image analysis techniques and can be used as a prescreening tool. Images in each category of pathologies are first filtered by Gabor filters and then various features are extracted and used for classification into normal and abnormal classes. Gabor filters are linear filters that can be characterized by the two parameters wavelength ? and orientation ?. With two different wavelength and five different orientations, a total of ten different filters were studied. Different combinations of camera views, filters, feature vectors, normalization methods, and classification methods, produce different tests that were examined and the sensitivity, specificity and success rate for each test were produced. Using the Gabor features alone, sensitivity, specificity, and overall success rates of 85% for each of the pathologies was achieved.

10214-12, Session 6

Method for constructing 3D dynamic thermograms with high resolution geometry

Grigory Chernov, Valery Chernov, Marcelino Barboza-Flores, Univ. de Sonora (Mexico)

3D thermography systems that combine 3D geometric data and 2D thermography data enable users to have a more accurate representation of the surface temperature distribution and aid in its interpretation. Additionally, dynamic thermography presents more opportunities for analysis as opposed to static thermography, and can be used to extract more information about the thermal pattern of the body. However, 3D thermography uses 3D scanning techniques to produce accurate geometric data, which can take minutes and thus are incompatible with most dynamic thermography.

In this work we present a method for combining high resolution 3D scans of the human body with dynamic thermography to obtain high quality 3D dynamic thermograms. The method consists of taking a high resolution 3D scan of the body and producing a 3D model. After the model is produced, thermograms are taken using a standard FLIR thermal camera physically coupled with a depth camera. The information from the depth camera is used to produce a low resolution 3D model that is then registered to the high resolution scan of the body which allows us to estimate the 6DOF pose of the depth camera and the thermal camera. The estimated pose is then used to project the thermogram onto a high quality 3D scan of the body to produce a 3D thermogram. Since the thermal camera and depth camera operate at similar frame rates, this method can be used to produce dynamic thermograms in order to observe the effects of thermal stimulation on the subject.

10214-13, Session 6

Non-invasive characterization of normal and pathological tissues through dynamic infrared imaging in the hamster cheek pouch oral cancer model

Maria Herrera, Andrea Monti Hughes, Natalia Salva, Amanda Schwint, Gustavo A. Santa Cruz, Claudio Padra, Comisión Nacional de Energía Atómica (Argentina)

Biomedical infrared thermography provides information on the normal and abnormal status and response of tissues in terms of spatial and temporal variations in body infrared radiance. It is especially attractive in cancer research and to evaluate healthy tissue response to radiation.

Based on our previous studies in melanoma patients treated with Boron Neutron Capture Therapy (BNCT) as well as in animal research, we performed Dynamic Infrared Imaging (DIRI) to understand and evaluate BNCT-induced tumor control and radiotoxicity in the hamster cheek pouch model of oral cancer focusing on the observation of temperature changes under forced transient conditions, associated with water exudation in the tissue-air interface of tumor and normal tissue in the pouch, related with the effects of the irradiation.

We examined 49 hamsters with DIRI, divided into 6 groups: non-irradiated normal hamster cheek pouch; dimethylbenz(a)anthracene (DMBA)-cancerized pouch + BNCT mediated by boronophenylalanine (BPA-BNCT) or beam-only; normal pouch + BPA-BNCT or beam-only; and sham group (DMBA-cancerized pouch without treatment). Tissue thermal responses were assessed before, during and after forced temperature changes at tissue-air interface. We modeled each transient process with the lumped capacity method, considering the heat transfer from tissue to ambient through convection and evaporation, to determine the typical time constant and degree of evaporation occurring on the tissue surface. Conduction and convection thermal parameters were determined by the 1-dimensional transient bioheat problem formulated by Pennes equation, attaching the evaporation term.

We found significant differences in the studied parameters between tumors treated with BPA-BNCT and sham or beam-only groups.

10214-14, Session 6

About possibility of temperature trace observing on a human skin through clothes by using computer processing of IR image

Vyacheslav A. Trofimov, Vladislav V. Trofimov, Ivan L. Shestakov, Roman G. Blednov, M.V. Lomonosov Moscow SU (Russian Federation)

We analyze IR images of a person, which drinks water and eats chocolate. We follow a temperature trace on human body skin, caused by changing of temperature inside the human body. Some experiments were made with measurements of a body temperature covered by T-shirt or other clothes. Shown results are very important for the detection of forbidden objects, cancelled inside the human body, by using non-destructive control without using X-rays.

10214-15, Session 6

Skin temperature bilateral differences at upper limbs and joints in healthy subjects

Ricardo Vardasca, Teresa Restivo, Joaquim Gabriel, Univ. do Porto (Portugal)

Infrared thermography has been used in healthcare to monitor physiology in real-time in a non-contact, non-invasive and non-ionizing procedure based in the skin surface temperature, which is highly influenced by the peripheral blood flow.

In order to correctly analyze the effect of any physical activity or mechanical provocation to the upper extremities with infrared thermal imaging, reference steady data is needed. To address that demand, infrared images were taken from 40 healthy adults, which provided informed consent, with an infrared camera FLIR E60sc, using standard capture protocols, which specify subject preparation, equipment settings and examination room conditions (environment temperature of 22±0.5 °C; relative humidity of < 50%; air flow of < 2m/s^2; and absence of incident lightning over the participant). The healthy status of the participants was considered based in the score 0 of the Euro-QOL 5D questionnaire.

Regions of interest such as: arm, forearm, hand, shoulder, elbow and wrist both in both anterior and dorsal views were assessed in terms of mean temperature distribution, standard deviation and its bilateral difference. The results presented a maximum bilateral difference of 0.5±0.2 °C at the anterior forearm region.

These findings are relevant for further research on musculoskeletal conditions complementary diagnosis with infrared thermography and in the monitoring of the process of their rehabilitation based in a convergence of higher differences to the healthy characterized range.

10214-16, Session 6

Pulse compression favourable aperiodic infrared imaging approach for non-destructive testing and evaluation of bio-materials

Ravibabu Mulaveesala, Geetika Dua, Indian Institute of Technology Ropar (India)

In recent years, aperiodic, transient pulse compression favourable infrared imaging methodologies demonstrated as reliable, quantitative, remote characterization and evaluation capabilities for testing and evaluation of various bio-materials. This present work demonstrates a pulse compression favourable aperiodic thermal wave imaging technique (frequency modulated thermal wave imaging technique (FMTWI)) for bone diagnostics, especially by considering the bone with tissue, skin and muscle over layers. In order to find the capabilities of the proposed FMTWI technique to detect the density variations in a multi layered skin-fat-muscle-bone structure, finite element modelling and simulation studies have been carried out. Further, various post processing approaches have been adopted on the temporal temperature data in order to improve the detection capabilities of FMTWI.

10214-17, Session 7

Thermal inspection of a composite fuselage section using a fixed eigenvector principal component analysis method

Joseph N. Zalameda, Sean Bolduc, Rebecca Harman, NASA Langley Research Ctr. (United States)

A composite fuselage aircraft forward section was inspected with flash thermography. The fuselage section is 24 feet long and approximately 8 feet in diameter. The structure is primarily configured with a composite sandwich structure of carbon fiber face sheets with a Nomex® honeycomb core. The outer area was inspected. The thermal data consisted of 477 data sets totaling in size of over 227 Gigabytes. Principal component analysis (PCA) was used to process the data sets for substructure and defect detection. A fixed eigenvector approach using a global covariance matrix was used and compared to a varying eigenvector approach. The fixed eigenvector approach was demonstrated to be a practical analysis method for the detection and interpretation of various defects such as paint thickness variation, water intrusion damage, and delamination damage. In addition, inspection considerations are discussed including coordinate system layout, manipulation of the fuselage section, and the manual scanning technique used for full coverage.

10214-18, Session 7

Numerical and experimental analyses for natural and non-natural impact composites via thermographic inspection, ultrasonic C-scan and terahertz spectroscopy

Hai Zhang, Univ. Laval (Canada); Stefano Sfarra, Univ. degli Studi dell'Aquila (Italy); Marc Genest, National Research Council Canada (Canada); Fabrizio Sarasini, Sapienza Univ. di Roma (Italy); Henrique C. Fernandes, Univ. Federal de Uberlândia (Brazil); Stefano Perilli, Univ. degli Studi dell'Aquila (Italy); Xavier P. V. Maldague, Univ. Laval (Canada)

Natural fiber reinforced composites are increasingly being used for

advanced industrial applications thanks to their low cost and environmental impact. However, their response to impact loading is generally weaker than that offered by traditional composites reinforced with man made fibers such as carbon and glass. An effective strategy to address this issue is the hybridization of natural fibers with synthetic ones.

In this paper, thermographic inspections were performed on composite materials made of bagasse, hemp, basalt fibers, as well as a mix of basalt and carbon fibers having different mixture. In particular, vibrothermography (VT), an ultrasonic excited thermography based technique, was compared with optical thermography (OT). In a few cases, finite element analyses (FEA) based on mechanical impacts were performed prior to the thermographic experiments to predict their behaviour. In the latter cases, a comparison between experimental and simulated (via image processing) thermographic results was afterwards conducted, with the intent to validate the method.

In addition, terahertz spectroscopy (THz) is also used to analyze the impact damages. The THz imaging performed both in reflection and transmission modes and compared to ultrasonic C-scan (UT). By this integration, complementary parameters can be determined monitoring thermophysical and optical properties.

Finally, the advantages and disadvantages of each method in the defect detection capability are summarized. Particular emphasis was given to the inspection of basalt and carbon fibers, which are currently the most in use in the mechanical field.

10214-19, Session 7

An overview on non-stationary thermal wave imaging for testing and evaluation of solids

Ravibabu Mulaveesala, Vanita Arora, Geetika Dua, Indian Institute of Technology Ropar (India)

Among various widely used InfraRed Non-destructive Testing (IRNDT) modalities such as pulse, lock-in, pulse phase, transient aperiodic pulse compression favourable excitation schemes gained wide acceptance in recent years for inspection and evaluation of various solid materials. Growing concerns of surface and subsurface anomaly detection with low peak power heat stimuli than the widely used conventional short duration high peak power pulse based thermographic methods and in a reasonable testing time with improved test resolution compared to conventional sinusoidal modulated lock-in thermography, make these aperiodic techniques invaluable for this field. The present work highlights a comparative study on various data processing approaches adopted on transient pulse compression favourable aperiodic thermographic techniques which can be performed with moderate peak power heat stimulus and in a limited span of time with enough resolution. This present work compares advantages and limitations of various aperiodic thermal wave imaging techniques for subsurface defect detection in mild steel sample.

10214-20, Session 7

Recent advances in infrared coded excited thermal wave imaging technique for non-destructive testing and evaluation of solid materials

Ravibabu Mulaveesala, Vanita Arora, Indian Institute of Technology Ropar (India)

In recent years infrared thermographic techniques have gained wide acceptance for testing and evaluation of various solid materials due to it's inherent merits such as non-contact, fast, quantitative and suitability for it's safe field inspection. This contribution introduces a novel Golay coded thermal wave imaging approach and associated data processing scheme for detection of defects located at various depths located inside a mild steel sample. Recently introduced time and conventional frequency domain based data processing methods are adopted on the generated temporal thermal data to reveal the hidden defects. Obtained results show the potential capabilities of proposed matched filtering based processing scheme in comparison with the conventional widely used frequency domain phase scheme by considering the signal to noise ratio as a figure of merit.

10214-48, Session PTue

Universal thermal imaging diagnostics for measuring parameters of pulsed electron beams

Galina Kholodnaya, Roman Sazonov, Denis Ponomarev, Alexander I. Pushkarev, National Research Tomsk Polytechnic Univ. (Russian Federation)

The paper presents the thermal imaging diagnostics for on-line control of the energy density distribution of the electron beam cross section, the electron energy spectrum, the spatial distribution of electrons with energies in the selected range, and the total energy of the pulsed electron beam. The thermal imaging diagnostics is based on the registration of the electron beam thermal print in a material with low bulk density and low thermal conductivity. To register the thermal print, a Fluke-Ti10 thermal imager was used. The registration interval of a heat pattern takes no more than 0.1-0.2 s. The sensitivity of the thermal imager provides the registration of the thermal print per a pulse at the density of the electron current ranging 0.1-0.4 kA/cm2.

To determine the sample depth electron beam energy release distribution, the target made from the material (SPB-C25 cellular polystyrene) with low bulk density and low thermal conductivity was used. The geometrical profile was examined and the ratios of the sample depth electron beam energy release for different cathodes (the material of the cathode is graphite, carbon cloth, tungsten) and the anode-cathode distances (10-16 cm) are obtained. Testing has been conducted using the TEA-500 pulsed electron accelerator. The parameters of the accelerator were as follows: the accelerating voltage was 350-450 kV, the pulse duration (at half-height) was 60 ns, and the total kinetic energy of electrons in the pulse was as high as 150 J.

The developed universal thermal imaging diagnostics for measuring the parameters of pulsed electron beams requires neither expensive consumables nor plenty of processing time. Testing showed that the sensitivity of a typical thermal imager provides the registration of a pulsed electron beam heat pattern within one pulse with energy density over 0.1 J/cm2 with the spatial resolution of 0.9-1 mm.

10214-49, Session PTue

Thermography based prescreening software tool for veterinary clinics

Rohini Dahal, Southern Illinois Univ. Edwardsville (United States) and Long Island Veterinary Specialists (United States); Scott E. Umbaugh, Deependra K. Mishra, Norsang Lama, Mehrdad Alvandipour, Southern Illinois Univ. Edwardsville (United States); Dominic J. Marino, Joseph Sackman, Long Island Veterinary Specialists (United States)

Under development is a software tool which will be used in veterinary clinics for prescreening these pathologies: anterior cruciate ligament (ACL), bone cancer and feline hyperthyroid. Currently, veterinary clinical practice uses several imaging techniques including radiology, computed tomography (CT), and magnetic resonance imaging (MRI). But, harmful radiation involved during imaging, expensive equipment setup, excessive time

consumption and the need for a co-operative patient all the time during imaging, are major drawbacks of these techniques. In veterinary procedures, it is very difficult for animals to sit still for the time periods necessary for standard imaging without resorting to sedation – which creates another set of complexities. Therefore, clinical application software integrated with a thermal imaging system and the algorithms with high sensitivity and specificity for these pathologies, can address the major drawbacks of the existing imaging techniques. A graphical user interface (GUI) has been created to allow ease of use for the clinical technician. The technician inputs an image, enters patient information, and selects the camera view associated with the image and the pathology to be diagnosed. The software will classify the image using an optimized classification algorithm that has been developed through thousands of experiments. Optimal image features are extracted, and the feature vector, along with the stored image database are used for classification. Classification success rates as high as 100% for bone cancer, 75% for ACL and 80% for feline hyperthyroid have been achieved. The software is currently undergoing preliminary clinical testing.

10214-50, Session PTue

Visualization and analysis of pulsed ion beam energy density profile with infrared imaging

Alexander I. Pushkarev, Yulia Isakova, National Research Tomsk Polytechnic Univ. (Russian Federation)

Intense pulsed ion beams (IPIB), having short pulse duration (80-150 ns) and high power density, produce a fast temperature rise (up to 10^7 – 10^9 K/s) on the surface, which finds many applications in material processing technologies. One of the most important parameters of IPIB is the distribution of the energy density over the cross section of the beam. Infrared imaging technique was used as a surface temperature mapping tool to record spreading of the temperature field distribution and evolution on a thin (100 μm) metal target. The technique enables the measuring of the total ion beam energy, energy density distribution at the cross section and was also found useful in the analysis of the ion beam divergence during transportation to the target and moving the ion beam spot at the focal plane from pulse to pulse. For infrared cameras Fluke Ti10 and Fluke Ti400, the technique can achieve surface energy density sensitivity of 0.1 J/cm2 and spatial resolution of 1-2 mm. For correct use of the thermal imaging technique for measuring of ion beam parameters, we analyzed the impact of high-energy electrons, anode plasma and other factors to target heating. Testing of the technique was carried out with IPIBs having the energy density in the range of 0.5 - 10 J / cm^2 (for different ion diodes), total energy in the pulse of 80-100 J and pulse duration of 150 ns.

10214-51, Session PTue

Thermal conductivity characterization of polyaniline doped material for thermoelectric applications

Alessia Famengo, Istituto di Chimica della Materia Condensata e di Tecnologie per l'Energia (Italy); Stefano Rossi, Paolo Bison, Consiglio Nazionale delle Ricerche (Italy); Stefano Boldrini, CNR-ICMATE (Italy)

Energy harvesting applications are moving the interest of researchers in the field of thermoelectric materials and devices from the inorganic to the organic materials to exploit low temperature (T<150°C) waste heat. Among organic thermoelectrics, polyaniline is an intrinsically conductive polymer which, after suitable doping, behave like thermocouples exhibiting interesting values of both electrical conductivity and Seebeck coefficient. Moreover, the possible manufacturing of such materials in light, thin and flexible sheets makes them easily integrated into unusual topologies to fit the geometrical requirements of applications spanning from wearable electronics to power supplies for mobile devices. Notwithstanding such peculiarities the figure of merit that characterizes the efficiency of the energy conversion (heat to electrical energy) for such materials is still far from the values reached by classical inorganic materials like Bi2Te3, PbTe, SiGe and Sb2Te3. Presumably the most difficult parameter to measure to evaluate the figure of merit is the thermal conductivity that in the synthesis of these polymeric material is anisotropic i.e. it shows different values if measured through the thickness of the sheet or in plane. IR thermography, thanks to its imaging capability is an interesting instrument to conduct photothermal experiment that allows the characterization of both the thermal conductivity components. A laser pulse, spatially localized, heats the material under test. IR thermography collects a sequence of images of the transient phenomena that are spatially decomposed by means of the Fourier Transform and successively analysed in time to determine the thermal diffusivity. The measurement of the specific heat and the density allows for the assessment of thermal conductivity in the two aforementioned direction.

10214-52, Session PTue

A sectioned calorimeter for fast measurement of energy distribution of a pulsed electron beam

Ivan Egorov, Maksim Serebrennikov, Artem Poloskov, Vitaliy Ezhov, National Research Tomsk Polytechnic Univ. (Russian Federation)

The paper describes principals and usage of a new device for measuring electron beam energy distribution. Calorimeter has a simple structure with the sectioned collector fixed in 3D printed matrix made of ABS plastic for low thermal conductivity between sections. The temperature field of sections is registered by an infrared camera for the period of less than 10 seconds after a beam shoot. This ensures accuracy for the energy density of more than 0.5 J/cm^2. The thickness of the calorimeter collector is enough to measure beams with the electron kinetic energy of up to 700 keV. The sealed case of the calorimeter with a preliminary calibrated CaF infrared-transmitting window provides both measurements for vacuum and for atmospheric pressure gases. Described device was successfully used for measurements of the electron beam profile and energy distribution. The obtained results were compared and fully verified with the results from a traditional single plate calorimeter.

10214-53, Session PTue

Infrared image correction for the reduction of background reflection

Nagahisa Ogasawara, Chie Kobayashi, Hiroyuki Yamada, National Defense Academy (Japan)

In infrared thermographic testing, a background reflection is one of the main causes of a false detection. The authors developed an image processing program that can reduce the effect of the background reflection from a thermal image. The program mainly consists of two parts. The first part is the correction of emissivity which depends on a face angle. The emissivity is changed not only by a material property and a surface roughness but also by a face angle. Especially in a test for a high building and an oil tank, the thermal image includes a wide range of face angle. In order to solve this problem, by using the theoretical equation of emissivity, the angle correction of emissivity is carried out for each pixel in the thermal image. It was confirmed that the first part of this program can correct efficiently the emissivity change for a flat plate and a curved surface which have a wide range of face angle respectively. The second part of the program is the reduction of a background reflection. The emissivity change causes the reflectivity change and, as a result, this changes the effect of the background reflection. To reduce this effect, the background heat source is measured separately and then is subtracted from the thermal image. At this

time, the specular reflectivity should be used. Consequently, this program can reduce the effect of reflection from the background heat source and extract the emission of the flaw part from the complex thermal image.

10214-54, Session PTue

High-performance interfaces for the implementation of various cooled IR detectors

Marian Wachs, Birgit Vollheim, Matthias Vettermann, Matthias Krausz, InfraTec GmbH (Germany)

The development of integrated detector cooler assemblies (IDCAs) is remarkable. Whereas a 640x512 frame format was still common some years ago, high-end detectors provide nowadays a resolution up to 2560x2048 pixels with appropriate frame rates. The data rates of cooled IR detectors have increased by one order of magnitude and reach meanwhile up to 5Gbit/s. The interfaces to these detectors had to change consistently with the demands. Defense and security applications solve these problems usually by developing a customized solution for a large quantity. This is less common for the civil application market with smaller sales volumes and a larger detector variety. Instead, it requires a flexible, scalable and cost-efficient system design that allows the implementation of high-end as well as smaller detectors. The tasks to overcome are challenging. The main issues concern the mechanical integration into a housing, the connection to the system electronic, the integration of a digital data interface and command interfaces, the optical path, the radiometric calibration capability and last but not least economic demands. This paper will concentrate on the electrical and digital interfaces.

Electrical issues are mainly down to the question: “How can I connect the detector to my system electronic?” The electrical characteristics (differential or single ended, voltage levels) and the connectors for the interfaces are not standardized. Every manufacturer of IDCAs can provide a special interface. This paper will discuss the required flexibility to successfully overcome the difficulties in connecting different detectors and enable communication and image transmission.

Digital issues are mainly down to the question: “How do I get the images?” There are many different protocols from CameraLink to proprietary solutions. The system design has to be flexible to adapt itself to the protocols the detectors are using. This paper will discuss a solution that can handle different protocols. After receiving the images from the detector they are usually transmitted to a PC. The interface to a computer should be faster than the detector interface to avoid image buffering. Storing frames inside a camera to get them later only masquerades a bottleneck. The 10GigE interface with GigE Vision protocol provides a fast and scalable solution for many demands and provides downward compatibility to 1GigE for a connection to low-performance device, e.g. a notebook. This paper will discuss the implementation of a 10GigE interface in a thermographic camera and present the relevant performance parameters like data rates and framerates.

10214-56, Session PTue

A study in long-term stability of breast thermal patterns in follow up thermography

Valery Chernov, Univ. de Sonora (Mexico); Enrique Martin-del-Campo-Mena, CECan Miguel Dorantes Mesa (Mexico); Grigory Chernov, Abraham N. Aldaco-Gastelum, Marcelino Barboza-Flores, Univ. de Sonora (Mexico)

Follow up breast thermography, in which two thermograms obtained with an interval of several months are compared, presents an additional opportunity to improve cancer detection and can decrease the rate of false diagnoses. A significant increase in vascular changes found on the second thermogram in the comparison to the first, baseline, thermogram exam could be a further confirmation of the presence of aggressive malignancy. Although follow up thermography has been known since the early sixties and is widely used by thermography practitioners, to our knowledge no systematic studies exist addressing the quantitative comparison of follow-up thermograms.

This work presents a systematic study in long-term stability of the thermal pattern of the breast (anterior view) for a population of symptom-free volunteer women. The first, baseline, and second thermograms were taken using Flir SC655 or IRIS Elite digital infrared cameras with intervals from 3 months to 4 years. Five ROIs: nipples with areolas, breasts, axillary tails, axillas and submammaries were selected on the right and left sides of the body. The thermograms were compared by two methods. In the first one, the differences between the mean temperatures of the ROIs and those of their standard deviations were evaluated. The second method consisted of the using various standard image comparison algorithms to quantify the image differences. The obtained results clearly show that the individual thermal patterns stay almost the same throughout long time. Quantitative criteria that separate the stable and unstable thermal patterns are proposed.

10214-57, Session PTue

Modified algorithm for mineral identification in LWIR hyperspectral imagery

Bardia Yousefi, Saeed Sojasi, Kévin Liaigre, Clemente Ibarra-Castanedo, Georges Beaudoin, Xavier P. V. Maldague, François Huot, Univ. Laval (Canada); Martin Chamberland, Telops Inc. (Canada)

The application of hyperspectral infrared imagery in the different fields of research is significant. It is mainly used in remote sensing for target detection, vegetation detection, urban area categorization, astronomy and geological applications. The geological applications of this technology mainly consist in mineral identification using in airborne or satellite imagery. We address a quantitative and qualitative assessment of mineral identification in the laboratory condition. We strive to identify nine different mineral grains (Biotite, Diopside, Epidote, Goethite, Kyanite, Scheelite, Smithsonite, Tourmaline, Quartz). A hyperspectral camera in the Long Wave Infrared (LWIR, 7.7-11.8 ?m) with a LW-marco lens having spatial resolution of 100μm, an infragold plate, and a heating source are the instruments used in the experiment. This paper addresses a quantitative and qualitative assessment on an algorithm for identification of minerals in the laboratory (indoor) conditions. The algorithm clusters all the pixel-spectra to identify the minerals. Then the best representatives of each cluster are chosen and compared with the spectral library of JPL/NASA through spectral comparison techniques. These techniques give the comparison amount as features which converts into false colors as the results of this algorithm. Spectral techniques used are Adaptive Matched Subspace Detector (AMSD) algorithm, PCA Local Matched Filter (PLMF), Spectral angle mapper (SAM), and Normalized Cross Correlation (NCC). Nine different mineral grains were tested in the Long Wave Infrared (LWIR, 7.7-11.8 ?m). The results of the algorithm indicate significant computational efficiency (more than 20 times faster than previous approach) and promising performance for mineral identification.

10214-58, Session PTue

Thermal image segmentation applying candid covariance-free incremental principal component thermography (CCIPCT)

Bardia Yousefi, Univ. Laval (Canada); Stefano Sfarra, Univ. degli Studi dell’Aquila (Italy); Clemente Ibarra-Castanedo, Xavier P. V. Maldague, Univ. Laval (Canada)

Thermal and infrared imagery creates considerable developments in Non-destructive Testing (NDT) area. A thermography infrared NDT regarding the inspection of specimens is addressed by involving a new technique for computation of eigen-decomposition (factor analysis) similar Principle Component Thermography(PCT). It is referred as Candid Covariance-Free Incremental Principal Component Thermography (CCIPCT).

The proposed approach uses a computational short-cut to estimate covariance matrix and Singular Value Decomposition(SVD) to obtain the PCT result and ultimately segments the defects in the specimens. The problem of computational expenses for high-dimensional thermal image acquisition is also investigated. Three types of specimens (CFRP, Plexiglass and aluminum) have been used for comparative benchmarking. Then a clustering algorithm segments the defect at the specimens. The results conclusively indicate the promising performance and demonstrated a confirmation for the outlined properties.

SUMMARY

Thermal imagery is shown a considerable assistant in the Non-destructive Testing (NDT) and a great tool to detect the defects. Principle Component Analysis (PCT) considers as one of the very efficient factor analysis methods to find the defects in thermal images. But it suffers from high computational complexity due to calculation of the covariance matrix. Also there are very valuable approaches strived to compute it faster such as Singular Value Decomposition (SVD) but this problem still seems one of the difficulties particularly in some applications that the fast computations is important. The proposed approach uses a computational algorithm called Candid Covariance-Free Incremental Principal Component Thermography (CCIPCT) to calculate principle component images and segments the defects through a clustering afterward. A comparative estimation of the decomposition time is shown the better timing performance as compare with current approaches.

10214-59, Session PTue

Fatigue limit estimation of titanium alloy Ti-6Al-4V with infrared thermography

Atsushi Akai, Toyota Central R&D Labs., Inc. (Japan); Daiki Shiozawa, Takahide Sakagami, Kobe Univ. (Japan)

A fatigue limit estimation method with infrared thermography has got an increasing attention recently. In the method, applied stress amplitude to the investigated material is increased step-wisely during a fatigue test and the temperature measurements of a specimen are performed at each stress amplitude. The values of the dissipated energy and mean temperature on the specimen plotted against the applied stress amplitude shows a sharp increase at certain stress amplitude. In addition, it is experimentally known that this value of the stress amplitude matches the fatigue limit obtained by a conventional fatigue test. However, the method has still been applied to limited materials in previous studies. Light weight metals which have high strength to weight ratio are positively used in automobile and aerospace industry. Therefore, an applicability evaluation of the method to the light weight metals is worthwhile. As part of the applicability evaluation, the method was applied to a plate specimen made of titanium alloy Ti-6Al-4V in this study. As a result, the value of dissipated energy plotted against the applied stress amplitude continuously increases in a linear manner without a sharp increase. On the other hand, the value of mean temperature plotted against the applied stress amplitude shows a sharp increase at certain stress amplitude, and the stress amplitude is similar to the fatigue strength which was presented in a literature. Therefore, the possibility of estimating fatigue limit by using the mean temperature is obtained, although it is difficult to estimate fatigue limit by using the dissipated energy.

10214-60, Session PTue

Role of continuous wavelet transform in mineral identification using hyperspectral imaging in the long-wave infrared (7.7 to 11.8 µm) by using SVM classifier

Saeed Sojasi, Bardia Yousefi, Kévin Liaigre, Clemente Ibarra-Castanedo, Georges Beaudoin, Xavier P. V. Maldague, François Huot, Univ. Laval (Canada); Martin Chamberland, Telops Inc. (Canada)

Hyperspectral imaging (HSI) provides spectral and spatial information concerning the emissivity of the surface of materials, which can be used for mineral identification. For this, an endmember, which is the purest form of a mineral, is required. All pure minerals have specific spectral profiles in the electromagnetic wavelength, which can be thought of as the mineral's fingerprint. The main goal of this paper is the identification of minerals by hyperspectral imaging using a machine learning scheme. The information of hyperspectral imaging has been recorded from the energy reflected from the mineral's surface. Solar energy is the source of energy in remote sensing, while a heating element is the energy source employed in laboratory experiments. Our work contains three main steps where the first step of this work involves obtaining the spectral signatures of pure (single) minerals with a hyperspectral camera, in the long-wave infrared (7.7 to 11.8 µm), which measures the reflected radiance from the minerals' surface. In the second step we extract features by continuous wavelet transform (CWT) and finally we use support vector machine classifier with radial basis functions (SVM-RBF) for classification/identification of minerals. The overall accuracy of classification in our work is 90.23± 2.66%. In conclusion, based on CWT's ability to capture the information of signals can be used as a good marker for classification and identification the minerals substance.

10214-61, Session PTue

Satellite image fusion by a using combination of IHS and HPM methods

Saeed Sojasi, Xavier P. V. Maldague, Univ. Laval (Canada)

Generally speaking, Image fusion refers to acquiring the information from two or more images from the same scene in a way that provides more information and facilitates computer-aided processing. The main objective of fusion is to reduce the redundancy of the image such that it increases the desired information embedded in the image. Image fusion algorithms fall into three categories:

1- Substitution methods such as IHS, PCA, etc. 2- Calculation-based methods such as Synthetic Variable Ratio (SRV) and Ratio Enhancement (RE).
3- Multiple-scale methods such as Laplacian pyramid and wavelet. These methods inject the special information from a high spatial precision image to a high spectral precision image.

Some image fusion techniques such as intensity-hue-saturation (IHS) transform and principal component analysis (PCA) are offering promising performance but the drawback with them is that they are not necessarily optimal in newer applications such as Ikonos and QuickBird. Color distortion is of vital importance in fusion image processing. The main result of this paper is the development of a fast HPM-enhanced version of the IHS method for application in fusion image processing in high-resolution satellite images. Combining these two methods makes it possible to benefit from the advantages of both methods. To evaluate the HPM-enhanced version of IHS method we used QuickBird data. The HPM-enhanced version of IHS and HPM-enhanced IHS are used interchangeably. The simulation results of this method show that it is capable of providing a significant improvement in preserving spectral and spatial information.

10214-62, Session PTue

Infrared thermography and finite element method applied to the detection of a plaster detachment

Mohamed El Afi, Sougrati Belattar, Cadi Ayyad Univ. (Morocco)

is one of the suitable techniques of non-destructive evaluation for the detection of defect in concrete structure in general and particularly in the habitat system. It allows a quick non-destructive testing of a given structure by studying the obtained thermal images. The main objective of these investigations is the analysis of a plaster slab containing two types of delamination: air blades and water blades. The study concerns the effect of the geometry and the size of this delamination on the surface temperature. The simulations results, using the finite element method, are presented and analyzed in form of thermographical images by interpreting different contrast in these images and the temperature spatial distribution changes.

10214-21, Session 8

Characterizing open and non-uniform vertical heat sources: towards the identification of real vertical cracks in vibrothermography experiments

Arantza Mendioroz, Alazne Castelo, Univ. del País Vasco (Spain); Ricardo Celorrio, Univ. de Zaragoza (Spain); Agustín Salazar, Univ. del País Vasco (Spain); Pablo López de Uralde, Izaskun Gorosmendi, Eider Gorostegui-Colinas, IK4-Lortek (Spain)

Ultrasound excited thermography is a powerful tool to detect defects such as cracks and delaminations in a wide variety of materials. In metals, where the viscoelastic effect is negligible, heat is generated at the defect mainly due to the rubbing between its surfaces so the defect behaves as a heat source in a cold environment. The resulting surface temperature distribution was used by the authors in previous works to retrieve the area and location of artificial kissing cracks with homogeneous heat generation along the whole crack surface. This inverse problem is ill-posed and thus the inversion is unstable. The algorithm was stabilized introducing a penalty term based on total variation functional which gave very good results for homogeneous heat source distributions along the crack. However, in real situations with surface breaking cracks, the closure state of the crack determines the portion of the crack surface that actually generates heat. Furthermore, non-uniform heat generation is expected as the rubbing of crack asperities is not homogeneous along the crack surface. In this work we apply lock-in vibrothermography to characterize position-dependent heat source distributions representing open vertical cracks excited by amplitude modulated ultrasounds. We first invert synthetic data corresponding to “half-penny” shaped heat sources with angle-, radius-, and depth-dependent flux distributions. Then we validate the results inverting experimental data obtained from calibrated artificial heat sources representing open cracks. Finally, we present inversions of experimental data obtained from real defects in bare welded Inconel 718 samples.

10214-22, Session 8

Fatigue damage evaluation of short fiber CFRP based on phase information of thermoelastic temperature change

Takahide Sakagami, Daiki Shiozawa, Yu Nakamura, Kobe Univ. (Japan); Shinichi Nonaka, DIC Corp. (Japan)

Carbon fiber-reinforced plastic (CFRP) is widely used in industry because of its excellent specific strength and specific rigidity. Short fiber composite material is receiving an increasing attention since it has excellent moldability and productivity. However, it shows complicated behavior in fatigue fracture due to the random fibers orientation. In this study, thermoelastic stress analysis (TSA) is applied to the evaluation of fatigue damage in short fiber composite. The range of thermoelastic temperature change and the phase difference between the thermoelastic temperature change and applied stress are measured during the cyclic loading fatigue test. The range of thermoelastic temperature change corresponds to the propagation of delamination, like thermoelastic damage analysis (TDA). The phase difference shows the change in distribution corresponding to the delamination damage propagation. It was found that a new fatigue damage evaluation technique based on the phase difference called the thermoelastic phase damage analysys (TPDA) can be applied to the evaluation of damage propagation in CFRP.

10214-23, Session 8

High-efficient ultrasonic vibrothermography: using resonance piezoelectric transducers for detecting impact damage in graphite/epoxy composites

Vladimir P. Vavilov, National Research Tomsk Polytechnic Univ. (Russian Federation); Daria A. Derusova, Tomsk Polytechnic Univ. (Russian Federation); Stefano Sfarra, Univ. degli Studi dell’Aquila (Russian Federation)

The use of wide-frequency band piezoelectric transducers in ultrasonic infrared thermography allows analyzing material structural defects under lower power of ultrasonic stimulation to compare with single-frequency stimulation, which is fulfilled, for example, by means of magnetostrictive stimulation. While developing hardware for practical applications, a key problem is the determination of defect resonance frequencies. This can be achieved through the detailed analysis of material surface vibrations by using a technique of laser vibrometry in a wide range of frequencies. Because of this peculiarity of practical vibrothermography, one should carefully choose technical characteristics of available piezoelectric transducers. In this study, we consider an approach which allows analyzing ultrasonic resonance in samples with hidden defects by using resonance piezoelectric transducers. The experimental illustration is presented with some examples of the inspection of graphite/epoxy composite samples including both external and internal layers of flax.

10214-24, Session 8

High-Speed and High-Definition Infrared Imaging for Material Characterization in Experimental Mechanics

Marc-André Gagnon, Frédérick Marcotte, Philippe Lagueux, Vincent Farley, Éric Guyot, Telops Inc. (Canada); Vince Morton, Telops (United States)

Heat transfers are involved in many phenomena such as friction, tensile stress, shear stress and material rupture. Among the challenges encountered during the characterization of such thermal patterns is the need for both high spatial and temporal resolution. Infrared imaging provides information about surface temperature that can be ascribed to the stress response of the material and breaking of chemical bounds. In order to illustrate this concept, tensile and shear tests were carried out on steel, aluminum and carbon fiber composite materials and monitored using high-speed (Telops FAST-IR 2K) and high-definition (Telops HD-IR) infrared imaging. The results illustrate how high-speed and high-definition infrared imaging in the midwave

infrared (MWIR, 3 – 5 μm) spectral range can provide detailed information about the thermal properties of materials undergoing mechanical testing.

10214-25, Session 8

Non-destructive thermo-mechanical behavior assessment of glass-ceramics for dental applications

Evangelos Z. Kordatos, Zaid Abdulkadhim, Antonio Feteira, Sheffield Hallam Univ. (United Kingdom)

Every year millions of people seek dental treatment in order to either repair damaged, unaesthetic and dysfunctional teeth or replace missing natural teeth. Several dental materials have been developed to meet the stringent requirements in terms of mechanical properties, aesthetics and chemical durability in the oral environment. Glass-ceramics exhibit a suitable combination of these properties for dental restorations. This research is focused on the assessment of the thermo-mechanical behavior of bio-ceramics and particularly lithium aluminosilicates glass-ceramics (LAS glass-ceramics). Specifically, techniques based on infrared thermography (IRT) and ultrasounds have been applied in order for the structure – property relationship to be evaluated. Non-crystallized, partially crystallized and fully crystallized glass-ceramic samples have been non-destructively assessed in order for their thermo-mechanical behavior to be associated with their micro-structural features. The combination of these methodologies has been successfully applied for the study of glass-ceramics behavior.

10214-26, Session 8

Energetic approach based on IRT to assess plastic behaviour in CT specimens

Rosa De Finis, Davide Palumbo, Francesco Ancona, Umberto Galietti, Politecnico di Bari (Italy)

In this work the Thermographic technique (IRT) was used to characterize the fracture mechanics behavior of stainless steels. In particular, IRT is proposed for evaluating the dissipated energy and the plastic area around the crack tip.

Generally, during fracture mechanics tests, two thermal effects related to elasto-plastic properties and mechanical hysteresis are generated. In this way, two heat sources responsible for temperature variations within the specimen can be considered: thermomechanical couplings and intrinsic dissipation. This phenomena lead to a change in phase signal between temperature and loading signal. In particular, during a fracture mechanics test, the phase signal remains constant up to the occurrence of plastic behaviour in the material and with increasing of damage; phase variations can be observed due to the previously discussed phenomena either in negative and positive values. The largest component of the dissipated heat energy during the cyclic mechanical loading occurs at twice the frequency of mechanical loading; indeed, for each cycle of elastic temperature response, two cycles of plastic temperature response occur.

Thermal signal was investigated in the time domain in order to separate the two heat sources and the component of the signal at the twice of loading frequency was used to estimate the dissipated energy for cycle at the crack tip. It was also demonstrated as the proposed approach is capable of monitoring the crack growth over time and in automatic way.

Thermographic data were acquired by means of a cooled infrared camera cable to acquire thermographic sequences every 2000 cycles with a geometrical resolution equal to 0.067 mm/pixel.

10214-27, Session 9

High speed thermographic analysis of coatings

Steven M. Shepard, Thermal Wave Imaging, Inc. (United States)

Flash thermography is frequently used for qualitative detection of coating anomalies, e.g. poor adhesion or large thickness variations. However. quantitative analysis is often regarded as beyond the scope of conventional approaches. This is particularly true when time scale of diffusion through the coating is less than the duration of an optical flashlamp pulse or IR camera integration time. It is possible to employ faster laser sources and higher frame rates by reducing the number of active pixels, but these solutions reduce the available field of view. Using dedicated hardware to control the duration of the flash and its precise relationship to the camera integration time, we have acquired full-frame (640 x 512) data sequences at effective frame rates of 5 kHz. The time resolution of the acquired sequence is sufficient to allow quantitative analysis of a 0.010" paint coating using the Thermographic Signal Reconstruction (TSR) method. Results are compared to numerical modeling and eddy current measurement. Similar results on thin materials and thermal barrier coatings will be presented.

10214-28, Session 9

Thermographic investigations of metal inclusions in 3D printed samples

Beata Oswald-Tranta, Roland Schmidt, Christoph Tuschl, Montan Univ. Leoben (Austria)

Subsurface defects can be well detected by flash thermography evaluating the temperature response at the sample surface. In many cases flat bottom holes or air inclusions are investigated as typical defects. In contrast, in the current paper the main emphasis is placed on metal inclusions hidden in an insulator material. As the thermal effusivity of the metal is significantly higher than of the base material, the temperature decreases quicker above such a defect. Calculations and finite element simulations have been used to investigate more closely these temperature signals. Additionally, 3D printed samples have been created, where in the plastic material different metal plates, as steel, aluminum and copper have been introduced. The measurement results on these samples show very good agreement with theoretically calculated curves. Also the question is investigated, how the material parameters of the included metal, as thermal effusivity or diffusivity can be estimated from the thermographic test result.

10214-29, Session 9

Liquid nitrogen cooling in IR thermography applied to steel specimen

Lei Lei, Univ. Laval (Canada); Giovanni Ferrarini, Alessandro Bortolin, Gianluca Cadelano, Consiglio Nazionale delle Ricerche (Italy); Paolo Bison, CNR Istituto per le Tecnologie della Costruzione (Italy); Xavier P. V. Maldague, Univ. Laval (Canada)

Pulsed Thermography (PT) is one of the most common methods in Active Thermography procedures of the Thermography for NDT & E (Nondestructive Testing & Evaluation), due to the rapidity and convenience of this inspection technique. Flashes or lamps are often used to heat the samples in the traditional PT. This paper mainly explores exactly the opposite external stimulation in IR thermography: cooling instead of heating. A steel sample with flat-bottom holes along different depths and sizes has been tested (along with a preliminary test on industrial samples CFRP). Liquid nitrogen (LN_2) is sprinkled on the surface of the specimen and the whole process is captured by a thermal camera. To obtain a good analogy, two other classic NDT techniques--Pulsed Thermography and Lock-In Thermography are also employed. In particular, the Lock-in method is implemented with three different frequencies. In the image processing procedure, Principal Component Thermography (PCT) method has been performed in all thermal images. For Lock-In results, both Phase and Amplitude images are generated by Fast Fourier Transform (FFT). Results show that all techniques presented part of the defects while the LN2 technique displays the flaws just at the beginning of the test. Moreover, a binary threshold post-processing is applied to the thermal images, and by comparing these images to a binary map of the location of the defects, the corresponding Receiver operating characteristic (ROC) curves are established and discussed. A comparison of the results indicates that the better ROC curve is obtained by the Flash technique.

10214-30, Session 9

Quantitative evaluation of water content in composite honeycomb structures by using one-sided IR thermography: is there any promise?

Vladimir P. Vavilov, Yang-Yang Pan, Denis A. Nesteruk, Arsenii Chulkov, Tomsk Polytechnic Univ. (Russian Federation)

The problem of detecting water ingress in airplane honeycomb panels is so serious that perspective aviation constructions are believed to be monolithic. However, the number of airplanes with plentiful honeycombs under exploitation will keep very high in the next decades. Therefore, quantitative water detection remains a challenging task in aviation. The qualitative aspect of this problem can be considered solved by using remote and fast infrared thermography. Hidden water can be detected for a certain period of time after landing, or some stimulation heat sources can be used to enhance water visibility in honeycomb panels. However, quantitative evaluation of water content is typically fulfilled by applying a point-by-point ultrasonic technique which allows measuring height of water in single cells thus compiling maps of water distribution. This technique is slow, contact and can be applied to the water which in contact with the skin due to gravitation. The use of solely IR thermography for evaluating water mass is difficult because of the indirect nature of this technique.

At Tomsk Polytechnic University, some efforts have been recently done to develop an active thermal/infrared inspection technique which may produce approximate evaluations of water content in honeycomb panels. We found that there is a certain promise in thermographically determining mass of water but the question is how precise (or how approximate) can be such evaluations. The paper contains modeling and experimental results obtained in this direction.

10214-31, Session 9

From passive IR to active thermography processing tools and THz Imaging for NDE

Nicolas P. Avdelidis, National Technical Univ. of Athens (Greece) and Univ. Laval (Canada); Dimitrios A. Exarchos, Univ. of Ioannina (Greece); Clemente Ibarra-Castanedo, Hai Zhang, Univ. Laval (Canada); Theodore E. Matikas, Univ. of Ioannina (Greece); Xavier P. V. Maldague, Univ. Laval (Canada)

Non invasive imaging tools such as infrared thermography (passive and active) and THz imaging are techniques that could find use for non-destructive testing and evaluation of materials and structures. In this paper, the advantages and limitations of IR inspection according to the application is discussed and the use of THz imaging for non-destructive evaluation of structures in order to identify abnormalities and/or delaminations and/or damage is also presented. These methods - approaches can play a significant role in a number of industries (i.e. aerospace, automotive, infrastructures, etc) for materials characterization applications and examples are demonstrated.

10214-32, Session 9

Surface crack detection in different materials with inductive thermography

Beata Oswald-Tranta, Montan Univ. Leoben (Austria)

Inductive thermography has been proved to be an excellent method for detecting surface cracks in metallic materials. The Joule heating is generated directly in the workpiece due to the induced eddy current. Its penetration depth is determined by material properties and by the excitation frequency. Whether an additional temperature increase or a colder area around the crack occurs, is determined by the ratio of the crack depth and the penetration depth. It is investigated how material parameters, excitation frequency, crack depth and its inclination angle affect the temperature distribution around a crack after a short heating pulse.

10214-33, Session 9

Coating defect evaluation based on stimulated thermography

Davide Palumbo, Rosanna Tamborrino, Umberto Galietti, Politecnico di Bari (Italy)

Coatings, such as TBC (Thermal Barrier Coatings) are used to protect the materials from severe temperature and chemical environments. In particular these materials are used in the engineering fields where high temperatures, corrosive environments and high mechanical stress are required.

Defects present between substrate material and coating, as detachments may cause the break of coating and the consequent possibility to exposure the substrate material to the environment conditions. The capability to detect the defect zones with non destructive techniques could allow the maintenance of coated components with great advantages in terms of costs and prediction of fatigue life.

NDT thermography techniques are used to detect defects on coated specimens such as pulsed thermography, lock-in thermography and pulsed phase thermography. In fact, these techniques allow for analyzing wide areas in very low time of tests. Each stimulated thermography technique is characterized by a different thermal source such as halogen lamps, flash lamps and laser.

In this work all the thermal sources cited above were used to detect the defects on different coatings (TBC and HVOF) and between base material and coating material. In particular various circular steel specimens (25mm diameter) were prepared and different drilled holes were realized to simulate defects in base material. After, a different thickness of thermal barrier coating was obtained through spraying process. Finally microscopy analysis were carried out to evaluate the goodness of the procedure used to obtain the specimens.

Different algorithms were used for the data analysis in order to investigate the feasibility of thermographic technique for evaluating defects in coated components.

10214-35, Session 10

Application of the quadrupole method for simulation of passive thermography

William P. Winfree, Joseph N. Zalameda, NASA Langley Research Ctr. (United States)

Passive thermography has been shown to be an effective method for in-situ and real time nondestructive evaluation (NDE) to measure damage growth in a composite structure during cyclic loading. The heat generation by subsurface flaw results in a measurable thermal profile at the surface. This paper models the heat generation as a planar subsurface source and calculates the resultant temperature profile at the surface using a three dimensional quadrupole. The results of the model are compared to finite element simulations of the same planar sources and experimental data acquired during cyclic loading of composite specimens.

10214-37, Session 10

Thermal diffusivity measurement of ring specimens by infrared thermography

Giovanni Ferrarini, Paolo Bison, Alessandro Bortolin, Gianluca Cadelano, Stefano Rossi, CNR Istituto per le Tecnologie della Costruzione (Italy)

The thermal diffusivity of solid materials is usually measured with the well-known flash method. In the traditional setup, the tested specimens have the shape of a small disc. However, several industrial applications need to test different typologies of samples. This work is focused on ring specimens, that are widely used as joints or sealants in various applications. The goal is investigating the possibilities and limitations of the flash method, applying minimum adjustments to the traditional experimental setup.

A preliminary numerical study is conducted with the creation of a 3D finite element model. The simulation firstly investigates the case of an aluminum oxide ring, that is taken as the reference case. Successively, the model is applied to rings of different materials and sizes in order to determine the limits of the proposed technique.

After the simulation, an experimental measurement is performed on the reference case of an aluminum oxide ring. Several samples are tested and useful information on the practical feasibility of the experimental setup are collected. The obtained thermal diffusivity values fall into the expected range for the material, confirming the validity of the suggested method.

10214-38, Session 10

IR thermography for the assessment of the thermal conductivity of aluminum alloys

Shuhratjon Nazarov, Technological Univ. of Tajikistan (Tajikistan); Stefano Rossi, Paolo Bison, Consiglio Nazionale delle Ricerche (Italy); Irene Calliari, Univ. degli Studi di Padova (Italy)

Aluminium alloys are here considered as a structural material for aerospace applications, guaranteeing lightness and strength at the same time. As aluminium alone is not particularly performing from a mechanical point of view, in this experimental solution it is produced as an alloy with Lithium added at 6 % in weight. To increase furtherly the strength of the material, two new alloys are produced by adding 0.5 % in weight of the rare earth element Neodimium and Yttrium. The improvement of the mechanical properties is measured by means of hardness tests. At the same time the thermophysical properties are measured as well, at various temperature, from 80 °C to 500 °C. . Thermal diffusivity is measured by Laser Flash equipment in vacuum. Specific heat is measured by Differential Scanning Calorimeter in Ar athmosphere to avoid oxidation phenomena at high temperature. From these measurements the thermal conductivity is obtained by multiplying diffusivity with density and specific heat. The variation of thermal conductivity is quite relevant showing a 50 % decreasing in the alloys containing rare earth in respect to the basic AlLi alloy. This is particularly interesting in view of a future simulation of the thermal behaviour of the aerospace structures built with such alloys. One possible drawback of the AlLi alloy produced at so high percentage of Li (6 %) is an essential anisotropy that is evaluated by IR thermography thank to its imaging properties that allows to measure simultaneously both the in-plane and through-depth thermal diffusivity. On the purpose, a pulsed laser spot shots the sample surface and a sequence of infrared images is collected during the cooling stage. The procedure and the algorithms adopted to separate the two components of the thermal diffusivity are based on the time analysis of the spatial Fourier transform applied to the infrared sequence of images collected during a transient thermography experiment.

10214-39, Session 10

Analysis of pulse thermography using similarities between wave and diffusion propagation

Meir Gershenson, Consultant (Mexico)

Pulse thermography or thermal wave imaging are commonly used as nondestructive evaluation (NDE) method. While the technical aspect has evolve with time, theoretical interpretation is lagging. Interpretation is still using curved fitting on a log log scale. A new approach based directly on the governing differential equation is introduced. By using relationships between wave propagation and the diffusive propagation of thermal excitation, it is shown that one can transform from solutions in one type of propagation to the other. The method is based on the similarities between the Laplace transforms of the diffusion equation and the wave equation. For diffusive propagation we have the Laplace variable s to the first power, while for the wave propagation similar equations occur with s2. For discrete time the transformation between the domains is performed by multiplying the temperature data vector by a matrix. The transform is local. The performance of the techniques is tested on synthetic data. The application of common back projection techniques used in the processing of wave data is also demonstrated. The combined use of the transform and back projection makes it possible to improve both depth and lateral resolution of transient thermography.

10214-40, Session 11

Infrared thermography applied to transport infrastructures monitoring: outcomes and perspectives

Jean Dumoulin, Institut Francais des Sciences et Technologies des Transports de l'amenagement et des Reseaux (France) and INRIA (France); Antoine Crinière, INRIA Rennes (France)

Being able to perform full field easily noninvasive diagnostics for surveillance and monitoring of transport infrastructures and structures is a major preoccupation of many technical offices. Among all the existing electromagnetic methods, long-term thermal monitoring by uncooled infrared cameras is a promising technique.

In situ measurements by infrared thermography on large scale structures in outdoor conditions will be introduced and constraints will be analyzed versus technological solutions available on the shelf.

Then, a first outdoor infrared system architecture developed and used for such experiments will be presented and discussed. A review of various experiments carried out on different transport infrastructures or large scale element of Civil Engineering structures in outdoor conditions will be proposed. The choice and development of few data processing approaches and inverse thermal model will be presented and discussed. Results obtained from few days of experiments to several month of experiments will be presented and analyzed.

Lessons learned from in situ outdoor experiments will be addressed and a new infrared system architecture dedicated to long term monitoring will be introduced and discussed. In particular, possible benefit of using some standards for measured data file format will be presented.

Finally, a conclusion on results obtained and limitations of the studied outdoor infrared long term monitoring solution will be given. Perspectives in term of measurements corrections or requirement on infrared sensors will be proposed.

10214-41, Session 11

Infrared thermography applied to the study of heated and solar pavement: from numerical modeling to small scale laboratory experiments

Nicolas Le Touz, Institut Francais des Sciences et Technologies des Transports de l'amenagement et des Reseaux (France) and INRIA (France); Thibaud Toullier, INRIA Rennes (France) and Institut Francais des Sciences et Technologies des Transports de l'amenagement et des Reseaux (France); Jean Dumoulin, Institut Francais des Sciences et Technologies des Transports de l'amenagement et des Reseaux (France) and INRIA (France)

If de-icers still are the main solution to avoid black ice occurrence and snow accumulation on pavements, some alternatives based on transportation infrastructure modifications (heated pavement using electrical or hot fluid in pipes inserted in pavement the base layer) have been tested over the past years. In the present study, pipes were replaced by a porous sub-layer coupled with a surface layer that can be opaque or transparent to solar radiation.

In practise, to prevent icing at the surface of the road, it is necessary to know when the de-icing systems should be active and to optimize the amount of energy to provide to these systems. To reach that aim, the surface temperature field has to be predicted by taking into account meteorological parameters coupled with a heat transfer model, here based on finite-element method with a multi-physic approach. This model takes into account the energy supply and losses coming from solar radiation, radiative exchanges with the atmosphere and convective exchanges with the air.

In order to validate this theoretical model, a lab scale experiment (using infrared cameras) on small specimens has been conducted. Thermographic cameras provide a rapid and non-destructive method to observe objects temperature evolution. Thanks to the coupling of different sensors to gather environment information and under some assumptions on the observed material properties, pavement surface temperature can then be monitored. Therefore, after calibrating the camera, surface temperature evolution for different boundaries conditions or heat power were analyzed and compared to the expected theoretical model.

Results obtained will be presented, analyzed and discussed in the paper.

10214-42, Session 12

Direct comparison of two pyrometers and a low-cost thermographic camera for time resolved LWIR temperature measurements

Simon Altenburg, Rainer Krankenhagen, Bundesanstalt für Materialforschung und -prüfung (Germany)

The contactless measurement of temperatures with pyrometers is state of the art and a number of different commercial devices are available. Alternatively, these temperature measurements can be performed by means of infrared cameras. In light of permanently falling costs, the application of IR cameras simply as contactless thermometers appears to be an alternative to the use of pyrometers. For a current study, the surface temperature development of a sample has to be measured and recorded with at least 20 Hz sampling rate in a temperature range between 0°C and 70°C and with a temperature resolution of 0.1 K. The absolute value of the temperature is not as important as relative changes. Due to disturbing irradiation in the SWIR and MWIR regions, the sensor should work in the LWIR. We compared two pyrometers and a low-cost infrared camera with regard to the requirements defined above. In this paper we describe the setup, the results and the data evaluation. Both, raw data and post processed data, were considered. Surprisingly, the infrared camera had by far the best performance of the considered devices. Particularly, due to the large number of pixel (160 x 120), the S/N could be reduced considerably compared to the pyrometers. We also studied the stability of the frame rate and the related time steps of the IR camera. Although the frame rate is unstable (running under Windows operating system), the output data for the time steps were found to be correct and the required time resolution was achieved.

10214-43, Session 12

Extending the capability of a pyroelectric infrared sensor to detect the presence of stationary and moving occupants by using a nonlinear vibrating chopper

Haili Liu, Kevin Wang, Ya S. Wang, Stony Brook Univ. (United States)

Owing to the unique features of passive sensing, low cost, long sensing distance and wide field of view, the pyroelectric infrared (PIR) sensors are widely used for motion detection, such as light control, intrusion detection. While, due to the pyroelctricity on which their sensing principles are based, PIR sensors cannot detect stationary objects, which confines their applications to advanced sensing systems, e.g. occupancy sensing. Although, thermopile sensors, which are based on the seebeck effect, can measure the temperature of both moving and stationary objects and can be applied for occupancy sensing, they are not ideal solutions either for occupancy detection due to their short sensing distance, narrow field of view, and higher price. In order to extend the function of PIR sensors for stationary object detection, this paper presented a PIR based occupancy sensor, which consists of a nonlinear vibrating chopper, a Fresnel lens, a PIR sensor and the corresponding sensing and control circuits. The nonlinear vibrating chopper is composed of a cantilever beam with a tip magnet, two external magnets on both sides of the beam and an excitation coil. An analytical model is built for the nonlinear vibrator for parametric identification, such as the magnet field intensity, distance between the beam and the magnets. A prototype of this vibrating chopper is developed and its size is small enough to integrate into a commonly used Fresnel lens, and therefore would not increase the volume of the traditional PIR sensor. Experiments show that the PIR based occupant sensor can detect human presence in the distance range up to 9 m.

10214-44, Session 12

Radiometric calibration of an ultra-compact microbolometer thermal imaging module

David Riesland, Paul W. Nugent, Seth Laurie, Joseph A. Shaw, Montana State Univ. (United States)

Ultra-compact, low-cost microbolometer cameras have entered the commercial market in recent years, thereby extending basic thermal imaging capabilities to the cell-phone and hobbyist level. One of the most prominent of these has been the FLIR Lepton, which has a similar form factor as most cell phone cameras. This presentation will show results of a radiometric calibration that builds on experience calibrating larger-format microbolometer cameras, such as the FLIR Photon and Tau and the DRS Tamarisk. These calibrations require characterizing the camera's response with changes in the focal plane array (FPA) temperature. The low

thermal mass of the ultra-compact Lepton poses significant challenges to its calibration. For example, performing a non-uniformity correction (NUC) using the attached shutter raises the FPA temperature and camera body temperature. If left uncompensated, this significantly degrades the radiometric accuracy. The presentation will report the level of achieved accuracy on this ultra-low cost sensor for extended operating periods.

10214-45, Session 12

Modeling the influence of degrees of freedom and defocus on thermal infrared measurement

Julien R. Fleuret, Hai Zhang, Bardia Yousefi, Lei Lei, Frank Billy Djupkep-Dizeu, Univ. Laval (Canada); Stefano Sfarra, Univ. degli Studi dell'Aquila (Italy); Xavier P. V. Maldague, Univ. Laval (Canada)

Long Wavelength Infrared (LWIR) cameras allow us to have a representation of a part of the light spectrum what is sensitive to temperature. These cameras also named Thermal Infrared (TIR) cameras are powerfull tools to detect features that can not be seen by other imaging technologies. For instance they enable defect detection on material, fever and anxiety for mammals and many other features for numerous applications. However, the accuracy of thermal cameras can be affected by many parameters; the most influent are the position of the camera from the object of interest and the focus of the camera.

Several models have been proposed in order to minimize the influence of some of the parameters but they are mostly related to an application or an other. Because such models are based on some prior related in context, their repeatability in other contexts cannot be easily assessed. The few models remaining are mostly associated to a specific device.

In this paper the authors studied the influence of the position and the focus on the measurement accuracy and propose a model to minimize the influence of each parameter. Modeling of the position of the camera from the object of interest depend on many parameters. In order to propose a model as accurate as possible, the position of the camera will be represented as a five dimensions model. With the aim to introduce a model as independent from the device as possible the authors produced the models using several cameras with different sensibility and with and without autofocus. A linear programming approach is then used to deduce the sensor's sensitivity and parameter of the model of correction.

10214-46, Session 12

Coaxial visible and FIR camera system with accurate geometric calibration

Yuka Ogino, Takashi Shibata, Masayuki Tanaka, Masatoshi Okutomi, Tokyo Institute of Technology (Japan)

A far-infrared (FIR) image contains critical invisible information for various applications such as night vision and fire detection, while a visible image includes colors and textures in a scene. To obtain the complementary information of both images simultaneously, we present a novel coaxial visible and FIR camera system accompanied by an accurate geometric calibration method. The proposed camera system is composed of three parts: a visible camera, a FIR camera, and a gold dichroic beam-splitter. The FIR radiation from the scene is reflected at the beam-splitter, while the visible radiation is transmitted through this beam-splitter.

To align the captured visible and the FIR images with high accuracy, we also present the joint calibration method which can simultaneously estimate accurate geometric parameters of both cameras, i.e. the intrinsic parameters of both cameras and the extrinsic parameters between both cameras. In the proposed calibration method, we use a novel calibration target which is the two-layer structure with different combinations of the thermal emission. By using the proposed calibration target, we can stably and precisely obtain the corresponding points of the checker pattern in the calibration target from the visible and the FIR images. The well-known Zhang's calibration algorithm can accurately estimate both camera parameters.

The proposed coaxial camera system accompanied by the proposed accurate joint calibration can capture precisely aligned and distortion-free visible and FIR images. Experimental results demonstrate that the proposed system is useful for various applications such as image fusion, image denoising, and image up-sampling.

Conference 10215: Advanced Environmental, Chemical, and Biological Sensing Technologies XIV

Sunday - Monday 9 –10 April 2017

Part of Proceedings of SPIE Vol. 10215 Advanced Environmental, Chemical, and Biological Sensing Technologies XIV

10215-1, Session 1

Functionalized polymer-based photonic devices for biosensing application *(Invited Paper)*

Tatsuro Endo, Osaka Prefecture Univ. (Japan)

No Abstract Available

10215-2, Session 1

Nanophotonic interferometric immunosensor for label-free and real-time monitoring of chemical contaminants in marine environment

Blanca Chocarro Ruiz, Sonia Herranz, Adrián Fernández Gavela, Institut Català de Nanociència i Nanotecnologia (ICN2) (Spain) and CIBER-BBN (Spain); Josep Sanchís, Marinella Farré, Instituto de Diagnóstico Ambiental y Estudios del Agua (Spain); M. Pilar Marco, Instituto de Química Avanzada de Cataluña (Spain) and Nanobiotechnology for Diagnostics Group (Spain); Laura M. Lechuga, Institut Català de Nanociència i Nanotecnologia (ICN2) (Spain) and CIBER-BBN (Spain)

Every year large quantities of wastes and pollutants are dumped in the sea contributing to a slow but constant degradation of the marine water quality. Conventional analytical methodologies are sensitive and selective tools for the sea quality control but they operate only at laboratory settings. Bringing the monitoring tools directly to the contaminated place can result in cost and time savings.

In the frame of the BRAAVOO (Biosensors, Reporters and Algal Autonomous Vessels for Ocean Operation) project, we are developing a nanoimmunosensor module for the on-site analysis of sea pollutants based on a silicon technology with a view to implement a complete lab-on-a-chip platform. The project funded by the European Union (Seventh Framework Programme) is dedicated to the development of biosensors for real-time monitoring of chemical contaminants of anthropogenic origin in the marine environment and its integration into ships and buoys. One of these pollutants is Irgarol 1051, a commonly used antifouling paint for marine vessels. Because of its biocidal effect, its presence in the marine environment has a negative impact on marine organisms like corals. We are developing a bimodal waveguide interferometer (BiMW) nano-immunosensor for real-time and label-free detection of Irgarol 1051. The detection is based on a competitive inhibition format assay using a hapten with a similar structure to Irgarol, but with a carboxylic group which can be covalently attached to the sensor surface. Results show limits of detection of few ng/L and the stability of the sensor surface up to 30 measure-regeneration cycles with sea water samples. Each measure-regeneration cycle takes 15 minutes and the sample does not require any pre-treatment.

Acknowledgement – This work has been funded by the 7FP (EU, BRAAVOO Grant Agreement No 614010). ICN2 acknowledges support from the Severo Ochoa Program (MINECO, Grant SEV-2013-0295).

10215-3, Session 1

Molecular biosensors using fluorescent proteins for visualizing biological events in live cells and in vivo *(Invited Paper)*

Xian-En Zhang, Institute of Biophysics (China)

No Abstract Available

10215-4, Session 2

Full automated ELISA by lab-on-a-paper with delay line *(Invited Paper)*

Yuzuru Takamura, Japan Advanced Institute of Science and Technology (Japan)

No Abstract Available

10215-5, Session 2

Rapid on-site monitoring of organophosphorus insecticide chlorpyrifosresidue using a simple plastic lab-on-a-chip *(Invited Paper)*

Piyasak Chaumpluk, Chulalongkorn Univ. (Thailand)

No Abstract Available

10215-6, Session 2

Single, duo, or flexible aptamer-based nanobiosensors *(Invited Paper)*

Man Bock Gu, Korea Univ. (Korea, Republic of)

invited presentation

10215-7, Session 2

Nanosensor for nucleic acid targets detection using SERS

Tuan Vo-Dinh, Duke Univ. (United States); Pietro Strobbia, Univ. of Maryland, Baltimore County (United States)

No Abstract Available

10215-8, Session 3

Downhole intrinsic fiber optic sensors for subsurface detection of CO2 in corrosive matrices *(Invited Paper)*

Jesus Delgado Alonso, Intelligent Optical Systems, Inc. (United States); Robert A. Lieberman, Lumoptix, LLC (United States); Sreekar Marpu, Narciso Guzman, Intelligent Optical Systems, Inc. (United States)

No Abstract Available

10215-9, Session 3

Review of side illuminated optical fiber sensors *(Invited Paper)*

Claudio Oliveira Egalon, Science & Sensors Technologies (United States)

No Abstract Available

10215-10, Session 3

Field deployable distributed fiber optic hydrocarbon fuel leak detection system

Edgar Mendoza, Yan Esterkin, Sunjian Sun, Redondo Optics, Inc. (United States)

No Abstract Available

10215-11, Session 3

Light propagation in evanescent field-based distributed chemical fiber sensors

Robert A. Lieberman, Lumoptix, LLC (United States); Leonard G. Cohen, JeBen LLC (United States)

No Abstract Available

10215-12, Session 3

Fano resonances in capped metallic nanostructures for highly sensitive sensors *(Invited Paper)*

Kuang-Li Lee, Pei-Kuen Wei, Research Center for Applied Sciences, Academia Sinica (Taiwan)

No Abstract Available

10215-13, Session 3

Electrophoretic plasmonic nanopore genome sequencing biochip *(Invited Paper)*

Edgar Mendoza, Redondo Optics, Inc. (United States); Alexander Neumann, Yuliya V. Kuznetsova, Steven R. J. Brueck, Jeremy S. Edwards, The Univ. of New Mexico (United States)

No Abstract Available

10215-14, Session 3

Plasmonic nanochip for SERS chemical and biomedical sensing

Tuan Vo-Dinh, Duke Univ. (United States); Pietro Strobbia, Univ. of Maryland, Baltimore County (United States)

No Abstract Available

10215-15, Session 3

In-situ SERS study of propene adsorption over Au nanoparticles

Shuyue He, Hui Chen, Kai Liu, Fei Tian, Stevens Institute of Technology (United States)

Current industrial technologies for selective oxidation of propene via a single-stage oxidation process in H2/O2 catalyzed by Au holds excellent prospect of green production of C3H6O. Fundamentals of the molecular mechanisms between catalytic Au and the oxidant remain unclear for decades, however, impeding the development of its rational design and implementation. We explore a multifunctional, highly organized nanoporous anodized aluminum oxide (AAO) substrate with immobilized Au nanoparticles (Au NPs) both as a catalytic reactor and an ultra-sensitive SERS probe to investigate the molecular level details during Au-catalyzed oxidation of propene in situ. Nanoporous AAO offers excellent thermal stability and enhanced particle coverage density for the immobilized Au NPs within to enable high temperature SERS interrogation, opening up new opportunities in the study of the catalytic reactions. Different size of Au NPs and pores of AAO are explored for improved SERS sensitivity and catalytic activity.

10215-16, Session 3

Towards chromium speciation by microplasma-on-chip optical emission spectrometry

Henry So, David A. Cebula, Vassili Karanassios, Univ. of Waterloo (Canada)

In environmental monitoring, the determination of the concentration of chemical species in their naturally occurring oxidation state (often called chemical speciation or simply speciation) is very important. Consider Chromium (Cr) in water samples as an example. Although Cr can exist in as many as 11 oxidation states, in the environment there are only two thermodynamically stable oxidation states: Cr (III) and Cr (VI). Importantly, there are significant toxicological differences between these two states. Specifically, while Cr (III) is an essential micro-nutrient, Cr (VI) is reported to be carcinogenic. Thus, in environmental samples, measurement of the

concentration of each oxidation state is of importance. In this presentation, steps taken toward the determination of the concentration of these two Cr oxidation states using a battery-operated microplasma-on-a-chip and optical emission spectrometry will be described in some detail.

10215-33, Session 3

Ultrasensitive lab-on-a-chip nanophotonic biosensors for portable diagnosis *(Invited Paper)*

Laura Maria Lechuga, Institut Català de Nanociència i Nanotecnologia (ICN2) (Spain)

Motivated by potential benefits such as sensor user-friendly, multiplexing capabilities and high sensitivities, nanophotonic lab-on-chip biosensors have profiled themselves as an excellent alternative to traditional analytical techniques. Modern diagnostics is demanding novel analytical tools that could enable quick, accurate, sensitive, reliable and cost-effective results so that appropriate treatments or remediantion actions can be implemented in time, leading to improved outcomes.

The main objective of our research is to achieve such ultrasensitive platforms for label-free analysis using nanophotonic technologies and custom-designed biofunctionalization protocols, accomplishing the requirements of disposability and portability. We are using innovative designs of nanophotonic biosensors based silicon photonics technology (nanointerferometers) and full microfluidics lab-on-chip integration. We have demonstrated the suitability of the photonic nanobiosensors for the detection, with extremely sensitivity and selectivity, of marine pollutants and human disease biomarkers. In all cases, our sensing methodology has shown excellent robustness with high reproducibility and sensitivity, rendering in valuable tool for the fast diagnostics of un-treated bodily fluids or environmental samples.

10215-17, Session 4

Direct imaging of shale gas leaks using passive thermal infrared hyperspectral imaging *(Invited Paper)*

Marc-André Gagnon, Pierre Tremblay, Simon Savary, Vince Morton, Philippe Lagueux, Vincent Farley, Martin Chamberland, Telops Inc. (Canada); Jean Giroux, Éric Guyot, Telops (Canada)

Natural gas is an energy resource in great demand worldwide. There are many types of gas fields including shale formations which are common especially in the St-Lawrence Valley (Qc). Regardless of its origin, methane (CH4) is the major component of natural gas. Methane gas is odorless, colorless and highly flammable. It is also an important greenhouse gas. Therefore, dealing efficiently with methane emanations and/or leaks is an important and challenging issue for both safety and environmental considerations. In this regard, passive remote sensing represents an interesting approach since it allows characterization of large areas from a safe location. The high propensity of methane contributing to global warming is mainly because it is a highly infrared-active molecule. For this reason, thermal infrared remote sensing represents one of the best approaches for methane investigations. In order to illustrate the potential of passive thermal infrared hyperspectral imaging for research on natural gas, imaging was carried out on a shale gas leak that unexpectedly happen during a geological survey near Hospital Enfant-Jésus (Québec City) in December 2014. Methane was selectively identified in the scene by its unique infrared signature. Quantitative information was also obtained. The results show how this novel technique could be used for research work dealing with methane gas.

10215-19, Session 4

Real time infrared backscattering spectroscopy using a rapidly tunable external cavity quantum cascade laser

Jan-Philip Jarvis, Marko Härtelt, Stefan Hugger, Lorenz Butschek, Fraunhofer-Institut für Angewandte Festkörperphysik (Germany); André Merten, Jan Grahmann, Fraunhofer-Institut für Photonische Mikrosysteme (Germany); Thorsten Tybussek, Klaus Rieblinger, Fraunhofer-Institut für Verfahrenstechnik und Verpackung IVV (Germany); Frank Fuchs, Ralf Ostendorf, Joachim Wagner, Fraunhofer-Institut für Angewandte Festkörperphysik (Germany)

In this work we report on real time backscattering spectroscopy using broadly tunable external cavity Quantum Cascade Lasers (EC-QCLs) in the mid infrared (MIR) range from 5 μm to 10 μm in several application scenarios such as standoff-substance detection and identification of food spoilage.

Real-time spectroscopic sensing is enabled by a rapid wavelength-scanning EC-QCL that utilizes a Micro Opto Electronic Mechanical System (MOEMS) diffraction grating as wavelength selective element in its Littrow-type external resonator. This allows for sweeping the QCL chip's full spectral tuning range of > 300 cm-1 within 1 ms, which provides a spectral sampling rate of 1 kHz. Under the given pulsed operation condition, the spectral resolution of the resulting laser spectroscopy device amounts to 1.5 cm-1.

The rapidly scanning EC-QCL is used as wavelength selective active illumination source for MIR backscattering spectroscopy in which the diffusely backscattered light is collected by a single element IR detector. The suggested sensing system is capable of remotely detecting chemical compounds like various pharmaceuticals or hazardous substance traces such as TNT, RDX, PETN and AN in real time.

Finally, we show applicability of the spectroscopic measurement principle in detection of food spoilage using a QCL chip that covers the spectral range between 5.6 μm and 5.9 μm. Measurement results show, that the suggested principle is capable of separating fresh and molded nuts by detection of free fatty acids on their surface.

10215-20, Session 4

Direct detection range resolved carbon dioxide differential absorption LIDAR measurements in the 2 μm range

Erwan Cadiou, Jean-Baptiste Dherbecourt, Guillaume Gorju, Myriam Raybaut, Jean-Michel Melkonian, Antoine Godard, ONERA (France); Jacques R. Pelon, Univ. Pierre et Marie Curie (France); Michel Lefebvre, ONERA (France)

Prevision of climate change is presently one of the main research goals. In order to improve the accuracy of current climate models, it is necessary to better characterize the main greenhouse gases concentration and fluxes (CO2, CH4, and water vapor) at a global scale. For this purpose one promising solution is the space-borne integrated path differential absorption lidar (IP-DIAL) technique, which is currently investigated by space agencies in the preparation of future missions such as MERLIN (CNES-DLR) for methane, or ASCENDS (NASA) for carbon dioxide. One of the challenges for these missions is to have high energy laser sources which can emit specific wavelength to address the species of interest. At ONERA, a high energy transmitter based on a broadly tunable parametric source has been developed in the 2 μm spectral region to address the main greenhouse gases absorption lines that are well-suited for space application [1]. This source has been recently implemented on the R30 CO2 absorption line at 2051 nm for ground-based range resolved measurements in the atmosphere. In our set-up the source emits 10 mJ pulses at a 30 Hz repetition rate. The back-scattered light from aerosols is collected with a Newton telescope and a direct detection scheme based on an InGaAs photodiode. CO2 concentration has been estimated with a precision better than 25 ppm for a 100 meter spatial resolution in the 100-500 m range and a 10 minutes acquisition time.

References :

[1] J. Barrientos Barria, et Al, Opt. Lett., 39, 6719–6722 (2014).

10215-21, Session 4

Four-wavelength LIDAR for in-situ speciation of aerosols

Michael D. Wojcik, Space Dynamics Lab. (United States)

No Abstract Available

10215-22, Session 4

Electronic nose for ambient detection and monitoring

Sudhir Shrestha, Miami Univ. (United States)

Our ambient carries hundreds of volatile organic compounds that can provide information about the toxicity and hygiene of our immediate environment. An electronic nose is a smart sensor system with an array of chemical sensors. This paper will present a miniaturized prototype electronic nose that integrates an array of highly sensitive chemical sensors to detect volatile organic compounds in our ambient that are indicative of unhygienic and toxic conditions. The portable electronic nose is equipped with hardware to collect and process the sensor data and communicate the information to the user. The sensor system controls and collects sensor data, performs necessary data cleaning, and uses an efficient pattern recognition technique to compare sensor data with training sets saved in the memory. The processed information is communicated to the user via an on-device display and transmitted to a smart phone for further logging and visualization using an application. The system design, developed data processing techniques, and preliminary results will be presented and discussed in the paper.

10215-23, Session 5

MID-IR absorbance and its relation to static permittivity as a robust in-field tool tracking oil deterioration

Alex Risos, Nicholas Long, Robinson Research Institute (New Zealand); Gideon Gouws, Victoria Univ. of Wellington (New Zealand)

The power grid depends critically on the use of voltage converters to supply mains electricity. Their conversion loss causes thermal stress on electrical insulation material and coolant fluid resulting in deterioration and thus formation of dissolved organic acids in the fluid. These acids are readily trackable via MID-IR spectroscopy through their strong C=O absorption band. However, the use of reliable in-situ optical monitoring systems is hampered by the presence of dissolved particles causing turbidity. The increase of C=O bonds also causes an increase in the relative permittivity (?r) through an increased bulk dipole moment whereby its measurement is unaffected by the Beer-Lambert law or scattering. An experiment mimicking a typical voltage converter environment artificially deteriorated coolant fluid in presence of electrical insulation material. The coolant fluid investigated with FT-IR and correlated with dielectrometry giving ?r verified our hypothesis using ?r for tracking of deterioration products. For this, a robust, temperature independent dielectric cell and a custom liquid IR sample cell was developed. MID-IR absorbance and dielectric measurements were performed at selected times in the degradation process. A distinct increased IR absorbance in the region 1700 - 1750 cm-1 linked to 4-oxopentanoic and formic acid correlated strongly with a measurable increase of ?r. This indicates acidic compounds in percentage concentration supported by theoretical modelling. Thus, IR absorption caused by polar compounds increases the permittivity trackable in-situ with dielectrometry probes where optical measurements provide insufficient reliability. This important result enables dielectrometry as a substitutional robust sensor technology for FT-IR in-field.

10215-24, Session 5

On feasibility of a rotating field eddy current sensor for nondestructive testing of ferromagnetic oil-well casings

Darko Vasic, Davorin Ambrus, Vedran Bilas, Univ. of Zagreb (Croatia)

In order to ensure the safety of the environment in the vicinity of hydrocarbon extraction operations, regular downhole nondestructive testing of the well casings is of the utmost importance. Remote-field eddy-current technique has proved to be very successful in search for hazardous defects by measuring the casing wall thickness. However, this method provides a circumferentially averaged casing wall condition, which requires formidable interpretation skills and does not allow early detection of smaller defects. To this end, the most advanced eddy current sensors employ several transmitters and receivers positioned along the casing internal circumference or mechanically rotating transmitters resulting in the image of the casing wall. Such an approach considerably complicates the sensor construction, increases the number of measurement channels and wiring, and complicates the excitation and data acquisition circuitry. This reduces the reliability and increases the cost and duration of the testing. Rotating field eddy current sensor for nondestructive testing of tubes has been recently proposed as an alternative to the state-of-the-art eddy current array sensors and mechanically rotating sensors. In this paper we present an analytical approach to modeling of such a sensor based on the second-order vector potential and series eigenvalue expansion. Furthermore, we study the sensor sensitivity on the small defects and its investigation depth by coupling the analytical model of the sensor with the dipole-based model of small defects. We also discuss the spatial-frequency characteristics of various transmitter-receiver configurations, as well as practical implementation issues connected with electronic instrumentation requirements.

10215-25, Session 5

UV LED based gas correlation spectrometer of aromatics for the standoff detection of industrials spills and emissions

François Babin, Jean-François Y. Gravel, Pascal Dufour, INO (Canada)

Although there is a well-developed commercial offering for the detection of gaseous emissions in natural gas infrastructures, the same does not exist in the transport or transformation of liquid petroleum products. In the case of aromatics, UV DOAS using lamps and retroreflectors are amongst the only choices, along with UV-DIAL. But these are limited in sensitivity and depend on long absorption paths or are very complex. There are also large airborne lidars for the detection of liquid hydrocarbon spills on water or land that rely on UV induced fluorescence (LIF). But there is a lack of simple techniques for the remote detection of vapor plumes or spills involving liquid petroleum products. There have been proposals for the use of UV enhanced Raman for the detection of vapor plumes, but these require large laser powers and detection optics for poor sensitivity. On the other hand, recent developments in UV LEDs allows for simple techniques in the detection of aromatics, benzene and toluene in particular. These are found in most liquid petroleum products. Using these new commercially available UV LEDs and a gas correlation spectrometer set-up, benzene vapor is measured using the electronic transition at 258.9nm and at other deep UV wavelengths. Standoff measurements up to 10 m are presented. It is shown that while there is significant fluorescence in liquid benzene, oxygen in air severely quenches the fluorescence for the vapor phase benzene, rendering fluorescence unusable for the standoff detection of the vapor phase. Various implementations of standoff benzene/toluene detection using UV LEDs and gas correlation are discussed, along with pros and cons of the technique.

10215-26, Session 5

Phosphorescence based oxygen sensors and probes for biomedical research

Dmitri B. Papkovsky, Alexander V. Zhdanov, Univ. College Cork (Ireland)

A range of in vitro and ex-vivo cell and tissue models are currently used in biomedical research, but for many of them control of oxygenation conditions and cellular O2 levels is inadequate. Since O2 is key parameter and biomarker of cellular function, implementation of reliable in situ control and knowledge of actual O2 levels in different compartments of biological samples is paramount. Quenched-phosphorescence O2 sensing technology provides such capabilities and versatility. In recent years, various O2 sensing systems, which operate with solid-state sensors, soluble probes or imaging nanosensors and in conjunction with portable handheld instruments, commercial plate readers or live cell imaging platforms, have been developed and deployed by us and other groups. Here we present the existing range of O2 sensing solutions describing their analytical capabilities and integration in the current paradigm of biomedical research. Examples of their use to ensure strict environmental control of O2 in the gas and liquid phase, macroscopically and microscopically, by point measurements and high-resolution imaging in 2D and 3D with different cell and tissue models and in complex physiological studies are provided.

10215-32, Session 5

A terrain-based comparison of chaos modulation in acoustic wireless sensor networks

Dasola Ayotunde Oluge, Henry Leung, Univ. of Calgary (Canada)

The operating environment, in which wireless sensor networks are deployed to function, has a significant impact on the network performance. This is due to the inherent non-ideal channel conditions present in the operating environment such as multipath, noise and propagation delays. However, most simulations ignore these non-idealities thus yielding very optimistic results.

This paper incorporates channel non-idealities such as multipath into a simulated wireless sensor network, and evaluates the effect on network performance in different terrains.

Given their inherent wideband characteristic which makes them robust to non-ideal conditions such as multipath, chaos-based modulation schemes are a possible alternative to conventional spread spectrum techniques. By incorporating these non-ideal conditions, and evaluating network performance when deployed in non-terrestrial terrains such as deep space Martian exploration or underwater acoustic localization, this paper contributes a more realistic simulation framework of the sensor network performance using the metrics of throughput and end-end delay. Furthermore, a comparison of the results when different chaos modulation schemes are applied in different terrains is presented.

10215-28, Session 6

Miniature multi-parameter fiber optic environmental sensor system for early-damage detection of Li-ion batteries

Edgar Mendoza, Yan Esterkin, Sunjian Sun, Redondo Optics, Inc. (United States)

No Abstract Available

10215-29, Session 6

Instant scanner device for identifying wound infection utilizing Mie scatter spectra

Robin E Sweeney, The University of Arizona (United States); Elizabeth Budiman, Jeong-Yeol Yoon, The Univ. of Arizona (United States)

The Mie-scatter based device designed through this work is able to use Mie scatter spectra to distinguish the presence or lack of a skin infection (despite the presence of commensal bacteria on skin) and, further, determine the species of bacteria responsible for the infection, allowing for rapid diagnosis and decreased time to treatment.

A 650 nm LED light source is used to illuminate the tissue sample from angles of 180°, 190°, 200°, 210°, and 225°. A custom 3D printed photodiode array is used to collect light scatter from the surface of a tissue sample at angles from 100° to 170° at 10° increments. Illumination of the tissue and collection of light scatter across a range of angles results in Mie-scatter spectra. An Arduino microcontroller is used to collect light scatter intensity at each angle. Light scatter intensity trends across the collection angles determine the presence of an infection versus the presence of only commensal bacteria. Principle component analysis (PCA) of Mie scatter spectra is able to distinguish the species of bacteria responsible for an infection.

Escherichia coli and Staphylococcus aureus have been tested on porcine and human cadaver skin with this system, resulting in distinct differences in Mie scatter spectra between these species. The device has been tested with common skin contaminants (e.g. lotion), and does not distinguish a difference between lotion and control groups. Light scatter data used to determine the presence and species of an infection is collected without contact with tissue and within 3 seconds.

10215-30, Session 6

A miniaturized total analysis system for real-time PCR

Hidenori Nagai, AIST (Japan)

The microfluidic device for the handheld RT-qPCR thermal cycler was attached with three heaters. The temperatures of these heaters were constantly controlled to 42˚C, 96˚C and 56˚C for reverse transcription, denaturization, and anealing/extension, respectively. The PCR solution was injected with about 20 μl and flowed in the microchannel repeatedly by a switching of two pumps. The two kinds of fluorescence for FAM and ROX were measured on a detection point placed between the two heaters for the denaturization and the anealing/extension.

For the microfluidic device, we have developed the handheld RT-qPCR thermal cycler. The size of the system is 200 x 100 x 50 mm and the weight is only 0.6 kg including dry-cell batteries. As the target for the high-speed microfluidic RT-qPCR, influenza A virus was examined. Reverse transcription and qPCR were carried out sequentially in the same microchannel as a one-step RT-qPCR. As the results of 45 cycles with 3 s for denaturation and 9 s annealing/extension after 30 s for RT and 10s for activation of DNA polymerase, influenza A virus could be detected within only 12 minutes, and the detection limit was approximately 50 pfu/ml.

10216-1, Session 1

Biosensing via light scattering from plasmonic core-shell nanospheres coated with DNA molecules

Huai-Yi Xie, Yia-Chung Chang, Academia Sinica (Taiwan); Minfeng Chen, Taiwan Semiconductor Manufacturing Co. Ltd. (Taiwan); Rakesh S. Moirangthem, Indian School of Mines (India)

We present both experimental and theoretical studies for investigating DNA molecules attached on metallic nanospheres. We have developed an efficient and accurate numerical method to investigate light scattering from plasmonic nanospheres on a substrate covered by a shell, based on the Green's function approach with suitable spherical harmonic basis. Next, we use this method to study optical scattering from DNA molecules attached to metallic nanoparticles placed on a substrate and compare with experimental results. We obtain fairly good agreement between theoretical predictions and the measured ellipsometric spectra. The metallic nanoparticles were used to detect the binding with DNA molecules in a microfluidic setup via spectroscopic ellipsometry (SE), and a detectable change in ellipsometric spectra was found when DNA molecules are captured on Au nanoparticles. Our theoretical simulation indicates that the coverage of Au nanosphere by a submonolayer of DNA molecules, which is modeled by a thin layer of dielectric material (which may absorb light), can lead to a small but detectable spectroscopic shift in both the ? and ? spectra with more significant change in ? spectra in agreement with experimental results. Our studies demonstrated the ultra- sensitive capability of SE for sensing submonolayer coverage of DNA molecules on Au nanospheres. Hence the spectroscopic ellipsometric measurements coupled with theoretical analysis via an efficient computation method can be an effective tool for detecting DNA molecules attached on Au nanoparticles, thus achieving label-free, non-destructive, and high-sensitivity biosensing with nanoscale resolution.

10216-3, Session 1

Lab-on-fiber optofluidic platform for in-situ study of therapeutic peptides and bacterial response (Rising Researcher Presentation)

Fei Tian, Fan Yang, Junfeng Liang, Stevens Institute of Technology (United States)

Hospital acquired infections in indwelling device have become a life-threatening issue accompanied by the wide use of medical devices and implants. The infection process typically involves the attachment, growth and eventual assemblage of microbial cells into biofilms, with the latter exhibiting extremely higher antibiotic tolerance than planktonic bacteria. Surface constructed antimicrobial coatings offer a viable solution for bacteria responsive antibiotic strategy in medical devices such as catheter and stents. Therapeutic peptide has pioneered the field for their attractive pharmacological profile with broad antibacterial spectrum, great efficacy and long life-span. It has been a common practice to separately assess bacteria responses through commercially available activity assay kits after their exposure to antibiotic coatings, limiting the assessment of their activity in vitro with a discontinuous fashion. We developed and demonstrated an innovative all-optical lab-on-fiber optofluidic platform (LOFOP) to fill in this technical gap by allowing in situ measurement of the bacteria attachment in a continuous manner. This LOFOP allows for evaluation of drug release and resultant bacterial response by integrating glass capillary with lytic peptide-containing LbL-coated long period graing (LPG) as its core. S. aureus suspension is introduced through the assembled optofluidic platform with the capillary and the peptide-coated LPG. The efficacy of the peptide-containing coating is evaluated in situ by monitoring the attachment of bacteria and the ensuing development of biofilms using the LPG. LPG without antimicrobial coatings will be explored and compared as control.

10216-4, Session 1

Visualizing the proteomic landscape of brain cancer stem cells

Anke Meyer-Bäse, Florida State Univ. (United States)

Glioma-derived cancer stem cells (GSCs) are tumor-initiating cells and play an important role in tumor biology and therapeutics. The analysis and interpretation of large proteomic data sets requires the development of new data mining and visualization approaches.

Traditional techniques are insufficient to interpret and visualize these resulting experimental data. We propose novel nonlinear dimension reduction and graph techniques to analyze and integrate these data.

The graph clustering and visualization results provide a more detailed insight into the proteomic landscape and pathway upregulators for the GSCs. They will improve therapeutics of the heterogeneous glioma.

10216-24, Session 1

Multimodal chemical imaging for physical and chemical characterization

Olga S. Ovchinnikova, Oak Ridge National Lab. (United States)

The functionality of materials is largely determined by the mechanisms that take place at sub-micron length scales and at interfaces. In order to understand these complex material systems and further improve them, it is necessary to measure and map variations in properties and functionality at the relevant physical, chemical, and temporal length scales. The goal of multimodal imaging is to transcend the existing analytical capabilities for nanometer scale spatially resolved material characterization at interfaces through a unique merger of advanced microscopy, scanning probe microscopy, mass spectrometry and optical spectroscopy, this merger is rooted in innovative data processing algorithms and techniques. In this talk I will discuss how to visualize material transformations at interfaces, to correlate these changes with chemical composition, and to distil key performance-centric material parameters using a multimodal chemical imaging. I will also talk about future instrumentation developments for multimodal chemical imaging.

10216-6, Session 2

Portable obstructive sleep apnea detection and mobile monitoring

Duygu Demirkol Çakmak, B. Murat Eyübo?lu, Middle East Technical Univ. (Turkey)

Obstructive sleep apnea syndrome is becoming a prevalent disease for both adults and children. It is described as the cessation of breath for at least 10 seconds during sleep. Detecting sleep apnea is considered as a troublesome and time-consuming method, which requires the patients to stay one or more nights in dedicated sleep disorder rooms with sensors physically attached to their body. Undiagnosed thereby untreated sleep apnea patients are under high risk of hypertension, heart attack, traffic accident through fatigue and sleeplessness. In this project, nasal and oral respiratory

information is obtained with utilizing thermocouple and oxygen saturation in the blood is obtained with utilizing pulse oximeter. An analog hardware circuit is designed to readout thermocouple and pulse oximeter signals. According to this respiratory and pulse oximetry signals, obstructive sleep apnea is detected in real time with using a software implemented into an ARM based processor. An Android mobile application is developed to record and display the oxygen saturation, heart rate and respiratory signal data during sleep. ARM based processor and mobile application communication is established via Bluetooth interface to reduce cabling on the patient. In summary, a portable, low cost and user friendly device to detect obstructive sleep apnea which is able to share the necessary information to the patients and doctors for the duration of the whole sleep cycle is developed.

10216-7, Session 2

Motion correction for improved estimation of heart rate using a visual spectrum camera

Elizabeth Tarbox, Cristian Rios, Balvinder Kaur, Vasiliki Ikonomidou, George Mason Univ. (United States)

Heart rate measurement using a visual spectrum recording of the face has drawn interest over the last years as a technology that can have various health and security applications. In our previous work, we have shown that it is possible to estimate the heart beat timing accurately enough to perform heart rate variability analysis for contactless stress detection. However, a major confounding factor in this approach is the presence of movement, which can interfere with the measurements.

In order to mitigate the effects of movement, in this work we propose the use of face detection and tracking based on the Karhunen-Loewe algorithm in order to counteract measurement errors introduced by normal subject motion, as expected during a common seated conversation setting. We analyze the requirements on image acquisition for the algorithm to work, and its performance under different ranges of motion, changes of distance to the camera, as well and the effect of illumination changes due to different positioning with respect to light sources on the acquired signal.

Our results suggest that the effect of face tracking on visual-spectrum based cardiac signal estimation depends on the amplitude of the motion. While for larger-scale conversation-induced motion it can significantly improve estimation accuracy, with smaller-scale movements, such as the ones caused by breathing or talking without major movement errors in facial tracking may interfere with signal estimation. Overall, employing facial tracking is a crucial step in adapting this technology to real-life situations with satisfactory results.

10216-8, Session 2

Reconfigurable wearable to monitor physiological variables and movement

Francisco J. Romero, Diego P. Morales, Encarnación Castillo, Antonio García, Univ. de Granada (Spain); Anke Meyer-Bäse, Florida State Univ. (United States)

The noninvasive research techniques for health-care applications have evolved to the Wearable Health Systems (WHS). These techniques require information harvesting from different sensor sources and to merge that information to allow monitoring the patient. Among them, heart rate and SpO2 monitoring wearables are widely employed. This work presents the design and development of a wearable device devoted to measure these signals along with the patient's steps.

The wearable system is implemented around a photoplethysmography sensor, which provides the signals that have to be merged in order to obtain the pulse oximetry values. In addition, the wearable includes a MEMS accelerometer which allows calculating the number of steps using a kinetic approximation. The fusion of this information provides an estimation of the walked distance, the running speed and the calories burned.

The employed processor is a programmable System-on-Chip (SoC) which provides adaptability and configurability to the whole conditioning signal processing, I.e., the analog and digital domains. This adaptability can be applied either during programming or while the system is running. This SoC also includes an ARM microcontroller whose main task is combining the information from the different sensors in order to obtain final measurements by means of the implemented fusion algorithm.

Once the multisource information has been processed and all parameters are computed, a Bluetooth link sends this information to a smartphone, used as display. The wearable`s smartphone app also allows modifying algorithm parameters such as user height and weight.

10216-9, Session 3

Dynamical graph theory networks methods for the analysis of sparse functional connectivity networks in dementia

Anke Meyer-Bäse, Florida State Univ. (United States)

Dementia is the most common neurodegenerative disease among the older generation involving irreparable memory loss and decline of cognitive functions. Disease evolution is poorly understood and treatment strategies are consequently only limited efficient. Applying modern dynamic graph network theory will lay the foundation for a transformational paradigm in dementia research regarding disease evolution at the patient level, treatment response evaluation and revealing some central mechanism in a network that drives alterations in dementia.

We model and analyze functional connectivity networks in dementia as two-time scale sparse dynamic graph networks with hubs (clusters) representing the fast sub-system and the interconnections between hubs the slow sub-system. Alterations in brain function as seen in dementia can be dynamically modeled by determining the clusters in which disturbance inputs have entered and the impact they have on the large-scale dementia dynamic system.

10216-12, Session 3

Parametric investigation of scalable tactile sensor arrays

Sumit Kumar Das, Zhong Yang, Joshua R. Baptist, Dan O. Popa, Univ. of Louisville (United States)

Tactile sensors are being integrated with robotics to get force feedback and accordingly control the motion of the robots. These sensors, embedded in artificial skin, are placed on the robot to sense forces from the surrounding environment. The characterization of these sensor modules, fitted inside artificial skin, is required in order to calculate the applied force on the robot from the sensor data or sensed force. When arrays of tactile sensors are used, the signal cross-talk, the SNR and the data acquisition rate also scales accordingly.

In our study, we explore the idea of modelling a 4 X 4 sensor arrays embedded in artificial skin. We simulate an external force applied on the sensor array and observe the effect on the sensor arrays. Finally we scale the results to larger tactile sensor arrays using a reduced order modelling simulation software. The simulations were validated through experimental results.

10216-13, Session 4

Optimal accelerometer placement for robot pose estimation

Indika B. Wijayasinghe, Shamsudeen Abubakar, Univ. of Louisville (United States); Joseph D. Sanford, The Univ. of Texas at Arlington (United States); Dan O. Popa, Univ. of Louisville (United States)

Sensor placement on a robot involves many parameters that affect the performance of the intended task. One such example, which is studied here, is placing accelerometers on a robot for the purpose of pose estimation. Parameters such as number, size, distribution and Signal-to-Noise Ratio (SNR) of accelerometers are studied together with their effects on robot pose estimation. Monte-Carlo simulations are performed with a two link planer robot arm to obtain the expected value of an estimation error metric for different accelerometer configurations, which are then compared to determine best parameter values. Two methods are used to estimate robot pose; one based on numerical integration and one utilizing rigid body constraints. Noise models studied include a fixed SNR model and a scaled SNR model where the SNR is a function of the accelerometer footprint. Simulation results are complemented with preliminary experiment results performed with a robot arm.

10216-14, Session 4

Design, fabrication, and characterization of an articulated four axes microrobot

Ruoshi Zhang, Univ. of Louisville (United States)

Articulated Four Axes Microrobot (AFAM) is a new type of miniature assembly and manipulation platform for nanoscale objects. Traditionally, Atomic Force Microscopy (AFM) is a conventional tool that can be used for nanomanipulation and nanoassembly. In contrast, AFAM is an assembled device that uses MEMS technology, and, when used in multiple units, can increase the throughput and performance of conventional AFMs. In previous work, an open-loop AFAM prototype was proposed and characterized with a reported resolution of 50nm. In this paper, we discuss design improvements, in particular better interconnects and proprioceptive joint sensors to boost positional accuracy. We also discuss cooperative manipulation capabilities of multiple AFAMs. Performance analysis and visual simulation in a ROS-Gazebo environment is used as design aid prior to fabrication at University of Louisville's cleanroom. Finally, we report on the assembly of AFAMs and their experimental characterization using custom microassembly hardware in our lab.

10216-17, Session 4

Mobile app driven interaction with socially assistive robots

Ankita Sahu, Sumit Kumar Das, Univ. of Louisville (United States); Yathartha Tuladhar, The Univ. of Texas at Arlington (United States); Brandon Young, Dan O. Popa, Univ. of Louisville (United States)

Philip K. Dick (PKD) is a social robot capable of achieving human-like facial expressions. Baxter is a interactive dual arm manipulator, capable of autonomous work in manufacturing environments. The Kuka-Youbot is a mobile manipulator platform that can help users retrieve objects from the environment. These examples of socially assistive robots must interact with human users to efficiently perform their tasks. In our study, we propose a mobile app that can be customized for each of these robots and can help users communicate a large number of representative tasks. The role of the mobile app is to augment the verbal commands given to a robot through natural speech, camera and other native interfaces. For example, the app can access video feed and sensor data from robots, and implement virtual joysticks and help with decision making on pick and place operations, and conversational dialogue in a shared control manner. Extensive experimentation with PKD, Baxter, and Youbot is reported in this paper to demonstrate the flexibility and usability of our interface.

10216-18, Session 5

User adaptable interface for complex robot control tasks

Indika B. Wijayasinghe, Univ. of Louisville (United States); Sven Cremer, The Univ. of Texas at Arlington (United States); Srikanth Peetha, Dan O. Popa, Univ. of Louisville (United States)

A vital part of human interactions with a machine is the control interface, which single-handedly could define the user satisfaction and the efficiency of performing a task. This work studies a method developed to derive the mapping between the user controls and the robot actuators, which could be complex and ambiguous, in such a way that the selected mapping is optimal for the given user. The method described uses a genetic algorithm to find the optimal parameters that produces the input-output mapping with optimality defined on a suitable cost function. The cost function is constructed to be a measure of the task completion difficulty, which in this work is considered to be the time for task completion. As a proof of concept, a simulation study performed in Gazebo is described. It is shown that the method converges to an intuitive mapping, which minimizes the task completion time.

10216-19, Session 5

Fabrication and characterization of modular multi-modal robotic skin

Joshua R. Baptist, Mohammad Nasser Saadatzi, Ruoshi Zhang, Dan O. Popa, Univ. of Louisville (United States)

The need for robots and machines to collect, process, and understand external and environmental stimuli is becoming an ever growing need. Though many examples and prototypes have been unveiled, there has yet to be a highly accepted method of sensorizing robots with functional 'skin' and few commercially available options on the market. One step in this direction is our investigation and deployment of multi-modal robot skin to provide haptic and other environmental information back to a control system for subsequent processing. Goals of this device are to create a multi-modal, conformable, and easily distributable patch for quick and easy deployment on robots and other systems. In this paper we describe "SkinCells", which are modular and multi-modal sensor skin patches that can be deployed and networked around robots and other systems requiring human machine interfacing (HMI). Sensors integrated in our modules include custom fabricated polymer strain gauge arrays employing Poly (3,4 –ethylenedioxythiophene) : Polystyrene Sulfonate (PEDOT:PSS) inks, combined in a package with off the shelf sensors for measurement of proximity, temperature (local and distant), and inertial forces. Quantified results on the performance of the SkinCells is presented using various methods of testing carried out in a variety of controlled experiments.

10216-20, Session 5

Characterization of large area pressure sensitive robot skin

Mohammad Nasser Saadatzi, Joshua R. Baptist, Ruoshi Zhang, Sumit Kumar Das, Brandon Young, Dan O. Popa, Univ. of Louisville (United States)

There is a lot of promise in multimodal robotic skin to enhance robots' perception of surrounding environments. For reliable performance and safe human-robot physical interaction, a sufficiently high spatial sensor density is required. In a previous study done in our laboratory, a 4x4 flexible array of strain sensors were successfully printed and packaged onto Kapton sheets and silicone encapsulants. In this paper, we are extending the surface area of the patch to larger arrays, with up to 512 tactel elements. To address scalability, sensitivity, and calibration challenges, a new electronic module, free of the traditional signal conditioning circuitry is proposed. The proposed methodology is based on a software-based calibration scheme that involves an electronic system with high-resolution analog-to-digital converters with internal programmable gain amplifiers. In this paper, we first show the efficacy of the proposed method with eight 4x4 skin arrays using controlled pressure tests, and then perform procedures to evaluate each sensor's characteristics such as dynamic force-to-strain property, crosstalk, repeatability, and signal-to-noise-ratio as well as sensitivity to ambient temperature changes.

Conference 10217: Sensing for Agriculture and Food Quality and Safety IX

Thursday 13 April 2017

Part of Proceedings of SPIE Vol. 10217 Sensing for Agriculture and Food Quality and Safety IX

10217-22, Session PWed

Classification of Peronospora infected grapevine leaves by hyperspectral imaging

Giuseppe Bonifazi, Laura D'Aniello, Valentina Luciani, Silvia Serranti, Sapienza Univ. di Roma (Italy)

Precision Viticulture (PV) is a group of methodologies allowing the monitoring and the site-specific management of the vineyard. Nowadays, the PV assigns a lot of importance to crop monitoring, that is in the information collection through direct "in site" observation of the phenological stages, the nutritional and health status, and the expected crops production. The developed systems, for vineyard monitoring, essentially refer to the Remote Sensing (RS) technologies, allowing to collect and handle multispectral images of the vineyards through the use of satellite or airborne optical sensors. Images are investigated with reference to spectral bands. RS, despite of its potentialities, shows some technical, economical and organizational characteristics limiting its application in a vineyard context characterized by a high fragmentation of the crops, especially in the hilly areas. Furthermore, time intervals between acquisitions, is in fact, linked to the transit of the satellite on the same area or to the frequency of the flights. Therefore, especially in the case of the satellite sensors, the obtained images often do not correspond to the interesting phenological phases or they are compromised by the adverse weather conditions. This work considers the possible utilization of proximal sensing technologies, directly on site, for the identification of different levels of Peronospora infection on grapevine leaves, utilizing two different hyperspectral devices working in different wavelength ranges: 100-1700 nm and 1000-2500 nm, respectively.

10217-23, Session PWed

Non-destructive quality control of kiwi fruits by hyperspectral imaging

Giuseppe Bonifazi, Valentina Luciani, Silvia Serranti, Sapienza Univ. di Roma (Italy)

Italy is the second world kiwifruit producer after China. In recent years, the marketable production has reached 460,000 tons although it has sometimes exceeded 510,000 tons, highlighting its great production potential.

Due to the continuous expansion of kiwifruit market, and the corresponding increase of the export of those produced in Italy, their monitoring in terms of degree of maturation and overall quality represent an important targets to fulfill in order to be competitive in a more and more demanding market. Postharvest ripening and the "early detection" of some specific kiwi diseases (i.e. Pseudomonas Syringae pv. Actinidiae) could dramatically contribute to realize cultivations characterized by a low environmental impact (i.e. water and pesticides reduction), a higher products quality and increased economic benefits for farmers.

In this work a non-destructive and non-invasive approach, hyperspectral imaging based, was applied in order to reach both the two previous mentioned goals, that is: i) evaluation of kiwi fruits postharvest ripeness and ii) Pseudomonas infection early detection directly in the field. To reach the 1st goal, kiwi hyperspectral images were acquired in the NIR spectral range (1000-1700 nm) utilizing an exploratory analysis carried out by Principal Component Analysis (PCA) in order to evaluate fruits degree of maturation. The same approach, but working in the VIS-NIR range (400-1000 nm), was adopted to reach the 2nd goal, in this latter case investigations have been carried out on infected and healthy leaves of green and yellow kiwi fruit plants.

10217-24, Session PWed

Detection of pesticide (Cyantraniliprole) residue on grapes using hyperspectral sensing

Jayantrao D. Mohite, Yogita Y. Karale, Srinivasu Pappula, Tata Consultancy Services Ltd. (India); Ahammed Shabeer T. P., S. D. Sawant, Sandip Hingmire, ICAR - National Research Ctr. for Grapes (India)

Pesticide residues on fruits, vegetables and agricultural commodities are harmful to humans and are becoming a health concern. Detection of pesticide residues in open environment is a challenging task. Hyperspectral remote sensing is one of the recent technologies used to detect the pesticide residues. This paper addresses the problem of detection of pesticide residues of 'Cyantraniliprole' on Grapes in open fields using multi temporal hyperspectral remote sensing data. The reflectance data of 686 samples of grapes with No, Single and Double dose application of Cyantraniliprole has been collected by handheld spectroradiometer (MS-720) with a wavelength ranging from 350 nm to 1052 nm. The data has been collected over a large feature set of 213 spectral bands during the period of March-May 2015. This large feature set may increase the computational time, so in order to get the most relevant features, various feature selection techniques viz Principle Component Analysis (PCA), LASSO and Elastic Net Regularization etc have been used. Using this selected features, we evaluate the performance of various classifiers like Artificial Neural Networks (ANN), Support Vector Machine (SVM), Random Forest (RF) and XGBoost to classify the Grape sample with No, Single or Double dose application of Cyantraniliprole. The key findings of this paper are; most of the features selected by the LASSO varies between 350-373 nm and 940-990 nm consistently for all days. Experimental results also shows that, by using the those features, SVM performs best among all, with average accuracy varying between 87.23% to 94.67 for all days.

10217-25, Session PWed

Design optimization of a surface-scanning detector for direct bacterial detection on fresh produce

Hyun Jung Min, Chungnam National Univ. (Korea, Republic of)

Direct detection of bacterial pathogens on fresh produce has been recently demonstrated using a method that combines a wireless magnetoelastic biosensor and a surface-scanning detector. The biosensor is placed directly on the surface of fresh produce, and a change in the biosensor's resonant frequency due to the specific binding of a target pathogen is measured wirelessly by the detector. The signal amplitude is known to be largely dependent on the distance between the biosensor and detector as well as on the electrical characteristics of the detector. In this work, a model was constructed to simulate the wireless measurement of biosensors for various detector designs. The surface-scanning detector is a microelectronically fabricated planar coil that is connected to a network analyzer operating in the S11 reflection mode. When close enough to the detector, the biosensor is placed into mechanical resonance. This causes the electrical impedance of the detector to change. The signal amplitude is maximized when the change in the detector impedance is at maximum. The ANSYS program was used to calculate the impedance change for various detector shapes and dimensions. The model presented in this work can be used to find the optimal detector design to maximize the signal amplitude and/or to estimate the signal amplitude for smaller sensors (e.g., 500 um or less in length) that have higher mass sensitivity. In addition, by optimizing the detector design, a larger stand-off distance can be realized, which is useful

for the testing of food surfaces with variable roughness and curvatures (e.g., leafy greens).

10217-26, Session PWed

A portable nondestructive detection device of quality and nutritional parameters of meat using Vis/NIR spectroscopy

Wenxiu Wang, China Agricultural Univ. (China); Yankun Peng, China Agricultural Univ. (China); Fan Wang, Hongwei Sun, China Agricultural Univ. (China)

The improvement of living standards has urged consumers to pay more attention to the quality and nutrition of meat and development of nondestructive detection device for quality and nutritional parameters was commercioganic undoubtedly. In this research, a portable device equipped with visible (Vis) and near-infrared (NIR) spectrometers, tungsten halogen lamp, optical fiber, ring light guide and embedded computer was developed to realize simultaneous and fast detection of color (L*, a*, b*), pH, total volatile basic nitrogen (TVB-N), fat, protein and water content in pork. The wavelengths of dual-band spectrometers were 400~1100 nm and 900~1700 nm respectively and the tungsten halogen lamp cooperated with ring light guide to form a ring light source and provide appropriate illumination intensity for sample. Software was self-developed to control the functionality of dual-band spectrometers, set spectrometer parameters, acquire and process Vis/NIR spectroscopy and display the prediction results in real time. In order to obtain a robust and accurate prediction model, fresh longissimus dorsi meat was bought and placed in the refrigerator for 12 days to get pork samples with different freshness degrees. Besides, pork meat from three different parts including longissimus dorsi, haunch and lean meat was collected for the determination of fat, protein and water to make the reference values have a wider distribution range. After acquisition of Vis/NIR spectrum, data from 400~1100 nm were pretreated with Savitzky-Golay (S-G) filter and standard normal variables transform (SNVT) and spectrum data from 900~1700 nm were preprocessed with SNVT. The anomalous were eliminated by Monte Carlo method based on model cluster analysis and then partial least square regression (PLSR) models based on single band (400~1100 nm or 900~1700 nm) and dual-band were established and compared. The results showed the optimal models for each parameter were built with correlation coefficients in prediction set of 0.93, 0.91, 0.90, 0.94, 0.95, 0.90, 0.92 and 0.89, respectively. It indicated this innovative and practical device can be a promising technology for nondestructive, fast and accurate detection of nutritional parameters in meat.

10217-27, Session PWed

Study on the detection of total viable count of chilled pork with high oxygen storage condition based on hyperspectral technology

Xiaochun Zheng, Yongyu Li, Yankun Peng, China Agricultural Univ. (China); Wensong Wei, China Agricultural Univ. (China); Kuanglin Chao, Jianwei Qin, Agricultural Research Service (United States)

The plate count method is the common method for detection of total viable count (TVC) of bacteria in pork, which is time-consuming and destructive. And many scholars study the changes of the total number of bacteria in chilled pork under different storage conditions by using this method. In recent years, the non-destructive methods on detecting TVC were explored by many scholars with visible near infrared technology and hyperspectral technology, which achieved good results. The total number of bacteria in chilled pork that stored under high oxygen condition was monitored in this study by using hyperspectral technology in order to evaluate the changes of total bacterial count during storage, and then evaluate advantages and disadvantages of the storage condition. The near infrared (NIR) hyperspectral images of samples stored in high oxygen condition was acquired by a hyperspectral system in range of 1000~2500nm. The reference value of total bacteria was measured by standard plate count method, and the results were obtained in 48 hours. The reflection spectra of the samples are extracted and used for the establishment of prediction model for TVC. The spectral preprocessing methods of standard normal variate transformation (SNV), multiple scatter correction (MSC) and derivation were conducted to the original reflectance spectra of samples. Partial least squares regression (PLSR) and support vector machine regression (SVR) of TVC were performed and compared to optimize the prediction model. The PLSR model combined with the first derivative () obtained the best results with the correlation coefficient of the prediction model (RP) more than 0.90. Then the growth pattern of total bacteria in chilled pork that stored in high oxygen condition was monitored on the basis of the optimized model. The results show that the near infrared hyperspectral technology based on 1000-2500nm combined with PLSR model can describe the growth pattern of the total bacteria count of the chilled pork under the condition of high oxygen very vividly and rapidly. The results obtained in this study demonstrate that the nondestructive method of TVC based on NIR hyperspectral has great potential in monitoring of edible safety in processing and storage of meat.

10217-28, Session PWed

A portable device for detecting fruit quality by diffuse reflectance Vis/NIR spectroscopy

Hongwei Sun, China Agricultural Univ. (China); Yankun Peng, Peng Li, Wenxiu Wang, China Agricultural Univ. (China)

Soluble solid content, water content and firmness are major quality parameters to fruit, which have influence on its flavor or texture. This study aimed to develop a portable device for accurate, real-time and nondestructive determination of quality factors of fruit mentioned above based on diffuse reflectance Vis/NIR spectroscopy (400~1000 nm). There are four units about device: light source unit, spectral acquisition unit, central processing unit, display unit. Halogen lamp was chosen as light source. At work, hand-held probe on the surface of fruit samples can form dark environment to shield the interferential light outside. Reflected light is received and measured by spectrometer (USB4000). ARM (Advanced RISC Machines), as central processing unit, controls all parts in device and analyses spectrum data. Liquid Crystal Display (LCD) touch screen is used to interface with users. The corresponding application software was designed under Linux platform calling the Qt Class Library. 90 apples were used in the experiment to validate the stability and reliability, 60 of which were as calibration, while others as validation. Their physicochemical characteristics such as soluble solid content, water content and firmness were measured in standard methods. The acquired spectrum data were then processed by standard normalized variables (SNV) and Savitzky-Golay filter (S-G) to eliminate the spectra noise. The partial least squares regression (PLSR) and multiple linear regressions (MLR) were used to build prediction models for soluble solid content, water content and firmness. By compared, PLSR could gain better prediction results with Rp of 0.93, 0.91, and 0.94 respectively. The results demonstrated that this device could be a promising tool applied to detecting apple quality attributes.

10217-29, Session PWed

Improvement of Raman detection system for pesticide residues on/in fruits and vegetables

Yan Li, Yankun Peng, Chen Zhai, China Agricultural Univ.

(China); Kuanglin Chao, Jianwei Qin, Agricultural Research Service (United States)

Pesticide residue is one of the major challenges to fruits safety, while the traditional detection methods of pesticide residue on fruits and vegetables can't afford the demand of rapid detection in actual production because of time-consuming. Thus rapid identification and detection methods for pesticide residue are urgently needed at present. While most Raman detection systems in the market are spot detection systems, which limits the range of application. In the study, our lab develops a Raman detection system to achieve area-scan thorough the self-developed spot detection Raman system with a control software and two devices. In the system, the scanning area is composed of many scanning spots, which means every spot needs to be detected and more time will be taken than area-scan Raman system. But lower detection limit will be achieved in this method. And some detection device is needed towards fruits and vegetables in different shape. Two detection devices are developed to detect spherical fruits and leaf vegetables. During the detection, the device will make spherical fruit rotate along its axis of symmetry, and leaf vegetables will be pressed in the test surface smoothly. The detection probe will be set to keep a proper distance to the surface of fruits and vegetables. It should make sure the laser shins on the surface of spherical fruit vertically. And two software used to detect spherical fruits and leaf vegetables will be integrated to one, which make the operator easier to switch. Accordingly two detection devices for spherical fruits and leaf vegetables will also be portable devices to make it easier to change. In the study, a new way is developed to achieve area-scan by spot-scan Raman detection system.

10217-30, Session PWed

Specificity tests of an oligonucleotide probe against food-outbreak salmonella for biosensor detection

I-Hsuan Chen, Shin Horikawa, Jianguo Xi, James M. Barbaree, Bryan Allen Chin, Auburn Univ. (United States)

Biosensors have played an important role in food safety and quality control in recent years. The biosensor is an integrated device that consists of a transducer and a biological recognition element. The biological element, sometimes also called the bio-probe, is responsible for interacting with the analyte. The detection response from the interaction is then converted into electrical signals. To develop an accurate biosensor detection system, it is critical to know the specificity of the bio-probe toward its target.

Phage based magnetoelastic biosensors have been shown to be able to rapidly detect Salmonella in different food systems. In the above biosensor platform, the free-standing strip-shaped magnetoelastic sensor is the transducer and the phage probe that recognizes Salmonella in food serves as the bio-recognition element. According to Sorokulova et al. at 2005, a developed oligonucleotide probe E2 was reported to have high specificity to Salmonella enterica Typhimurium. Here, we tested the specificity of the developed probe E2 to thirty-three Salmonella enterica serotypes that were present in foodborne outbreaks during the past ten years (according to Centers for Disease Control and Prevention).

The tests were conducted through an Enzyme linked Immunosorbent Assay (ELISA) format. This assay can mimic probe immobilized conditions on the magnetoelastic biosensor platform and also can effectively study the binding specificity of oligonucleotide probes toward different Salmonella while avoiding sensor lot variations. Test results confirmed that this oligonucleotide probe E2 was highly specific to Salmonella Typhimurium cells but showed some cross reactivity to Salmonella Tennessee among thirty-three tested Salmonella serotypes.

10217-31, Session PWed

Nondestructive measurement of yield grade of beef carcass using 3D imaging technique

Seung Hwan Yang, Youngwook Seo, Wang-Hee Lee, Chungnam National Univ. (Korea, Republic of); Changyeun Mo, Rural Development Administration (Korea, Republic of); Moon S. Kim, Agricultural Research Service (United States); Byoung-Kwan Cho, Chungnam National Univ. (Korea, Republic of)

The evaluation of beef carcass salable yield often forms the basis for the agreement between livestock producers and meat processors. Precise prediction technique for yield grade of beef carcass is helpful for the beef industry to control the overall beef supply in the country. Despite of the increasing needs for accurate and rapid prediction of beef yield grade, there is still no potent method. In this study, we purposed a 3D image processing technique for non-destructive measurement of yield grade for beef carcass. Strip shape pattern light was projected on the carcass surface to take 3D images of each sample using a CMOS sensor camera. The collected images were processed using image processing techniques to recognize pattern and morphology of the samples. Using the image morphology and depth information, the volume and weight of the beef carcass can be estimated and compared with the measured ones. The developed technique suggested its possibilities for calculating the profile of beef carcass for the effective and accurate determination of meat production. This technique may be able to be used as a routine part of normal commercial beef processing.

10217-32, Session PWed

Rapid detection of E.coli forming biofilms on baby spinach leaf surfaces using hyperspectral fluorescence imaging

Hyunjeong Cho, Agricultural Research Service (United States) and National Agricultural Products Quality Management Service (Korea, Republic of); Insuck Baek, Mirae Oh, Agricultural Research Service (United States); Sungyoun Kim, Dongho Kim, National Agricultural Products Quality Management Service (Korea, Republic of); Moon S. Kim, Agricultural Research Service (United States)

Bacterial biofilm formed by pathogens on fresh produce surfaces is a food safety concern because its structural attribute of complex extracellular matrix reduces reduction and removal efficacies of washing and sanitizing such as chemical or irradiation treatments. Therefore, rapid and nondestructive method to identify pathogenic biofilm on produce surfaces is essential to ensure safe consumption of produce. This research aimed to evaluate the feasibility of hyperspectral fluorescence imaging for detecting Escherichia.coli (ATCC 25922) forming biofilms on baby spinach leaf surfaces. Baby spinach leaves were immersed and inoculated with five different levels (from 2x104 to 2x108 CFU/mL) of E.coli and stored at 4°C for 24 h and 48 h to induce biofilms formation. Following the two treatment days, individual leaves were gently washed to remove excess liquid inoculums from the leaf surfaces and evaluated by hyperspectral fluorescence imaging system equipped with UV-A (365 nm) and violet (405 nm) excitation sources. The imaging results showed that leaves with the lowest level of inoculation could be differentiated from control leaf surfaces with accuracies of 80.56 % in UV-A and 83.33 % in violet excitation. This preliminary investigation demonstrated that the fluorescence imaging techniques can be used to detect pathogenic biofilms on green leaf surfaces.

10217-33, Session PWed

Detection of pesticide residues on paprika by Raman Spectroscopy

Namkyoung Choi, Univ. of Science & Technology (Korea, Republic of); Yong-Il Kim, Korea Research Institute of Standards and Science (Korea, Republic of); Byounggab Im, Master Korea Co. Ltd (Korea, Republic of); Byoung-Kwan Cho, Chungnam National Univ. (Korea, Republic of); Ki-Bok Kim, Korea Research Institute of Standards and Science (Korea, Republic of)

In Korea, the paprika is one of the high added value products as well as the most briskly exported produce. Recently, pesticide residue is emerging as a critical issue. Especially, some pesticides are bound to remain on the surface of the paprika after washing it. One of typical detecting methods of pesticide residue is chemical analysis. However, this needs high skilled manpower and spends a lot of time on analysis. Therefore it needs a nondestructively and quickly detecting method for pesticide residue on the surface of the paprika over maintaining value of produce.

In this study, as a tool for detecting the pesticide residue on paprika surface, a feasibility of Raman spectroscopy combined with microscope was evaluated. Thirteen kinds of pesticide such as pencycuron, kresoxim-methyl, thiophanate-methyl, metalaxyl, procymidone, carbendazim, tolclofos-methyl, flufenoxuron, chlorpyrifos, carbofuran, azoxystrobin·chlorotalonil, endosulfan, and methidathion were used. Qualitative analyses for 13 pesticides were conducted by PCA (principal component analysis).

As a result, the experimented pesticides could be classified through the PCA method, successfully.

10217-34, Session PWed

Nondestructive detection of artificially water-injected frozen octopus by microwave reflection technique

Jeongseok Lee, Korea Research Institute of Standards and Science (Korea, Republic of); Sangdae Lee, Korea Institute of Industrial Technology (Korea, Republic of); Byounggab Im, Master Korea Co. Ltd. (Korea, Republic of); Seunghyun Lee, Byoung-Kwan Cho, Chungnam National Univ. (Korea, Republic of); Ki-Bok Kim, Korea Research Institute of Standards and Science (Korea, Republic of)

As imports of frozen marine products increase, import and distribution companies are amplifying the weight of the marine products by intentionally injecting water or using a 'glazing' method, which coats water on the surface of the products. Moreover, they also artificially increase the weight of the marine products using chemicals such as caustic soda or phosphate. Phosphate (sodium polyphosphate), a food additive, is moistly used in hams or sausages to increase the binding properties or enhance elasticity and conservation of the product. However, such chemicals are being used in marine products such as sea cucumbers, shellfish, shrimps, and octopuses to artificially absorb moisture and can increase the product's weight by over 30 percent. In Korea, the pricing the imported marine products is done using the weight of the marine products, which leads to amplification of such side effects.

The goal of this research was to develop a method to nondestructively verify whether water has been injected into the frozen octopus or not, using microwave reflection technique. A microwave reflection measurement system was constructed using S-band and X-band horn antennas, and microwaves reflected from the frozen octopus samples with different amount of waters were measured and analyzed. A classification factor base on reflection coefficient to differentiate frozen octopuses with and without water injection was presented and evaluated. As a conclusion, a water-injected frozen octopus will be detectable by the presented classification factor in this research.

10217-35, Session PWed

LC electrical impedance matching for broad-band ultrasonic transducer for NDE application

Geonwoo Kim, Univ. of Science & Technology (Korea, Republic of); Mukyoung Seo, Sungkyunkwan Univ. (Korea, Republic of); Ki-Bok Kim, Korea Research Institute of Standards and Science (Korea, Republic of)

To detect small defects (less than hundreds of um) by ultrasonic testing, ultrasonic transducers with high resolution and resonance frequency are required. Resonance frequency and resolution of ultrasonic transduce are closely related to the thickness of piezo-electric materials, backing materials, and electric impedance matching technique. Among them, an electrical impedance matching plays an important role to reduce loss and reflection of ultrasonic energy due to difference in electrical impedance between ultrasonic transducer and ultrasonic measurement system.

The mainly used electric matching method is LC matching circuit. To compensate the difference of electrical impedance between both connections, the electrical impedance of ultrasonic transducer should be nearly 50 ohm. In this study, 15 MHz-immersion ultrasonic transducer was fabricated and LC electrical impedance circuit was applied to that for having broad-band frequency characteristic.

10217-36, Session PWed

Development of surface acoustic wave sensor system for evaluating the freshness of chicken meat

Mukyoung Seo, Sungkyunkwan Univ. (Korea, Republic of); Ki-Bok Kim, Korea Research Institute of Standards and Science (Korea, Republic of); Geonwoo Kim, Univ. of Science & Technology (Korea, Republic of); Yong-Il Kim, Korea Research Institute of Standards and Science (Korea, Republic of); Byoung-Kwan Cho, Chungnam National Univ. (Korea, Republic of)

The aim of this study was to develop a surface acoustic wave (SAW) sensor system to evaluate the freshness of chicken meat. To accomplish this, gas components were analyzed during the storage time of chicken meat by means of GC-MS (Gas chromatograph mass spectrometry). From the results of the GC-MS analyses, as a freshness detection factor, acetaldehyde showing a rapid increase after five days was selected. As a sensitive layer of the SAW device, PDMS (polydimethylsiloxane) film was coated onto the surface of a SAW device between input and output inter-digital transducers (IDTs) using a spin-coating method. The IDTs were fabricated on the surfaces of LiNbO3 piezoelectric wafers by standard photolithographic techniques. To analyze the performance of the fabricated SAW sensor, N2 gas (carrier gas) and various concentrated CH3CHO gases were mixed and fed into the PDMS-sensitive layer of the SAW sensor. The phase shift of the SAW sensor increased with an increase in the concentration of CH3CHO. Thus the developed SAW sensor showed good sensitivity and stability. The SAW sensor system consisted of a voltage-controlled oscillator, two frequency counters, a voltage regulator, a LCD display unit, a microprocessor, a small chamber with the SAW sensor. Because a distinct frequency change of the developed SAW sensor system was found during the storage of the chicken meat, the freshness of chicken meat can be evaluated.

10217-1, Session 1

Phage-based biomolecular filtering for the efficient isolation of bacterial pathogens from liquid streams

Songtao Du, Shin Horikawa, I-Hsuan Chen, Yuzhe Liu, Bryan Allen Chin, Auburn Univ. (United States)

This paper presents a filtration method that enables the evaluation of large volumes of liquids for the presence of small quantities of bacterial pathogens. The method relies on biomolecular recognition filtering to capture, concentrate, and isolate target pathogens that may exist in a liquid of interest. The filter is a multi-layered arrangement of phage-coated, strip-shaped magnetic particles (4 mm ? 0.8 mm ? 0.03 mm) through which the liquid flows. This “phage filter” is designed to capture specific bacterial pathogens and allow non-specific targets to pass, eliminating the common clogging issue, which often occurs in conventional bead filters. The phage filter elements include a support frame, solenoid coils coupled to the support frame, and a plurality of phage-coated magnetic particles. The support frame is fabricated from a soft magnetic material and defines an opening. The solenoid is configured to, when energized, cause the support frame to generate a defined magnetic field pattern. The phage-coated magnetic particles, magnetically coupled to the support frame, are arranged in a planar array, positioned within the opening of the support frame. Each magnetic particle can rotate about the attached end of the particle, allowing large, non-specific debris to pass. The ANSYS Maxwell program was used to simulate the magnetic field pattern required to hold particles densely and to optimize the frame design to improve the efficiency of pathogen capture. A proof-in-concept experiment has been conducted where liquid solutions containing different concentrations of Salmonella were passed through the filter, and the capture efficiency quantified by plate counting. The biomolecular recognition filter may be combined with standard detection methods, such as qPCR, to detect and identify pathogens rapidly.

10217-2, Session 1

Highly sensitive surface-scanning detector for the direct bacterial detection using magnetoelastic (ME) biosensors

Yuzhe Liu, Songtao Du, Shin Horikawa, Yating Chai, Howard Clyde Wikle III, Bryan Allen Chin, Auburn Univ. (United States)

This paper presents the design, fabrication and characterization of a highly sensitive surface-scanning detector that is to combine with magnetoelastic (ME) biosensors for the direct, wireless detection of bacterial pathogens on fresh produce. The former surface-scanning detector was a single-layered planar coil, which had a limitation in signal amplitude. By contrast, the new detector is a microelectronically fabricated double-layered coil with which the excitation power and detection sensitivity can be enhanced. Hence, not only the wireless detection distance can be increased, but also smaller ME biosensors can be used in the detection, providing higher mass sensitivity. Several design parameters, including the thickness of layers, width, height, and spacing of coil turns, as well as the microfabrication methods (photolithography, electroplating, etching and sputtering) of the double-layered coil detectors, were studied. Both theoretical calculations and experimental data showed that the above coil design parameters had significant impacts on the signal amplitude and stand-off distance. Finally, with the newly fabricated double-layered coil detector, simultaneous measurement of multiple biosensors on a food grade ultra-high-molecular-weight polyethylene (UHMW-PE) board surface was demonstrated. This double-layered scanning coil detector therefore facilitates the detection of pathogens on food and food contact surfaces.

10217-3, Session 1

Automated surface-scanning detection of pathogenic bacteria on fresh produce

Shin Horikawa, Songtao Du, Yuzhe Liu, I-Hsuan Chen, Jianguo Xi, Michael Crumpler, Donald Sirois, Steve R. Best, Howard Clyde Wikle III, Bryan Allen Chin, Auburn Univ. (United States)

This paper presents an investigation into rapid, automated detection of pathogenic bacteria on fresh produce. The method combines phage-coated magnetoelastic (ME) biosensors, a robot arm for sensor placement on food, a surface-scanning detector, and a programmable motorized translation system, enabling automated testing of food surfaces for the presence of specific bacteria. The ME biosensor used in this investigation is composed of a strip-shaped ME resonator (1 mm x 0.2 mm x 30 um) upon which E2 phage is coated to capture Salmonella Typhimurium specifically. The biosensors were placed at desired positions on the surface of tomatoes using the robot arm sensor placement apparatus. Upon contact, Salmonella on the tomato surface was bound to the biosensor specifically, resulting in an increase in the biosensor’s mass and a decrease in the biosensor’s resonant frequency. Monitoring of this mass-induced resonant frequency change over time allows the real-time detection and quantification of Salmonella. In this work, multiple biosensors were placed on tomatoes to test large surface areas. This methodology offers rapid, automated detection of specific bacteria on food, and may be used as a screening method at ports of entry, warehouses, and processing plants.

10217-4, Session 2

Rapid detection of parasite in muscle fibers of fishes using a portable microscope imaging technique

Jayoung Lee, Chungnam National Univ. (Korea, Republic of); Hoonsoo Lee, Moon S. Kim, Agricultural Research Service (United States); Byoung-Kwan Cho, Chungnam National Univ. (Korea, Republic of)

Fishes are a widely used food material in the world. Recently about 4% of the fishes are infected with Kudoa thyrsites in Asian ocean. Kudoa thyrsites is a parasite that is found within the muscle fibers of fishes. The infected fishes can be a reason of food poisoning, which should be sorted out before distribution and consumption. Although Kudoa thyrsites is visible to the naked eye, it could be easily overlooked due to the micro-scale size and similar color with fish tissue. In addition, the visual inspection is labor intensive works resulting in loss of money and time. In this study, a portable microscopic camera was utilized to obtain images of raw fish slices. The optimized image processing techniques with polarized transmittance images provided reliable performance. The result shows that the portable microscopic imaging method can be used to detect parasites rapidly and non-destructively, which could be an alternative to manual inspections.

10217-5, Session 2

Spatially offset Raman spectroscopy method for detection of chemicals in subsurface layer

Sagar Dhakal, Kuanglin Chao, Jianwei Qin, Moon S. Kim, Diane E. Chan, Agricultural Research Service (United States)

Proper chemical analyses of materials inside closed containers are important for quality control purpose. Although it is feasible to detect chemicals at top surface layer, it is relatively challenging to detect objects beneath obscuring surface. This study proposes spatially offset Raman spectroscopy (SORS) method for detection of chemicals in deep subsurface layer beneath diffusely scattering media. A point-scan Raman system utilizing a 785 nm laser source was used to collect spatially offset Raman spectral signals of four different chemicals (Urea, Ibuprofen, Tetracycline Hydrochloride and Acetaminophen) packed separately inside capsule. Capsule was selected as a representative material used for packaging food and pharmaceuticals powders. Array of SORS signal was collected from sample at offset distance of 0 (no offset) to 10 mm. Unique spectral peak of capsule and four chemicals were used to identify each material. It was observed that with increase in offset distance the contribution of Raman spectral signal from deep layer material (chemical) gradually outweigh that from top layer (capsule). Difference in the contribution of Raman spectral signal was utilized to identify the top surface and deep subsurface layer material. Self modeling mixture analysis (SMA) algorithm was used to extract pure component spectra of capsule and individual chemicals from the array of SORS data. Results show that SORS technique together with SMA method has a potential for non-invasive detection of chemicals at deep subsurface layer.

10217-6, Session 2

Detecting benzoyl peroxide in wheat flour by line-scan macro-scale Raman chemical imaging

Jianwei Qin, Moon S. Kim, Kuanglin Chao, Agricultural Research Service (United States); Maria Gonzalez, New Mexico State Univ. (United States); Byoung-Kwan Cho, Chungnam National Univ. (Korea, Republic of)

Excessive use of benzoyl peroxide (BPO, a bleaching agent) in wheat flour can destroy flour nutrients and cause diseases to consumers. A high-throughput Raman chemical imaging method was developed to directly inspect BPO mixed in wheat flour. A 785 nm line laser was used as an excitation source in a push-broom Raman imaging system. Hyperspectral Raman images were acquired from dry wheat flour mixed with BPO at different concentrations. A sample holder was used to create a thin layer (2 mm thick) of the powdered sample for line-scan image acquisition. The fluorescence signals from the flour were removed using a baseline correction method. A unique Raman peak was selected for the BPO detection. A simple thresholding method was applied to the single-band fluorescence-free images at the selected peak wavenumber to separate BPO particles from the flour background. Chemical images were generated to detect and map the BPO particles. Pixel concentrations were calculated from the percentages of the BPO pixels in the chemical images, and they were used to estimate the limit of detection. High correlation was found between the pixel concentrations and the mass concentrations of the BPO, suggesting that the Raman chemical imaging method can be used for quantitative detection of the BPO mixed in the wheat flour.

10217-7, Session 3

NIR spectroscopy for point-of-need freshness assessment of meat, fish, vegetables and fruits

Seoho Lee, Tae-Gyoon Noh, Jun Hoe Choi, Jeongsu Han, Joo Young Ha, Ji Young Lee, SAMSUNG Electronics Co., Ltd. (Korea, Republic of)

Foodborne illness is a public health burden which is estimated to affect 48 million people annually in the United States alone. While monitoring the freshness of food before consumption could significantly lower the number of such incidences, there is a lack of a simple system that one can use to assess the freshness of their food. Currently, the most common practice for food quality determination is by visual inspection which lacks objectivity, accuracy and precision. Near infrared (NIR) spectroscopic techniques can help address this problem by providing rapid and non-destructive means to estimate the freshness state of various foods based on the changes to their characteristic spectra in the NIR region. Recent advancements in the development of portable NIR spectrometers are also enabling the realization of this technique at the point-of-need. In this study, we have evaluated the feasibility of using NIR spectroscopy at the point-of-need to estimate the freshness of various foods including: meat (pork, beef), fish (bass, salmon, corvina), vegetables (tomato, pepper) and fruits (water melon). Using commercial NIR spectrometers, we periodically scanned and collected NIR spectra from food items which were prepared from a common stock and stored for up to 30 days. For each food item, we show the NIR spectra can be classified by the food's aging day with high accuracy, which represents high prospects for NIR spectroscopy in point-of-need freshness assessment of meat, fish, vegetables and fruits.

10217-8, Session 3

In-motion optical sensing for assessment of animal well-being

Colton Atkins, Kevin Pond, Colorado State Univ. (United States); Christi K. Madsen, Texas A&M Univ. (United States)

Musculoskeletal unsoundness is a common and debilitating issue within the livestock sector. Affliction to an animal's limbs can result in loss of production, economics and animal quality of life. This research investigated proof-of-concept application of an in-motion, diagnostic technology with real-time data acquisition to better understand musculoskeletal unsoundness for improvement of animal well-being. An optical sensor-based platform was used to collect in-motion, force and pressure of hoof impacts. The platform was divided into three sectors and nine subsectors. Eight steers weighing between 1500 and 2500 lbs., of British and Continental influence were tested. Initial bodyweights and hoof circumferences were collected prior to testing. Two linear passes were completed at a walking gait. Each steer's pass was recorded electronically and with a video camera for comparison and analysis. Videos were evaluated concurrently. Fifty-eight strides, in total, were obtained. Approximately two strides per hoof were observed. Mean velocity of strides at a walking gait was 2.6 m/s, ranging from 2.0 to 4.0 m/s. First fore and hind limb impacts located in sectors one and two displayed the largest readings. Optical deflection showed muting in signal for impacts located in sector three. Animal speed held high correlation to impact force. Of the eight steers tested, unsoundness was detected in one animal and later confirmed by veterinarian analysis. Overall, kinematic and kinetic differences between animals displayed real-time, biometric patterns. Through use of optical sensors, this research aims to form market-accessible handling technologies for producers to increase their awareness of an animal's state of health.

10217-9, Session 3

Detection of artificially ripened mango using spectrometric analysis

Mithun B.S., Milton Mondal, Harsh Vishwakarma, Sujit Shinde, Sanjay Kimbahune, Tata Consultancy Services Ltd. (India)

Hyper spectral sensing has been proven to be useful to determine the quality of food in general. It has also been used to distinguish naturally and artificially ripened mangoes by analyzing the spectral signature. However the focus has been on improving the accuracy of classification after performing dimensionality reduction, optimum feature selection and using suitable learning algorithm on the complete visible and NIR spectrum range data, namely 350nm to 1050nm. In this paper we focus on, (i) the use of low wavelength resolution and low cost multispectral sensor to reliably identify artificially ripened mango by selectively using the spectral information so

that classification accuracy is not hampered at the cost of low resolution spectral data and (ii) use of visible spectrum i.e. 390nm to 700 nm data to accurately discriminate artificially ripened mangoes. Our results show that on a low resolution spectral data, the use of logistic regression produces an accuracy of 98.83% and outperforms other methods like classification tree, random forest significantly. And this is achieved by analyzing only 36 spectral reflectance data points instead of the complete 216 data points available in visual and NIR range. Another interesting experimental observation is that we are able to achieve more than 98% classification accuracy by selecting only 15 irradiance values in the visible spectrum. Even the number of data needs to be collected using hyperspectral or multispectral sensor can be reduced by a factor of 24 for classification with high degree of confidence.

10217-10, Session 3

Finite element simulation of light transfer in turbid media under structured illumination

Dong Hu, Zhejiang Univ. (China) and Michigan State Univ. (United States); Renfu Lu, Agricultural Research Service (United States); Yibin Ying, Zhejiang Univ. (China)

Spatial-frequency domain imaging (SFDI) provides a novel and noncontact means for measuring the optical absorption (ua) and scattering (us') properties of biological tissues in a wide field of view, which is based on analytical solutions to diffusion approximation under structured illumination. Since the accuracy of estimating ua and us' is dependent on selected spatial frequency (fx) and the actual tissue properties, it is important to quantify the effect of these parameters on the SFDI reflectance in order to improve the measurement accuracy of the technique. This research is therefore aimed at using finite element method (FEM) to model light propagation in turbid media, subjected to structured illumination under normal incidence. The FEM simulation results are compared with analytical solutions and Monte Carlo (MC) simulations, the latter of which accurately predict fluence rate and diffuse reflectance. Different sets of optical properties that are typical for agro-food products are considered in the FEM simulation. The effect of spatial frequency is evaluated since it directly influences the penetration depth of the light in turbid media. Special attention is paid to high frequencies because they are related to sub-diffusive scattering. Moreover, the optical parameter us'/fx, representing dimensionless scattering, is studied to better understand its influence on the demodulation reflectance and sub-diffusive scattering. FEM is effective for modeling light transfer in turbid media and can be used for improving measurement accuracy for the SFDI technique.

10217-11, Session 3

Non-invasive real time remote monitoring of vegetation using multimodal Brillouin and Raman spectroscopies

Adiya Rakymzhan, Talgat Yakupov, Zarina Yelemessova, Rostislav Bukasov, Nazarbayev Univ. (Kazakhstan); Vladislav V. Yakovlev, Texas A&M Univ. (United States); Zhandos N. Utegulov, Nazarbayev Univ. (Kazakhstan)

In this report, Brillouin spectroscopy was used for real time analysis of elastic properties of Populus and Geranium leaves, while Raman spectroscopy and imaging were employed for assessment of their chemical variation during drying. Both micro-spectroscopic techniques can provide significant advances in the understanding of mechano-chemical changes of plants in response to environmental stress and pathogens at micron scale or less.

Our results have demonstrated for the first time the ability of multimodal assessment of elasticity modulus, hydraulic conductance and interatomic vibrational modes in plants as emerging new markers for remote, real time non-invasive and quantitative assessment of agricultural crops in real time.

Green Populus leaf was harvested and plucked for the study. Brillouin scattering measurements were taken every two hours until plucked Populus leave was completely dried out accompanied by the increase of stiffness, as evidenced by the rise of Young's modulus of a drying leaf, from 705.044 MPa to 885.260 MPa. Raman spectroscopy assessed at 3, 6, 9, 12, 24, 27 and 30 hours after plucking the leave, has demonstrated 5-fold increase in the area of 485 cm-1 peak, attributed to the increase of amylose and aminopectine. 1007 cm-1 peak attributed to C-H bending increased 2.7-fold, while 1525 cm-1 peak of – C=C- stretching, attributed to carotene and/or lutein increased by 70%. These changes were accompanied with the overall loss of the original mass up to 63%. Brillouin spectra taken from the same point of living Geranium leaf surface has not revealed any changes in elastic properties.

10217-12, Session 4

Near infrared hyperspectral imaging system for root phenotyping

Thomas Arnold, Raimund Leitner, CTR Carinthian Tech Research AG (Austria); Gernot Bodner, Univ. für Bodenkultur Wien (Austria)

This paper presents the development and application of a hyper-spectral imaging system for root phenotyping. For sustainable plant production root systems optimized for growing conditions in the field are required. Therefore, the presented system is used for the research in the field of drought resistance of roots. The system is used to acquire spatially resolved near infrared (NIR) spectroscopy data of rhizoboxes. In contrast to using visible light (380nm to 780nm) the NIR wavelength range (1000nm to 2500nm) allows to discriminate essential features for the root segmentation and water distribution mappings. The increased image contrast in the NIR range allows roots to be segmented from soil and additional information, e.g. basic root-architecture, to be extracted. In addition, the water absorption bands in the NIR wavelength range can be used to determine the water content and to estimate the age of the roots. In this paper the hardware setup of the hyper-spectral root imaging system, the data analysis, the soil water content estimations and the root segmentation using different methods to optimize separation between roots and soil, both constituting complex materials of variable properties, are presented.

10217-13, Session 4

Fish freshness estimation using eye image processing under white and UV lightings

Katsuhiro Kanamori, Panasonic Corp. (Japan); Yuri Shirataki, Qiuhong Liao, Yuichi Ogawa, Tetsuhito Suzuki, Naoshi Kondo, Kyoto Univ. Graduate School of Agriculture (Japan)

A non-destructive method of estimating the freshness of fish is required for appropriate price setting and food safety. In particular, for determining the possibility of eating raw fish (sashimi), freshness estimation is critical. We studied such an estimation method by capturing images of fish eyes and performing image processing using the temporal changes of the luminance of pupil and iris. To detect subtle non-visible changes of these features, we used UV (375 nm) light illumination in addition to visible white light illumination. Polarization and two-channel LED techniques were used to remove strong specular reflection from the cornea of the eye and from clear-plastic wrap used to cover the fish to maintain humidity. Pupil and iris regions were automatically detected separately by image processing after the specular reflection removal process, and two types of eye contrast were defined as the ratio of mean and median pixel values of each region. Experiments using 16 Japanese dace (Tribolodon hakonensis) at 23? and 85% humidity for 24 hours were performed. The eye contrast of raw fish

increase non-linearly in the initial period and then decreased; however, that of frozen-thawed fish decreased linearly throughout 24 hours, regardless of the lighting. Interestingly, the eye contrast using UV light showed a higher correlation with time than that using white light only in the case of raw fish within the early 6-hour period postmortem. These results show the possibility of estimating fish freshness in the initial stage when fish are eaten raw using white and UV lightings.

10217-14, Session 4

The HR spectrometer application for air pollutant measurement

Jin-Soo Park, National Institute of Environmental Research (Korea, Republic of)

No Abstract Available

10217-15, Session 4

Three-dimensional (3D) shape reconstruction in structured-illumination reflectance imaging (SIRI) for fruit curvature correction and stem/calyx (SC) detection

Yuzhen Lu, Michigan State Univ. (United States); Renfu Lu, Agricultural Research Service (United States) and Michigan State Univ. (United States)

SIRI provides a new, promising imaging modality for enhancing defect detection of fruit. Automatic defect detection, however, is still faced with two issues that are common to different imaging modalities, i.e., the intensity distortion due to fruit curvature and the presence of SC regions. Fruit curvature causes non-uniformity of light intensity in captured images, typically manifested by darker edges and brighter center, making it difficult to detect defects around the edge; whereas, SC, which is natural parts of fruit, tends to be confounded with true defects because of its dark appearance in the images. This study reports on the correction of fruit curvature and the recognition of SC regions in SIRI images based on the reconstruction of 3D shape of fruit. The 3D shape is reconstructed by means of a digital fringe projection (DFP) approach. With this approach, phase-shifted sinusoidally-modulated fringe patterns at a given spatial frequency are projected onto a fruit sample by a digital light projector, and the reflected pattern images are acquired by a camera and then processed to retrieve phase images via phase demodulation and unwrapping algorithms. The retrieved phases are finally converted to height information based on a pre-calibrated phase-to-height relationship, thus along with planar information, to generate the 3D shape of the sample. With knowledge of 3D shape, the amplitude image of the sample is corrected for the fruit curvature effect, and possible SC regions in the image are identified by detecting the shape concavity and excluded from subsequent analysis for defect detection. The proposed approaches are evaluated through detection of defects on apples.

10217-16, Session 4

Determination of total volatile basic nitrogen (TVB-N) content in pork meat using hyperspectral imaging technique

Hoonsoo Lee, Mirae Oh, Agricultural Research Service (United States); Byoung-Kwan Cho, Chungnam National Univ. (Korea, Republic of); Moon S. Kim, Agricultural Research Service (United States)

Total volatile basic nitrogen (TVB-N) content is one of the important factors to measure the quality of meat. However, conventional chemical analysis methods for measuring TVB-N contents are time-consuming and labor-intensive, and are destructive procedures. The objective of this study is to investigate the possibility of fluorescence hyperspectral imaging techniques for determination of total volatile basic nitrogen (TVB-N) in beef meat. High intensity LED lights at 365 nm and 405 nm were used as the excitation for acquiring fluorescence images. Prediction algorithms based on simple band-ratio, partial least square discriminant analysis (PLS-DA) have been developed. This study shows that fluorescence hyperspectral imaging system has a good potential for rapid measurement of TVB-N content in meat.

10217-17, Session 4

Analysis of peanuts inoculated with toxigenic and atoxigenic Aspergillus flavus using fluorescence and reflectance hyperspectral imagery

Fuguo Xing, Institute of Food Science and Technology, CAAS (China); Haibo Yao, Geosystems Research Institute (United States)

Aflatoxin contamination in peanut products has been an important and long-standing problem around the world. Produced mainly by Aspergillus flavus and Aspergillus parasiticus, aflatoxins are considered among the most toxic and carcinogenic compounds. This study investigated the use of fluorescence and reflectancehyperspectral imaging to assess spectral differences among peanut kernels inoculated with toxigenic and atoxigenic strains of A. flavus. Peanut kernels were inoculated with NRRL 3357, a toxigenic strain of A. flavus, and AF36, an atoxigenic strain of A. flavus, respectively. Both fluorescence hyperspectral images under ultraviolet (UV) excitation and reflectance hyperspectral images under halogen illumination were recorded. After imaging, each of the three-kernel samples was chemically analyzed with affinity column fluorometry to determine aflatoxin levels. Two threshold values, 20 and 100 ppb, were used to group kernels as contaminated or healthy. Contaminated peanut kernels exhibited different fluorescence and reflectance spectral features compared with healthy peanuts. Spectral datasets were compressed and interpreted using principal component analysis (PCA). Least squares support vector machines (LS-SVM) and k-nearest neighbor (KNN) classifiers were used on the fluorescence and reflectance principal components to classify both peeled and un-peeled peanut kernels as contaminated or healthy. This study demonstrated the potential of fluorescence and reflectance hyperspectral imaging techniques for screening of aflatoxin-contaminated peanut kernels that could potentially lead to the production of rapid and non-destructive scanning-based detection system for the peanut industry.

10217-18, Session 4

Automatic detection and counting of cattle in UAV imagery based on machine vision technology

Maryam Rahnemoonfar, Texas A&M Univ. Corpus Christi (United States); Jamie Foster, Texas A&M AgriLife Research (United States); Michael J. Starek, Texas A&M Univ. Corpus Christi (United States)

Beef production is the main agricultural industry in Texas, and livestock are managed in pasture and rangeland which are usually huge in size, and are not easily accessible by vehicles. The current research method for livestock location identification and counting is visual observation which is very time consuming and costly. For animals on large tracts of land, manned aircraft may be necessary to count animals which is noisy and disturbs the animals, and may introduce a source of error in counts. Such manual approaches are

expensive, slow and labor intensive. In this paper we study the combination of small unmanned aerial vehicle (sUAV) and machine vision technology as a valuable solution to manual animal surveying. A fixed-wing UAV fitted with GPS and digital RGB camera for photogrammetry was flown at the Welder Wildlife Foundation in Sinton, TX. Over 600 acres were flown with four UAS flights and individual photographs used to develop orthomosaic imagery. To detect animals in UAV imagery, a fully automatic technique was developed based on spatial and spectral characteristics of objects. This automatic technique can even detect small animals that are partially occluded by bushes. Experimental results in comparison to ground-truth show the effectiveness of our algorithm.

10217-19, Session 4

Determination of pork and poultry meat and bone meal using hyperspectral imaging

Mirae Oh, Hoonsoo Lee, Agricultural Research Service (United States); Irina Torres, Ana Garrido-Varo, Dolores Pérez-Marín, Univ. de Córdoba (Spain); Sang-Ho Moon, Eun-Kyung Kim, Konkuk Univ. (Korea, Republic of); Moon S. Kim, Agricultural Research Service (United States)

Meat and bone meal (MBM) has been banned as animal feed for ruminants since 2001 because it is the source of bovine spongiform encephalopathy (BSE). Moreover, many countries have banned the use of MBM as animal feed for not only ruminants but other farm animal to prevent potential outbreak. Recently, the EU is introducing use of some MBM, such as poultry MBM for pork feed and pork MBM for poultry feed, for economic reasons. Therefore, species-specific MBM identification methods have being required. Spectral imaging techniques have allowed rapid and non-destructive assessment of various foods and feeds. The objective of this study was to develop rapid and accurate spectral imaging methods for discriminating pork and poultry MBM. A preliminary investigation of hyperspectral imaging techniques for assessing pork and poultry MBM characteristics is presented in this paper.

10217-20, Session 4

Development and calibration of a new multipurpose, multichannel hyperspectral imaging probe for food quality detection

Yuping Huang, Nanjing Agricultural Univ. (China); Renfu Lu, Agricultural Research Service (United States); Kunjie Chen, Nanjing Agricultural Univ. (China)

This paper reports on the development and calibration of a new multichannel hyperspectral imaging probe for measuring optical properties and spatially-resolved spectra of food products over the spectral region of 550-1,650 nm. The detection probe consists of a 910 μm fiber as a point light source and 30 light receiving fibers of three sizes (i.e., 50 μm, 105 μm and 200 μm) arranged in a special pattern to enhance signal acquisitions over greater spatial distances. A key feature of the probe is its flexibility for measuring samples with either flat or curved surface. The probe was designed to estimate the scattering and absorption properties of measured samples based on a light propagation model, and also obtain spectral information from various depths within the sample based on the different distances between the light source and detecting fiber. Several types of calibration that are unique to this probe were carried out. They included linearity calibrations for the hyperspectral imaging instrument to ensure consistent linear responses of individual channels, and spectral response calibrations of individual channels for each fiber size group and between the three groups of different sized fibers. The new detection probe was demonstrated through optical property and spatially-resolved spectral measurements for food products such as tomato. This multichannel detection probe has the potential for enhancing property measurement and quality detection of food and agricultural products.

10217-21, Session 4

Big data analytics in hyperspectral imaging for detection of microbial colonies on agar plates

Seung-Chul Yoon, Bosoon Park, Kurt C. Lawrence, Agricultural Research Service (United States)

Various types of optical imaging techniques measuring light reflectivity and scattering can detect microbial colonies of foodborne pathogens on agar plates. Until recently, these techniques were developed to provide solutions for hypothesis-driven studies, which focused on developing tools and batch/offline machine learning methods with well defined sets of data. These have relatively high accuracy and rapid response time because the tools and methods are often optimized for the collected data. However, they often need to be retrained or recalibrated when new untrained data and/or features are added. A big-data driven technique is more suitable for online learning of new/ambiguous samples and for mining unknown or hidden features. Although big data research in hyperspectral imaging is emerging in remote sensing and many tools and methods have been developed so far in many other applications such as bioinformatics, the tools and methods still need to be evaluated and adjusted in applications where the conventional batch machine learning algorithms were dominant. The primary objective of this study is to evaluate appropriate big data analytic tools and methods for online learning and mining of foodborne pathogens on agar plates. After the tools and methods are successfully identified, they will be applied to rapidly search big color and hyperspectral image data of microbial colonies collected over the past 5 years in house and find the most probable colony or a group of colonies in the collected big data. The meta-data, such as collection time and any unstructured data (e.g. comments), will also be analyzed and presented with output results. The expected results will be novel, big data-driven technology to correctly detect and recognize microbial colonies of various foodborne pathogens on agar plates.

Conference 10218: Autonomous Air and Ground Sensing Systems for Agricultural Optimization and Phenotyping II

Monday - Tuesday 10–11 April 2017

Part of Proceedings of SPIE Vol. 10218 Autonomous Air and Ground Sensing Systems for Agricultural Optimization and Phenotyping II

10218-1, Session 1

Scaling up high throughput field phenotyping of corn and soy research plots using ground rovers *(Invited Paper)*

Boyan Peshlov, Monsanto Co. (United States); Akash D. Nakarmi, The Climate Corp. (United States); Scott Essner, Monsanto Co. (United States); Steven Baldwin, Jasenka French, The Climate Corp. (United States)

Crop improvement programs require large and meticulous selection processes that effectively and accurately collect and analyze data in order to generate quality plant products as efficiently as possible, develop superior cropping and/or crop improvement methods. Typically data collection for such testing is performed by field teams using hand-held instruments or manually-controlled devices. Although steps are taken to reduce error, the data collected in such manner can be unreliable due to human error and fatigue, which reduces the ability to make accurate selection decisions. Monsanto engineering teams have developed a high-clearance mobile platform (Rover) as a step towards high throughput and high accuracy phenotyping at an industrial scale. The rovers are equipped with GPS navigation, multiple cameras and sensors and on-board computers to acquire data and compute plant vigor metrics per plot. The supporting IT systems enable automatic path planning, plot identification, image and point cloud data QA/QC and near real-time analysis where results are streamed to enterprise databases for additional statistical analysis and product advancement decisions. Since the rover program was launched in North America in 2013, the number of research plots we can analyze in a growing season has expanded dramatically. This talk would describe some of the successes and challenges in scaling up of the rover platform for automated phenotyping to enable science at scale.

10218-2, Session 1

Autonomous field-based phenotyping

K. Thomas McPeek, William E. Clifton, Angela M. Kim, Tyler Mullenbach, AGERpoint, Inc. (United States)

AGERpoint is defining a new technology space for the growers' industry by introducing novel applications for sensor technology and data analysis to growers of permanent crops. Serving data to a state-of-the-art analytics engine from a cutting edge sensor platform, a new paradigm in precision agriculture is being developed that allows growers to understand the unique needs of each tree, bush or vine in their operation. AGERpoint's solutions scale effectively from small family farms to large corporate concerns without compromising the precision of their data. Autonomous aerial and terrestrial vehicles equipped with precision light detection and ranging (LiDAR), hyperspectral, inertial, global positioning, photogrammetric, and other sensors give AGERpoint the ability to analyze individual features on specific trees, providing growers with the opportunity to tailor their responses and apply them discretely to affected trees. This reduces resource use and minimizes the risk to the surrounding ecosystem. AGERpoint employs big data algorithms to fuse information from a variety of sensors to provide actionable metrics to growers, for example, in situ phenotyping as well as yield prediction and measurement. With a variety of terrestrial and aerial platforms available, AGERpoint can choose the sensor and transport options that provide the data and perspective most appropriate to investigate a grower's pressing concerns. This system gives growers the information they need to make intelligent farm level decisions that consider the unique resources, stressors, and interrelationships of each plant.

10218-3, Session 1

A custom multi-modal sensor suite and data analysis pipeline for aerial field phenotyping

Paul Bartlett, Lauren Coblenz, Gary Sherwin, Adam Stambler, Andries van der Meer, Near Earth Autonomy, Inc. (United States)

Our group has developed a custom, multi-modal sensor suite and data analysis pipeline to phenotype crops in the field using unpiloted aircraft systems (UAS). This approach to high-throughput field phenotyping is part of a research initiative intending to markedly accelerate the breeding process for refined energy sorghum varieties.

To date, single rotor and multi-rotor helicopters, roughly 14 kg in total weight, are being employed to provide sensor coverage over multiple hectare-sized fields in tens of minutes. The quick, autonomous operations allow for complete field coverage at consistent plant and lighting conditions, with low operating costs.

The sensor suite collects data simultaneously from six sensors and registers it for fusion and analysis. High resolution color imagery targets color and geometric phenotypes, along with lidar measurements. Long-wave infrared imagery targets temperature phenomena and plant stress. Hyperspectral visible and near-infrared imagery targets phenotypes such as biomass and chlorophyll content, as well as novel, predictive spectral signatures. Onboard spectrometers and careful laboratory and in-field calibration techniques aim to increase the physical validity of the sensor data throughout and across growing seasons. Off-line processing of data creates basic products such as image maps and digital elevation models. Derived data products include phenotype charts, statistics, and trends.

The outcome of this work is a set of commercially available phenotyping technologies, including sensor suites, a fully integrated phenotyping UAS, and data analysis software. Effort is also underway to transition these technologies to farm management users by way of streamlined, lower cost sensor packages and intuitive software interfaces.

10218-4, Session 1

Hyperspectral imaging to identify wheat line with salt stress adaptation

Ali Moghimi, Ce Yang, Univ. of Minnesota, Twin Cities (United States); Marisa E. Miller, Agricultural Research Service (United States) and Univ. of Minnesota, Twin Cities (United States); Shahryar Kianian, Agricultural Research Service (United States)

In order to address the worldwide growing demand for food, agriculture is facing certain challenges and limitations. One of the important threats limiting crop productivity is salinity. Identifying varieties that tolerate salt stress is crucial to mitigate the negative effects of this abiotic stress in agricultural production systems. Traditional measurement methods of this stress, such as biomass reduction, are labor intensive, environmentally influenced, and often poorly correlated to salinity stress alone. In this study, hyperspectral imaging, as a non-destructive and rapid method, was utilized to expedite the process of analyzing five different wheat lines for salt adaptation through early detection of non-visible symptoms. For this purpose, image and spectral analysis was carried out on images obtained one, three, seven, and 12 days after stress induction. Initial analysis of

data revealed differences in the spectral response of control and stressed plants. In the near infrared bands, stressed plants tended to have a lower reflectance compared to control plants. This can be attributed to changes caused by salt in leaf. Furthermore, leaves suffering from salt were darker such that reflectance in green band was lower than control. These differences in spectral reflectance of five lines were quantified to more precisely identify candidate superior lines.

10218-5, Session 2

Towards collaboration between unmanned aerial and ground vehicles for precision agriculture *(Invited Paper)*

Subodh Bhandari, Amar Raheja, Robert Green, California State Polytechnic Univ., Pomona (United States)

This paper presents the work being done at Cal Poly Pomona on the collaboration between unmanned aerial and ground vehicles. The unmanned aerial vehicles (UAVs), equipped with multi- and hyper-spectral cameras, will take images of the crops and process the images. The processed images will be used in the detection of unhealthy plants. Moreover, the images from UAVs will be used by the UAVs and unmanned ground vehicles (UGVs) for care of crops and harvest estimation. UGVs are easy to deploy, fast to response, and have a closer and more detailed observation of the environment. While UAVs and UGVs are individually advantageous to the agricultural industry and have been used in many applications, the teaming of the two can further enhance cost effectiveness. For example, the UAVs can provide necessary information about the crops such as unhealthy and stressed plants to the UGVs, which can then be used for care of crops. The images can also be useful for optimized harvesting by isolating low yielding plants. These vehicles can be operated autonomously with limited or no human intervention, thereby reducing cost and limiting human exposure to agricultural chemicals.

The paper will discuss the autonomous UAV and UGV platforms used for the research, sensor integration, and experimental testing. Methods for ground truthing the results obtained from the UAVs will be used. The paper will also discuss equipping the UGV with a robotic arm for removing the unhealthy plants and/or weeds.

10218-6, Session 2

Automatic mission planning algorithms for aerial collection of imaging-specific tasks

Paul Sponagle, Carl Salvaggio, Rochester Institute of Technology (United States)

The rapid advancement and availability of unmanned aircraft systems has led to many novel exploitation tasks utilizing the unique aerial image data that are captured. A number of proprietary commercial and open-source mission planning software systems include automated functions to generate flight paths for these image collection missions, however, these systems often fall short of meeting the flexible requirements necessary to achieve the results desired. Understanding when these systems fail, and how to improve upon them, are critical steps to enhancing the quality and timeliness of collection. This research will present algorithms that aim to fill these mission planning gaps in order to provide scientists additional tools to effectively employ unmanned aircraft systems by creating flight paths/mission plans that can be imported by existing ground control software (e.g. UgCS). For example, a calibration algorithm allows the aircraft to revisit calibration panels as frequently as meteorological conditions dictate as necessary. A bidirectional reflectance distribution function measurement algorithm controls the aircraft attitude and a gimbaled sensor to ensure the target is at the center of the frame and provides a means rapid collection without disturbing soil and vegetation. Multiple structure-from-motion (SfM) algorithms minimize occlusions otherwise found when performing constant altitude flights used by commercially available platforms, providing the means to conduct infrastructure inspection and volumetric analysis. These mission planning algorithms will serve the UAS community as a launch point for permitting a variety of new tasks to be accomplished meeting the myriad of unique future requirements that will evolve.

10218-7, Session 2

Melon yield prediction using small unmanned aerial vehicles

Tiebiao Zhao, Univ. of California, Merced (United States); Zhongdao Wang, Tsinghua Univ. (China); Qi Yang, Shenyang Ligong Univ. (China); YangQuan Chen, Univ. of California, Merced (United States)

Thanks to the development of camera technologies, small unmanned aerial systems (sUAS), it is possible to collect aerial images of field with more flexible visit, higher resolution and much lower cost. Meanwhile, the performance of objection detection based on deeply trained convolutional neural networks (CNNs) has been improved significantly. In this study, we applied these technologies in the melon production, where high-resolution aerial images were used to count melons in the field and predict the yield. Two CNN-based object detection frameworks-Faster Region-based CNN (RCNN) and Single Shot MultiBox Detector (SSD) were applied in the melon detection. Furthermore, these melons were classified into three groups according to the ripe range, unripe, fully ripe, and overripe. Performance of these two methods were compared in both detection and classification. Experiments showed that Faster-RCNN had a higher accuracy and SSD was running faster. However, both methods simply took raw images as input, saving lots of effort in “low-level” image analysis and feature designing. Results proved that they both were able to generate accurate melon yield prediction in the late harvest season.

10218-8, Session 2

Real time yield estimation based on deep learning

Maryam Rahnemoonfar, Clay Sheppard, Texas A&M Univ. Corpus Christi (United States)

Crop yield estimation is an important task in product management and marketing. Accurate yield prediction helps farmers to make better decision on cultivation practices, plant disease prevention, and the size of harvest labor force. The current practice of yield estimation based on the manual counting of fruits is very time consuming and expensive process and it is not practical for big fields. Robotic systems including Unmanned Aerial Vehicles (UAV) and Unmanned Ground Vehicles (UGV), provide an efficient, cost-effective, flexible and scalable solution for product management and yield prediction. Recently huge data has been gathered from agricultural field, however efficient analysis of those data is still a challenging task. Computer vision approaches currently face diffident challenges in automatic counting of fruits or flowers including occlusion caused by leaves, branches or other fruits, variance in natural illumination, and scale. In this paper a novel deep convolutional network algorithm was developed to facilitate the accurate yield prediction and automatic counting of fruits and vegetables on the images. Our method is robust to occlusion, shadow, uneven illumination and scale. Experimental results in comparison to the state-of-the art show the effectiveness of our algorithm.

10218-9, Session 3

Use of UAVs for support of intensive agricultural management decisions: going from science to commercial application *(Invited Paper)*

Alfonso Torres-Rua, Utah State Univ. (United States)

No Abstract Available

10218-10, Session 3

Radiometric calibration approach for UAV-based remote sensing

Yeyin Shi, Univ. of Nebraska-Lincoln (United States); J. Alex Thomasson, Texas A&M AgriLife Research and Extension Ctr. (United States); Chao Sima, Ctr. for Bioinformatics and Genomic Systems Engineering (United States)

Low-altitude remote sensing with unmanned aerial vehicles (UAVs) has become popular in agriculture. Raw data collected by airborne sensors as digital numbers are influenced by environmental variables like lighting and atmospheric conditions. Converting digital numbers to absolute reflectance values based on the known reflectance of ground control points (GCPs) is called radiometric calibration. In traditional airborne remote sensing conducted at higher altitudes, it is possible to set up and identify GCPs in one large image covering an entire agricultural field. To cover the same area with a UAV, many more images, each with much smaller ground coverage and collected over a period of time, are required. Radiometric calibration for an entire set of images thus must be implemented, if at all, with GCPs visible in only a handful of images. Few if any studies have been conducted to systematically evaluate the performance of radiometric calibration in UAV-based agricultural remote sensing. In this study, we developed methods and evaluated the performance of a radiometric calibration approach for UAV-based crop sensing. Low-cost GCPs were designed to be permanently installed in the field for frequent UAV flights throughout the growing season. Their absolute reflectance was measured periodically on the ground and used to calibrate entire image mosaics. Different calibration models were compared, and the performance of the overall approach was evaluated against radiometric calibration with a higher-altitude manned aircraft and standard large calibration tarps. This study contributes to the development of a radiometric calibration standard for UAV-based remote sensing for agricultural applications.

10218-11, Session 3

UAV remote sensing for phenotyping drought tolerance in peanut

Maria Balota, Joseph Oakes, Virginia Polytechnic Institute and State Univ. (United States)

Farmers can benefit from growing drought tolerant peanut cultivars with improved yield when rainfall is sporadic. In the Virginia-Carolina (VC) region, drought is magnified by hot summers and usually occurs in July and August when pod and seed growth are intense. At these growth stages, weekly supply of 50 to 75 mm of water is needed to ensure profitability. Irrigation can supplement crop water needs, but only 10% of the peanut farms are irrigated. In this frame, drought tolerant varieties can be profitable, but breeding for cultivars with improved drought tolerance requires fast yet accurate phenotyping. Our objective was to evaluate the potential of UAV remote sensing technologies for drought tolerance selection in peanut.

In this study, we examined the effect of drought on 23 peanut cultivars (Virginia, Runner, & Valencia type). These varieties were arranged in a randomized complete block design, with four replications drought stressed and two replications well-watered. Drought was imposed by covering the drought stressed plots with rainout shelters on July 18; they remained covered until August 29 and only received 7 mm irrigation in early August. The well-watered plots continued to receive rain and supplemental irrigation as needed. During this time, Canopy Temperature Depression (CTD) and Normalized Differential Vegetative Index (NDVI) were collected from the ground on all plots at weekly intervals. After the shelters were removed, these measurements were collected daily for approximately 2 weeks. At the same time, Red-Green-Blue (RGB), near-infrared (NIR), and infrared (IR) images taken from an UAV platform were also collected. Vegetation indices were derived from the ground and aerial data and used for estimation of varietal drought stress responses. These results will be presented.

10218-12, Session 3

Evaluating crop stress using thermal images at multiple spatial resolutions

Gregory Rouze, Haly L. Neely, Cristine L. S. Morgan, J. Alex Thomasson, Texas A&M AgriLife Research and Extension Ctr. (United States); Chenghai Yang, Agricultural Research Service (United States); John Valasek, Texas A&M Engineering Experiment Station (United States)

Unmanned aerial vehicle (UAV) imaging provides a potential opportunity to detect responses associated with crop stress throughout the growing season. With UAV platforms and new thermal sensors, the spatial resolution of temperature data continues to decrease. However, the increased value of finer spatial resolution information should be investigated. The purpose of this study was to assess multiple thermal sensing platforms and thermal sensors in cotton (Gossypium hirsutum L.) at varying spatial resolutions. The experimental site was located on a 30.7 ha field under both irrigated and dryland systems located within the Texas AgriLife Research Farm in College Station, TX. During the 2016 field season, thermal imagery was collected using UAVs (150 m altitude), aircraft (670, 1400, 3200 m altitude), and satellite imagery from Landsat (30 m resolution). The maps produced by these systems were then compared in terms of their ability to separate between plant and soil-based thermal pixels using textural analysis. In addition, platforms were compared in terms of various vegetation indices provided by multi-spectral imaging and supplemented with field data. The ability of thermal maps at different spatial resolutions to measure crop stress will be evaluated. The results presented here will help improve the decision-making process for members of the precision agriculture community in diagnosing crop stress.

10218-13, Session 3

UAS imaging for automated crop lodging detection: a case study over an experimental corn field

Tianxing Chu, Michael J. Starek, Texas A&M Univ. Corpus Christi (United States); Michael Brewer, Texas A&M AgriLife Research and Extension Ctr. (United States); Tiisetso Masiane, Texas A&M Univ. Corpus Christi (United States)

Lodging has been recognized as one of the major destructive factors for crop quality and yield, particularly in corn. A variety of contributing causes, e.g. disease and/or pest, weather conditions, excessive nitrogen, and high plant density, may lead to lodging before harvesting season. Current lodging detection strategies mainly rely on ground data collection, which is insufficient in efficiency and accuracy. To address this problem, this research focuses on the use of unmanned aircraft systems (UAS) for automated detection of crop lodging. The study was conducted over an experimental corn field at the Texas A&M AgriLife Research and Extension

Center at Corpus Christi, Texas, during the growing season of 2016. Nadir-view images of the corn field were taken by small UAS platforms equipped with consumer grade RGB and NIR cameras on a per week basis, enabling a timely observation of the plant growth. 3D structural information of the plants was then reconstructed using structure-from-motion photogrammetry. The structural information is then applied to calculate crop height, rates of growth, and lodging detection by searching for anomalous height changes. Additionally, the fusion of spectral information with structural information is also assessed to determine if results for lodging detection are improved. Ground truth data of lodging was collected on a per row basis and used for fair assessment and tuning of the detection algorithm. In this presentation, the UAS survey methodology, developed algorithm, and results of detection accuracy will be discussed. Lodging in relation to the yield loss will also be discussed.

10218-14, Session 4

Vineyard management in virtual reality: autonomous control of a transformable drone *(Invited Paper)*

He Shen, N. Li, H. Griffiths, S. Rojas, N. Perkins, California State Univ., Los Angeles (United States); M. Liu, The Climate Corp. (United States)

Grape vines are susceptible to many diseases. Routine scouting is critically important to keep vineyards in healthy condition. Currently, scouting relies on experienced farm workers to inspect acres of farm land while arduously filling out reports to document crop health condition. This process is both labor and time consuming. Using the drones to assist farm workers in scouting has great potential to improve the efficiency of grape farm management. Due to the complexity in grape farm disease detection, the drones are normally used to detect suspicious areas to help farm workers to priorities scouting activities. It still relies on human for further inspection to be certain about the health conditions of the farm. This paper talks about autonomous transition flight control method for a transformable drone, which is suitable for the future virtual presence of human for inspections of the suspected areas. The transformable drone adopts a tilt-rotor mechanism to automatically switch between hover and horizontal flight modes according to commands from virtual reality devices. The conceptual design and transformation dynamics of the drone will be first discussed. Following that, a model predictive control system is developed to automatically control the transition flight. Simulation is also provided to show the effectiveness of the proposed control system.

10218-15, Session 4

Estimating plant population with UAV-derived vegetation indices

Joseph Oakes, Maria Balota, Virginia Polytechnic Institute and State Univ. (United States)

In the Virginia-Carolina (VC) region, the large seeded Virginia market type peanut is preferred to the runner peanut even if the cost of certified seed is one of the most expensive inputs in peanut production in this region. For example, to plant an acre of ‘Bailey’ peanut, a relatively small seeded Virginia type peanut, a farmer will pay 97 USD. To achieve a similar plant population of 80,000 plants per acre with ‘Wynne’ peanut, a relatively large seeded peanut, the seed cost is 128 USD. Our objectives were to determine if reducing plant population may or not result in yield reduction and, when numerous cultivars are tested, if UAV-collected indices could successfully estimate seeding rate and plant population, and estimate pod yield. Red-Green-Blue (RGB) and near-infrared (NIR) images were collected from a UAV platform starting two weeks after planting and continued weekly for the next six weeks. Ground NDVI was also collected each time aerial images were collected. Vegetation indices were derived from both the RGB and NIR images. Greener area (GGA- the proportion of green pixels with a hue angle from 80° to 120°) and a* (the average red/green color of the image) were derived from the RGB images while Normalized Differential Vegetative Index (NDVI) was derived from NIR images. Both the NDVI derived from the NIR camera and the RGB derived vegetation indices were well correlated with ground-taken NDVI and were successful in discriminating among the seeding rates. These indices were also successful in discriminating among varieties. At the end of the growing season, a relationship will be established between the indices and yield in order to determine if UAV-mounted cameras can successfully estimate yield early in the season. These results will be presented.

10218-16, Session 4

A predictive model for turfgrass color and quality evaluation using deep learning and UAV imageries

Claude Phan, Amar Raheja, Subodh Bhandari, Robert Green, California State Polytechnic Univ., Pomona (United States)

Millions of Americans come into contact with turfgrass on a daily basis. Often undervalued and seen as visual support stimulus for a larger entity, millions of acres of turfgrass can be found on residential lawns (which also provides an area for recreation), commercial landscape, parks, athletic fields, and golf courses. Besides these uses, turfgrass provides many functional benefits to the environment, such as reducing soil erosion, cooling its surrounding area, and soil carbon sequestration. However, rapidly expanding uses of turfgrass have also raised alarm for natural resources conservation and environmental quality, the largest impact being water consumption. This paper presents a machine learning approach that can assist growers and researchers in determining the overall quality and color rating of turfgrass, thereby assisting in turfgrass management including optimized irrigation water scheduling. Tools from Google and NVIDIA enable models to be trained using deep learning techniques on personal computers or on small form factor processors that can be used aboard small unmanned aerial vehicles (UAVs). The typical evaluation process is a long, laborious process, which is subjective by nature, and thus often exposed to criticism and concern. A computational approach to quality and color assessment will provide faster, accurate, and more consistent ratings, which in turn will help increase irrigation water use efficiency. The overall goal of the ongoing research is to use deep learning techniques and UAV imageries for the turfgrass quality assessment and help all the stakeholders to optimize water conservation.?

10218-17, Session 4

3-D reconstruction optimization using imagery captured by unmanned aerial vehicles

Abby L. Bassie, Robert J. Moorhead, Gray Turnage, Sean Meacham, David Young, Geosystems Research Institute (United States)

Because UAV’s are rising in popularity as an indispensable tool in precision agriculture, it is vitally important that researchers understand how to optimize the performance of UAV’s and their associated camera payloads for 3-D reconstruction of surveyed areas. In this study, imagery captured by a Nikon RGB camera attached to a Precision Hawk Lancaster was used to survey an agricultural field from six different altitudes ranging from 45.72 m (150 ft.) to 121.92 m (400 ft.). Six 3-D point clouds of the field were generated from the images at each altitude, and the linear measurements made on reference objects within each point cloud were compared to the actual dimensions of the reference objects. These changes were recorded as ?x, ?y, and ?z. These values at each altitude were then averaged to show average change in each coordinate direction for each of the six flight

scenarios. Results showed that while fewer images were required to survey the field at high altitudes, the spatial resolution of the 3-D point cloud was considerably lower when imagery was collected at the highest altitude. In three of the six flight scenarios flown, the 3-D imaging software was able to measure object dimensions from 50.8 to 76.2 cm (20-30 inches) with greater than 93% accuracy. The largest average deviation in any flight scenario from actual measurements was 14.77 cm (5.82 in.). These results are satisfactory in a wide variety of precision agriculture applications focused on differentiating and identifying objects using remote imagery.

10218-18, Session 4

Label-free mapping of agrochemical distribution in plants in vivo using chlorophyll fluorescence lifetime

Elizabeth Noble, Paul M. W. French, Christopher W. Dunsby, Imperial College London (United Kingdom); Chris Stain, Syngenta (United Kingdom)

Visualizing the distribution and uptake of chemicals and understanding their mode of action is very crucial in the development of new agrochemicals. Current techniques employed in the screening process for more efficient Active Ingredients and formulations, based on solvent extraction or cell culture analysis, can provide highly specific chemical information but are destructive and time-consuming. Hence there is a need for a non-invasive, high resolution and label-free technique that can be employed for studying the real-time distribution of agrochemicals in live plants. We explore the potential of fluorescence lifetime based techniques to this extent.

The changes in intrinsic chlorophyll fluorescence(1)of plants is used as an indirect read-out of the agrochemical presence at three different scales, utilising multiphoton-excited fluorescence lifetime imaging (FLIM)(cellular), wide-field single-photon excited macroscopic FLIM (whole leaf) and single point fluorescence lifetime measurements via a fibre-optic probe (1 mm2). The latter instrumentation, originally designed for label-free biomedical applications(2), is portable and can be deployed outside the laboratory. We demonstrate that we can detect and map the local impact of a photosystem II inhibitor on living plant leaves with spatial and temporal resolution. Thus this indirect readout could provide a portable system for monitoring the distribution of herbicides in growing plants.

References

1. Perkins RG, Oxborough K, Hanlon A. RM, Underwood GJC, Baker NR. Can chlorophyll fluorescence be used to estimate the rate of photosynthetic electron transport within microphytobenthic biofilms? Mar Ecol Prog Ser. 2002;228:47–56.

2. Lagarto J, Dyer BT, Talbot C, Sikkel MB, Peters NS, French PMW, et al. Application of time-resolved autofluorescence to label-free in vivo optical mapping of changes in tissue matrix and metabolism associated with myocardial infarction and heart failure. 2015;6(2):1637–52.

10218-19, Session 5

Automated geographic registration and radiometric correction *(Invited Paper)*

J. Alex Thomasson, Yeyin Shi, Chao Sima, Texas A&M Univ. (United States)

In our current research project, image files are taken to the computer laboratory after the flight, and pre-processing is implemented on the raw image data, including ortho-mosaicking with Pix4Dmapper and radiometric calibration. Ground control points (GCPs) are critical for high-quality geographic registration of images during mosaicking. Applications requiring accurate reflectance data also require radiometric-calibration references so that reflectance values of image objects can be calculated. We have developed a method for automated geographic registration and radiometric correction with targets that are installed semi-permanently at distributed locations around fields. The targets are a combination of black (≈5% reflectance), dark gray (≈20% reflectance), and light gray (≈40% reflectance) sections that provide for a linear transformation in the dynamic range of crop fields. Their exact spectral reflectance is known, having been measured with a spectrophotometer. The targets remain covered to protect against sun and weather damage or dust, and they are uncovered at the beginning of a flight and re-covered at the end of it. The targets sections are sized such that they are clearly distinguishable from adjacent sections and the background with a minimum of 6 ? 6 pixels, with more pixels available at higher image resolutions. At the time of installation, each target is measured for position with a real-time kinematic GPS receiver to give its precise latitude and longitude. Automated location of the reference targets in the images is required for precise, automated, geographic registration; and automated calculation of the digital-number to reflectance transformation is required for automated radiometric calibration.

10218-20, Session 5

Swimming in sensors and drowning in data: What is needed for UASs to be effective *(Invited Paper)*

Robert J. Moorhead, Geosystems Research Institute (United States)

Unmanned aerial vehicles offer what has been called “an unparalleled and powerful view of the landscape that would be very difficult to get from the ground when monitoring large parcels of land.” Yet for most producers the technology is more of a novelty that, partially due to regulations and partially due to the challenges in converting data into useful information, has been little employed in their agricultural operations. Another factor that has limited adoption is the lack of information on the value and utility of this technology. An unmanned aerial vehicle (UAV) will not fix every problem on the farm, but there are some practical applications for which UAVs have demonstrated value. In this talk, I will present several applications for which UAS have shown value, as well as areas where they should be playing a larger role soon.

10218-21, Session 5

The remote sensing data from your UAV probably isn’t scientific, but it should be! *(Invited Paper)*

Mac McKee, Utah State Univ. (United States)

No Abstract Available

10218-22, Session 6

Artificial intelligence for weather prediction *(Invited Paper)*

Rick Thielke, Ayata (United States)

No Abstract Available

10218-23, Session PTue

PlantEye F500: combine 3D and multsipectral information in one sensor

ÍGrégoire Hummel, Phenospex (Netherlands)

PlantEye is a high-resolution 3D laser scanner that computes a robust and validated set of morphological plant parameters fully automatically. A core feature of PlantEye is that it can be operated in full sunlight without any restrictions - crucial for plant phenotyping under field conditions or if you follow a “sensor-to-plant-concept”. Phenospex has now developed a new sensor generation, which combines the actual features of PlantEye on the fly with a 7-channel multispectral camera in the range between 400 – 940nm. This unique hardware-based sensor fusion concept allows us to deliver spectral information for each data point of the plant in X, Y, Z-direction and we can compute parameters like NDVI, color index and many other vegetation indices. This new sensor generation opens a wide range of new possibilities in plant phenotyping and increases its efficiency.

10219-1, Session 1

Three-dimensional display based on computer-generated holography *(Keynote Presentation)*

Toyohiko Yatagai, Utsunomiya Univ. (Japan); Yusuke Sando, Technology Research Institute of Osaka Prefecture (Japan)

A basic spectral relation between a 3-D object and its 2-D diffracted wavefront has been derived by interpreting the diffraction calculation in the 3-D Fourier domain. Information on the 3-D diffracted object is clearly understood by using this relation. After the derivation, a method for obtaining the Fourier spectrum that is required to synthesize a hologram with a realistic sampling number for visible light is described. Some fast calculation methods for the diffraction calculation, including the hidden surface removal are discussed. In order to verify the validity and the practicality of the above-mentioned spectral relation, fast calculation of a series of wavefronts radially diffracted from a 3-D voxel-based object is demonstrated. Finally, a method for a continuous optical rotation compensation in a time-division-based three dimensional display with a rotating mirror is presented.

10219-2, Session 1

Common-path incoherent digital holography *(Invited Paper)*

Osamu Matoba, Xiangyu Quan, Kobe Univ. (Japan); Yasuhiro Awatsuji, Kyoto Institute of Technology (Japan)

The invention of laser light has pushed holographic era to real life. Especially the technique of digital holography suggests unprecedented benefits in display, sensing, storage and other area. However, it is desirable to apply the technology to incoherent light. Incoherent light such as day light, fluorescence are more inexpensive and sometimes, unavoidable. This paper discuss some techniques to realize incoherent digital holography. Common path incoherent holography is preferred by taking fewer space and presenting higher stability. This paper also suggests off-axis incoherent digital holography for measuring dynamic incoherent objects. The suggested method uses phase only spatial light modulator with patterns of dual-focusing Fresnel lens and respective gratings. It enables modulate wavefront coming from a point source to different radiuses and different directions. Hence, two quadratic wavefronts can make off-axis interference. We only make use of first order diffraction signals from SLM. So the zero order signals which contributing to noise are avoided. The off-axis incoherent digital holography is suitable to measure incoherent particles in three dimensions with high mobility.

10219-3, Session 1

Spatially incoherent Fourier digital holography *(Invited Paper)*

Takanori Nomura, Kaho Watanabe, Wakayama Univ. (Japan)

Spatially incoherent Fourier holography has also been developed in recent years. In this paper, we propose a method to record an incoherent Fourier digital hologram using a rotational shearing interferometer. The interferometer is a Michelson interferometer, in which two right angle prisms are used in place of the mirrors. Two split waves self-interfere and give the cosine transform of an object. The reason of introduction of the interferometer is the simpleness of the configuration. It does not require active optical devices such a spatial light modulator. As mentioned above, the hologram is essentially obtained as the figure of cosine transformation. Therefore the reconstruction of the hologram has a twin image problem. To clear the problem, a phase-shifting technique with a help of polarization for the interferometer is introduced. Namely three or four step phase-shifting method using a quarter wave plate and an eighth wave plate is realized. Some experimental results are given to demonstrate the phase-shifting method. Furthermore, the characteristics of the reconstruction image such as its depth of focus are also discussed.

10219-4, Session 1

Generation of binary holograms with a Kinect sensor for a high speed color holographic display *(Invited Paper)*

Thibault Leportier, Korea Institute of Science and Technology (Korea, Republic of); Min-Chul Park, Korea Institute of Science and Technology (Korea, Republic of) and Univ. of Science and Technology (Korea, Republic of); Sumio Yano, Shimane Univ. (Japan); Jung-Young Son, Konyang Univ. (Korea, Republic of)

The Kinect sensor is a device that enables to obtain both a RGB image and a depth map of a scene. Data of large real scenes can then be processed to generate complex holograms with different approaches. The depth layer based method is well adapted to the format provided by the Kinect since the layers are directly defined by the depth map. Then, RGB holograms of real scenes can be generated in a fast way. For optical reconstruction, it is necessary to add a processing step in order to convert the data into a format adapted to the display device. Binary holograms are commonly used since they present several advantages. Among the methods that were proposed to convert holograms into a binary format, the direct-binary search (DBS) not only gives the performance, it also offers the possibility to choose the display parameters of the binary hologram differently than the original complex hologram. Since wavelength and reconstruction distance can be modified, compensation of chromatic aberration can be handled. In this study, we examine the potential of DBS for RGB holographic display.

10219-5, Session 1

Digital 3D holographic display using scattering layers for enhanced viewing angle and image size

Hyeonseung Yu, KyeoReh Lee, Jongchan Park, YongKeun Park, KAIST (Korea, Republic of)

In digital 3D holographic displays, the generation of realistic 3D images has been hindered by limited viewing angle and image size due to the limited space bandwidth product of current wavefront modulators. In order to overcome this practical issue, several methods have been proposed that employ spatial multiplexing or time multiplexing. Though multiplexing systems provide enhanced viewing angle and image size, complex and expensive systems are required and the extension to a larger scale is limited. Recently, hologram generations using meta-materials or phased arrays with a near-wavelength scale pixel pitch are actively studied, however, the fabrication is difficult and dynamic hologram generation cannot be achieved.

In this work, we demonstrate a digital 3D holographic display using volume speckle fields produced by scattering layers in which both the viewing angle and the image size are greatly enhanced. Although volume speckle fields

exhibit random distributions, the transmitted speckle fields have a linear and deterministic relationship with the input field. By modulating the incident wavefront with a digital micro-mirror device, volume speckle patterns are controlled to generate 3D images of micrometer-size optical foci with 35° viewing angle in a volume of 2 cm x 2 cm x 2 cm. We also discuss the image contrast of the projected 3D images in relation with background speckle fields.

10219-6, Session 2

Multiview image acquisition based on an aperture sharing *(Invited Paper)*

Jung-Young Son, Hyoung Lee, Jina Byeon, Konyang Univ. (Korea, Republic of); Beom-Ryeol Lee, Electronics and Telecommunications Research Institute (Korea, Republic of); Min-Chul Park, Korea Institute of Science and Technology (Korea, Republic of)

A typical way of obtaining mulyiview images is a multiview camera array. But this array is too bulky to be a portable anf difficult to calibration. To solve these problems involved in the array, a plenoptic camera is devised. This camera is not different from a usual digital camera but it equipped with a micro-lens array near the detector plane of the digital camera. The typical structure of this plenoptic camera is not different from the integral photography with a field lens in front of the microlens array. The images obtained with the plenoptic camera is different from those from the multiview camera array: The former is localized but the latter whole object/scene viewed from different viewing directions. Hence the former is convenient but can provide images with a poor depth resolution and a small depth range. In this paper, a single digital camera which can acquire a multiview image set, based on aperture sharing is introduced, and image and optical characteristics of this camera are compared with those of the multiview camera array and the plenoptic camera. This camera has both characteristics of other two cameras but it is not good for moving images. However, combining a high speed shutter and high speed camera will allow capturing moving images

10219-7, Session 2

Object tracking on plenoptic image sequences *(Invited Paper)*

Jae Woo Kim, Seong-Jun Bae, Seongjin Park, Do Hyung Kim, Electronics and Telecommunications Research Institute (Korea, Republic of)

Difficulties of object tracking usually come from appearance variations and background clutter. We developed plenoptic video data acquisition system and novel object tracking algorithms that address the problems caused by appearance variations and background clutter. Plenoptic images contain information about the light field emanating from a scene that includes both intensity and directional information of the light rays traveling in space. We developed a camera array based plenoptic image acquisition system to capture plenoptic video data. We integrated 25 industrial cameras with an external exposure synchronization devices to capture plenoptic image sequences of a high resolution up to 1920 by 1080. The system can record synchronized plenoptic images from the cameras with under-millisecond level accuracy and plenoptic video data up to 30 frames per second. Our approach for object tracking take advantage of the capabilities that plenoptic imaging provides such as refocus, perspective shift, and depth calculation. Firstly, our approach uses depth information of the scene to distinguish the object from the background to overcome background clutter problem. Secondly, it take advantage of refocus and perspective shift capabilities to cope with appearance variation problems. While conventional object tracking algorithms search for neighboring regions based on a single image to track objects of interest, our approach extended the search process by incorporating images from different focuses and perspectives into the search process. The experimental results showed that our approach drastically improved the tracking accuracy especially for the image sequences containing objects' rotational movements and partial occlusion as well as cluttered background.

10219-8, Session 2

Plenoptic image watermarking to preserve copy right

Amir Ansari, Adrián Dorado, Genaro Saavedra, Manuel Martínez-Corral, Univ. de València (Spain)

Common camera loses a huge amount of information obtainable from scene as it does not record the value of individual rays passing a point and it merely keeps the summation of intensities of all the rays passing a point. Plenoptic images can be exploited to provide a 3D representation of the scene and watermarking such images can be helpful to protect the ownership of them. In this paper we propose a new method for watermarking the plenoptic images to achieve this aim. The performance of the proposed method is validated by experimental results and a compromise is held between imperceptibility and robustness.

10219-9, Session 3

Integral imaging with Fourier plane recording *(Invited Paper)*

Manuel Martínez-Corral, Genaro Saavedra, Univ. de València (Spain)

In the past few years Integral-Imaging cameras have demonstrated an unusual capacity for capturing the 3D structure of microscopic (in case of integral microcopy) or macro-scopic scenes (in case of plenoptic cameras). However such devices have the drawback of wasting the pixels that are at the outer ring of any microimage. As result, the angular and the lateral resolution of reconstructed scenes is reduced by a factor close to the 50%.

Very recently our Group has demonstrated that this effect can be avoided if one captures the elemental images directly at the Fourier plane of the imaging system. Besides, this method of capture provides directly, without any need of digital processing, the per-spective views of the 3D scene. In the talk we will show our last results in this field and will demonstrate the possibility of applying this technique to macroimage recording.

10219-10, Session 3

Perception of depth distance of integral photography through the measurement of eye movement and subjective test *(Invited Paper)*

Sumio Yano, Shimane Univ. (Japan); Makoto Suzuki, MEIWA e-TEC Co., Ltd. (Japan); Min-Chul Park, Korea Institute of Science and Technology (Korea, Republic of)

We evaluated the perception of the depth distance of the integral photography through the measurement of binocular eye movement and the subjective test. Furthermore, we compared between the perception of the depth distance of the integral photography and the real object through the measurement of eye movement.

At first, we developed the measurement tool of binocular eye movement for detection of the perception of the depth distance. As a result, the developed eye movement measurement tool showed that the possible measurement range was less than 100 cm when we adopted the angular calibration method to the developed tool.

Next, we evaluated the perception of the depth distance of the integral photography through the measurement of the eye movement and subjective tests, which used the scale evaluation method, for the visual stimuli from the range of 46 cm to 74 cm in 2 cm step. These two evaluation methods, which were different in the perception of modality, showed the same results in the perception of depth distance.

Furthermore, we evaluated the perception of depth distance of the integral photography and the real object through the measurement of eye movement. The results showed that there were differences of the perception of the depth distance for two visual stimuli. However, the difference was almost the constant in the near range to the viewer from the display screen and also the range of a constant spatial frequency of the integral photography image. Other hand, the difference gradually increased in the far range from the viewer.

10219-11, Session 3

A simulator for a light field display *(Invited Paper)*

Beom-Ryeol Lee, Electronics and Telecommunications Research Institute (Korea, Republic of); Jung-Young Son, Konyang Univ. (Korea, Republic of); Hyung Ki Son, Univ. of Science & Technology (Korea, Republic of); Ilkwon Jeong, Electronics and Telecommunications Research Institute (Korea, Republic of)

Light field display becomes a major research topic in 3-D imaging lately. It is considered that this display can provide a continuous parallax to viewers. This means that it can deliver at least two same/different view images at the same time to a viewer's each eye. But it is not known that how many images are actually getting into each eye in the light field displays. Hence the actual performances of the displays cannot be confirmed. For the measuring of the expected performances of the displays, a simulator for a light field display which can deliver up to 4 same and different view images at the same time to each eye was developed and identified that the focusable depth range increases with the increasing number of images. But the presense of monucular depth sense that was expected when there is a continuous parallax, and the limit of extension in the focusable depth range, was not identified.

In this paper, a simulator which can deliver simultaneously up to eight same or different view images to each eye is introduced. It is expected that this simulator can identify the presense of monocular depth sense and extension range of the focusable depth.

10219-12, Session 4

Full-parallax virtual view-images synthesis using image based rendering for light field content generation *(Invited Paper)*

Namho Hur, Youngsoo Park, Hong-Chang Shin, Gwangsoon Lee, Won-Sik Cheong, Electronics and Telecommunications Research Institute (Korea, Republic of)

Light field content requires to provide full-parallax (FP) 3D view with dense angular resolution. However, it is very hard to directly capture such dense FP view images using the camera system because it requires specialized micro-lens arrays or heavy cameras array. Therefore, in this paper we present an algorithm to synthesize FP virtual view images using image based rendering (IBR) appropriate for light field contents generation. The proposed algorithm consists of depth map estimation, 8-directional image warping for intermediate virtual view images and view- spatial hole filling. The experimental result shows that dense FP virtual view images can be generated from sparse FP view images with as less as image artifact. Finally, it is confirmed that proposed FP View synthesis algorithm can used for light field contents generation without dense camera array system.

10219-13, Session 4

Average crosstalk in multiview 3D display *(Invited Paper)*

Sung Kyu Kim, Ki-Hyuk Yoon, Korea Institute of Science and Technology (Korea, Republic of)

Point Crosstalk is a criteria for representing 3D image quality in glassless 3D display and motion parallax is coupled, a part, with point crosstalk when we consider smoothness of the motion parallax. Therefore we need to find a relationship between point crosstalk and motion parallax. Lowering point crosstalk is important for better 3D image quality but more discrete motion parallax appears at lower point crosstalk at OVD (Optimal Viewing Distance). Therefore another consideration for representing smoothness of motion parallax is necessary. And we analyze average crosstalk for smoother motion parallax as a candidate of another parameter for representing 3D image quality in glassless 3D display.

10219-14, Session 4

Dynamic integral imaging technology for 3D applications *(Invited Paper)*

Yi-Pai Huang, National Chiao Tung Univ. (Taiwan); Bahram Javidi, Univ. of Connecticut (United States); Manuel Martínez-Corral, Univ. de València (Spain); Han-Ping D. Shieh, Tai-Hsiang Jen, Po-Yuan Hsieh, Amir Hassanfiroozi, National Chiao Tung Univ. (Taiwan)

Depth and resolution are always the trade-off in integral imaging technology. With the dynamic adjustable devices, the two factors of integral imaging can be fully compensated with time-multiplexed addressing. Those dynamic devices can be mechanical or electrical driven. In this presentation, we will mainly focused on discussing various Liquid Crystal devices which can change the focal length, scan and shift the image position, or switched in between 2D/3D mode.

By using the Liquid Crystal devices, dynamic integral imaging have been successfully applied on 3D Display, capturing, and bio-imaging applications.

10219-15, Session 4

Nonlinear correlation of photon-counting elemental images for distance extraction *(Invited Paper)*

Seokwon Yeom, Daegu Univ. (Korea, Republic of)

Integral imaging combined with photon-counting detection has been researched for three-dimensional information sensing under low-light-level conditions. This paper addresses the distance information extraction with photon-counting integral imaging. The longitudinal distance to the object is obtained by utilizing the photon-counting elemental images. The pixel disparity is estimated by maximizing the nonlinear correlation of photo-counts. The first and second order statistical properties of the nonlinear correlation are theoretically derived. In the experiments, these properties are verified by varying the mean number of photo-counts in the scene. The average distance is compared with that from the intensity information showing the robustness of the proposed system at a low level of photo-counts.

10219-16, Session 5

Forming an aerial heater and its application for aerial information display *(Invited Paper)*

Hirotsugu Yamamoto, Utsunomiya Univ. (Japan) and Japan Science and Technology Agency (Japan); Tomoyuki Okamoto, Hitomi Horie, Utsunomiya Univ. (Japan); Ryosuke Kujime, Utsunomiya Univ. (Japan) and Japan Science and Technology Agency (Japan); Haruki Mizushina, Shiro Suyama, The Univ. of Tokushima (Japan); Takaho Itoigawa, Utsunomiya Univ. (Japan)

This paper proposes a new way of using light in information display technology. In the conventional information display, light is mainly used for showing spatial information. In this paper, we use light for warming mid-air and providing thermal sensation.

The conventional thermal display technique gives thermal sensation together with haptic perception because its user needs to touch the thermal display surface. By utilizing light for warming, we can give thermal sensation without touching a physical hardware.

In order to converge infrared radiation from a heater, we have investigated four types of reflective optical elements. A parabolic mirror converges infrared radiations with a high efficiency. A crossed-mirror array (CMA) converges visible light, infrared radiations, and also sonic waves. A square-pipe array (SPA) also converges infrared radiations and features a high scalability and a low cost. A double-layered rectangular mirrors (WARM) converges infrared radiations with a higher efficiency than CMA and SPA.

In this invited talk, we report optical simulations and experimental results in forming aerial heaters by use of these reflective optical elements. Psychophysical experiments have been also conducted to investigate effectiveness of our proposed aerial heaters.

Furthermore, we have succeeded in aerial visual and thermal information display. The developed display system is composed of an aerial information display with aerial imaging by retro-reflection (AIRR) and an aerial heater by use of WARM. For example, an aerial image that contains a fire and a snow is formed in the mid-air and when users touch the aerial fire, they feel warmth.

10219-17, Session 5

European training network on full-parallax imaging

Manuel Martínez-Corral, Genaro Saavedra, Univ. de València (Spain)

Current displays are far from truly recreating visual reality. This requires a full-parallax display that can reproduce radiance field emanated from the real scenes. The develop-ment of such technology will require a new generation of researchers trained both in the physics, and in the biology of human vision. The European Training Network on Full-Parallax Imaging (ETN-FPI) aims at developing this new generation. Under H2020 funding ETN-FPI brings together 8 beneficiaries and 8 partner organizations from five EU countries with the aim of training 15 talented pre-doctoral students to become future research leaders in this area. In this contribution we will explain the main objectives of the network, and specifically the advances obtained at the University of Valencia.

10219-18, Session 5

Integral-imaging display from stereo-Kinect capture

Seokmin Hong, Amir Ansari, Genaro Saavedra, Manuel Martínez-Corral, Univ. de València (Spain)

In this paper, we propose the fusion between two Kinect device, v1 and v2, which per-mits the registration in real time of big diffusing 3D scenes, and integral-imaging technology, which permits the display of 3D images with full parallax. We propose the correction progress between two different devices' field-of-view, scale, and resolution in order to unite the 3D scene more precisely, and the integrating technique between two corrected 3D scenes. This fused 3D information transforms into an array of microimages 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 a 3D scene displayed with merged stereo perspectives.

10219-19, Session 6

Enabling focus cues in head-mounted displays for virtual and augmented reality *(Invited Paper)*

Hong Hua, College of Optical Sciences, The Univ. of Arizona (United States)

Developing head-mounted displays (HMD) that offer uncompromised optical pathways to both digital and physical worlds without encumbrance and discomfort confronts many grand challenges, both from technological perspectives and human factors. Among the many challenges, minimizing visual discomfort is one of the key obstacles. One of the key contributing factors to visual discomfort is the lack of the ability to render proper focus cues in HMDs to stimulate natural eye accommodation responses, which leads to the well-known accommodation-convergence cue discrepancy problem. In this talk, I will provide a comprehensive summary on various technical approaches toward enabling focus cues in HMDs for both virtual reality (VR) and augmented reality (AR). I will also review recent advancements of head-mounted light field displays and demonstrate examples of HMD systems developed in my group.

10219-20, Session 6

Computational microscopy: illumination coding and nonlinear optimization enables gigapixel 3D phase imaging *(Invited Paper)*

Lei Tian, Boston Univ. (United States)

I will present recent advancements in computational microscopy based on coded illumination and nonlinear phase retrieval, which enables wide field-of-view and high-resolution Gigapixel and 3D phase microscopy capability, breaking the limit of space-time-bandwidth product in traditional systems.

10219-22, Session 6

3-Dimensional stereo implementation of photoacoustic imaging based on a new image reconstruction algorithm without using discrete Fourier transform

Woonchul C. Ham, Chul-Gyu Song, Chonbuk National Univ. (Korea, Republic of)

In this paper, we propose a new three-dimensional stereo image reconstruction algorithm for a photoacoustic medical imaging system.

We also introduce and discuss a new theoretical algorithm by using the physical concept of Radon transform. The main key concept of proposed theoretical algorithm is to evaluate the existence possibility of the acoustic source within a searching region by using the geometric distance between each sensor element of acoustic detector and the corresponding searching region denoted by grid. We derive the mathematical equation for the magnitude of the existence possibility which can be used for implementing a new proposed algorithm. We handle and derive mathematical equations of proposed algorithm for the one-dimensional sensing array case as well as two dimensional sensing array case too. We implement the proposed algorithm by using a CUDA parallel programming based on two multi Quadro K4200 GPU hardwares for improving and reducing the calculation time.

A mathematical k-wave simulation data are used for comparing the image quality of the proposed algorithm with that of general conventional algorithm in which the FFT should be necessarily used. From the k-wave Matlab simulation results, we can prove the effectiveness of the proposed reconstruction algorithm.

10219-23, Session 6

Real-time visualization of magnetic flux densities for transcranial magnetic stimulation on commodity and fully immersive VR systems

Vijay K. Kalivarapu, Iowa State Univ. of Science and Technology (United States); Ravi L. Hadimani, Ciro H. Alcoba-Serrate, Virginia Commonwealth Univ. (United States)

Transcranial Magnetic Stimulation (TMS) is a non-invasive neuromodulation technique that uses time varying short pulses of magnetic field to induce an electric field in the tissues of the brain, thus modulating the synaptic transmission of neurons. In this method, a magnetic field generator ("TMS coil") produces small electric fields in the region of the brain via electromagnetic induction. This technique can be used to excite or inhibit firing of neurons, which can then be used for treatment of various neurological disorders such as Parkinson's disease, Alzheimer's disease, and depression. It is however challenging to focus the induced electric field from TMS coils to smaller regions of the brain. Since electric and magnetic fields are governed by laws of electromagnetism, it is possible to numerically simulate and visualize these fields to accurately determine the site of maximum stimulation and also to develop TMS coils that can focus the fields on the targeted regions. However, current software to compute and visualize these fields are not real-time and can work for only one position/orientation of TMS coil, severely limiting their usage. This paper describes the development of an application that computes magnetic flux densities (h-fields) and visualizes their distribution for different TMS coil position/orientations in real-time using GPU shaders. The application is developed for commodity VR (Oculus) using leapmotion gesture recognition controller, bring-your-own-smartphone VR (Google Cardboard), and fully immersive VR CAVE systems, for use by researchers, scientists, and medical professionals to quickly and effectively view the distribution of h-fields from MRI brain scans.

10219-25, Session 6

Validation of optical codes based on 3D nanostructures *(Keynote Presentation)*

Artur Carnicer, Univ. de Barcelona (Spain); Bahram Javidi, Univ. of Connecticut (United States)

In this communication we discuss different methods for validating physical unclonable codes using optical measurements. These devices are made using a variety of techniques including nanotechnology, thin film deposition or 3D phase encoding. Very frequently these codes are built using metallic nanoparticles because of their interesting dichroic properties. Different non-invasive macroscopic measurements such as polarimetric or speckle techniques are used to authenticate samples. In particular, they generate a unique and distinctive signal that can be used to distinguish among different classes. Since the recorded signatures are very similar and difficult to differentiate it is required to use machine learning algorithms.

10219-21, Session 7

Focus measurement in 3D focal stack using direct and inverse discrete radon transform

Óscar Gómez-Cárdenes, José Gil Marichal-Hernandez, Juan M. Trujillo-Sevilla, José M. Rodríguez Ramos, Univ. de La Laguna (Spain)

The discrete Radon transform, DRT, proposed around 1996, independently by Götz and Druckmüller, and Brady, calculates, with O(N^2 log N) complexity, the sum of pixels through a set of carefully selected discrete lines covering all posible slopes and intercepts in an image of size NxN.

In 2006, W.H. Press proposed a method to compute the inverse DRT that remains exact and fast, in spite of being iterative. Both direct and inverse transform pair, make use exclusively of sums, what makes them specially efficient in comparison with Radon transforms based on Fourier methods.

In a previous work the authors used a modified direct DRT in order to create a 3D volume consisting of a sequence of images sweeping the focal range of the main lens of a integral camera starting from a 4D integral image. They called it 4D:3D transform, or approximate focal stack transform.

Now they propose to directly capture this volume, a focal stack, and then estimate depth to objects based on the plane where they get into focus.

To recover the Shape From Focus, the DRT pair is not used directly, instead, a Ridgelet and a Curvelet transform based on the DRT pair will be proposed. These transforms are basically a mixture of wavelet transforms and DRT. The proposed transforms are advantageous on their own, but in this work their advantages and limitations will be studied in the context of their application to SFF.

10219-24, Session 7

Correlation between projector calibration error and depth expression range for autostereoscopic optical display system using laser beam scanning projector

Yeo Hun Kim, Korea Institute of Science and Technology (Korea, Republic of) and Yonsei Univ. (Korea, Republic of); Min Koo Kang, Ki-Hyuk Yoon, Korea Institute of Science and Technology (Korea, Republic of); Kwang Hoon Sohn, Yonsei Univ. (Korea, Republic of); Sung Kyu Kim, Korea Institute of Science and Technology (Korea, Republic of)

In autostereoscopic displays using laser beam scanning (LBS) type of multiple projectors, accurate projector calibration (PC) is essential to alleviate optical distortions such as keystone distortion and binocular asymmetry that degrade stereopsis making accurate depth perception. However, calibrating hundreds of projectors with high accuracy is strenuous, and expensive with respect to time and computational power. Moreover, there exist a limited range where viewers can percept correct depth with respect to human visual system (HVS) although the ideal PC is possible. So we need to certain value for efficient PC process. For this, we make a PC error artificially by controlling intrinsic parameter of projector and we define

a several of PC error rate condition by implementing PC process. Under these conditions, we measure depth expression range (DER). Through this we analyzed DER in the given accuracy with respect to HVS. Eventually, we proposed a perceptive threshold for acceptable PC accuracy for whole system's efficiency.

10219-26, Session 7

Assessment of variation levels between 3D printer prints

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

Three-dimensional printing has demonstrated the capability to provide significant benefit to numerous industries, leading to Berman terming it a "new industrial revolution." The reliability of the technology varies greatly, however, with many attempted prints ending up unusable. While previous work has looked at techniques for mitigating problems, this current work seeks to characterize how different 3D prints from the same printer can be in a repetitive production environment. Specifically, this seeks to answer the question about whether the process can be optimized and relied on (tying in with principles of Six Sigma and Just in Time manufacturing) or if printer, filament and environmental variables make it so that the 3D printing process produces inconsistent results. The former being true would suggest that hardware optimization and process quality improvement may be a suitable approach to ensuring quality. If the latter is the case, inspection-based metrics (or other non-process assurance based techniques) would need to be utilized to ensure suitable quality, for many applications.

This paper answers this question by presenting work on the characterization of print-to-print differences between multiple printed objects on several different types of 3D printers. It provides both visual and numeric analysis of the differences and assesses whether the levels of difference detected is practically significant or superficial. The paper discusses the implications of these results on the ongoing development of a 3D printer quality assessment technology. Future work and a discussion of the potential additional uses for quality-assured 3D printing are discussed, before concluding.

10219-27, Session 7

Challenges in miniaturized automotive lidar system design

Thomas Fersch, Robert Bosch GmbH (Germany) and Friedrich-Alexander-Univ. of Erlangen-Nürnberg (Germany); Robert Weigel, Alexander Kölpin, Friedrich-Alexander-Univ. of Erlangen-Nürnberg (Germany)

This paper discusses the current technical limitations posed on endeavors to miniaturize LiDAR systems for use in automotive applications and how to possibly extend those limits. The focus is set mainly on long range scanning direct time of flight LiDAR systems using APD photodetectors. Miniaturization evokes severe problems in ensuring absolute laser safety while maintaining the systems' performance in terms of maximum range, signal-to-noise ratio, detection probability, pixel density, or frame rate.

First a general calculation of the maximum permitted optical energy per measurement is shown. This value is dependent on system parameters like laser wavelength or emitter area. Additionally, the choice of the laser deflection principle is critical and will be investigated. The calculations are based on international laser safety standards.

Next the variation in time of an optimal and practicable function of optical power is derived. High peak power emissions are strongly favored which however have to be kept very short to limit their optical energy. In regard to a cost sensitive and miniaturized system the problems emerging from very short emissions are revealed in detail. Exemplary calculations with parameters of available and academically proposed system components like photo diodes, laser drivers, amplifiers or pulse detection circuits are given.

Eventually a detailed analytical calculation of the maximum range at which a single measurement can be taken with commonly accepted detection confidence is given for a set of exemplary system configurations. The calculations reveal the limiting parameters amongst the system components. It allows to suggest future research topics to increase the range of the investigated LiDAR system configurations.

10219-28, Session 7

Optical characterization of silicon light-emitting device display

Kaikai Xu, State Key Lab. of Electronic Thin Films & Integrated Devices (China)

Silicon light-emitting device (LED) which is useful in 3D display has drawn much attention in recent years. In this work, a silicon MOS-like LED manufactured in a standard 3-?m silicon complementary metal–oxide–semiconductor (CMOS) technology is demonstrated. The device can work in two- and three- terminal modes. When working in three-terminal mode, the breakdown voltage, the reverse current, as well as the light intensity can be well modulated by the gate voltage. Furthermore, both the quantum efficiency and the power conversion efficiency can be enhanced obviously by reducing the reverse-bias/current of the p–n junction. In addition, the light-emitting structure has an intrinsic high-frequency operating capability, and can work near gigahertz range. It is noted that the device can reduce the volume of a 3D display device, simplify the manufacturing process of the device, and reduce the cost of the whole system.

10219-38, Session 7

Off-axis incoherent digital holographic microscopy

Xiangyu Quan, Osamu Matoba, Kobe Univ. (Japan); Yasuhiro Awatsuji, Kyoto Institute of Technology (Japan)

Off-axis incoherent digital holographic microscopy with common-path configuration is introduced. The method uses phase only spatial light modulator with patterns of dual-focusing Fresnel lens and respective gratings. The SLM diffracts light coming from a point source to different focal points and directions. We extract 1st order signals by using a spatial filter. This process can avoid noise that is caused by ordinary rays in a polarisation sensitive SLM, and low diffraction efficiency of SLM. Two quadratic wavefronts with a certain angle propagates in the free space with high degree of spatial coherence. Hence the off-axis incoherent digital holography is realized.

This method is prior to previous studies in incoherent digital holography due to high signal-to-noise ratio (SNR) in holograms, and single-shot recording. Thus it is suitable to measure incoherent particles in three dimensions with high mobility. We are aim to apply the off-axis incoherent digital holography to the microscopic systems. Measuring objects are autofluorescence or extrinsic fluorescence in biological samples. preliminary experiments using fluorescent micro-beads are presented in this paper.

10219-30, Session PTue

3D measurement of large-scale object using independent sensors

Liu Yong, Jia Yuan, Jiang Yong, Southwest Univ. of Science and Technology (China)

A new optical 3D measurement system using finge projection is presented, which is divided into four parts, including moving device, link camera, stereo cameras and projector. Two rotating arms consists of the moving device, stereo cameras and the projector are fixed on the top of them, seperately.

Controlled by a computer, the two rotating arms move around the unique center in proper order, fringe patterns are projected to the surface the measured object by the projector, and the images are captured by stereo cameras. Thus a sequence of local sets of points can be obtained based on time phase unwrapping and stereo vision. Two basic principles of place dependance and phase dependance are used to register these local sets of points into one final data set. In the condition of the projector moved, because of stereo cameras keep unmoved, the two adjacent local sets of points can be conbined togeter directly. Otherwise, if stereo cameras moved but the projector keeps unmoved, for the points on the surface of measured object, the x- and y-phase values must be the same between the two adjacent measurement in according to fringe projection technology, which is called phase dependance in this paper. Hence, the relative parameters of stereo cameras can be computed by the two sets of points, and it canbe use to transformate the second set of points into the coordinate system of the first set of points. Link camera is used to capture the first set of fringe imges and the last set of fringe images projected by the projector. Phase dependance principle is used to obtain two set of sampling points between the first and the last measurement, so the iterative closest points (ICP) method can be used to eliminate the register errors.

A device is developed to help shoes manufacturing enterprise for obtaining the 3D model of athlete's feet. It's main technical parameters describes as below: the measurement device covers 120mm*120mm, the max measured object volumn is 40mm*40mm*40mm, 8 sets of points will be captured in one complete measurement, the measurement time is 42 second, the precision of combined set of points is 0.1mm.

10219-31, Session PTue

Synthetic depth data creation for sensor setup planning and evaluation of multi-camera multi-person trackers

Manuel Martin, Fraunhofer-Institut für Optronik, Systemtechnik und Bildauswertung (Germany); Marco Pattke, Hochschule Karlsruhe Technik und Wirtschaft (Germany); Michael Voit, Fraunhofer-Institut für Optronik, Systemtechnik und Bildauswertung (Germany)

Today many public areas are equipped with large numbers of cameras. But automated image exploitation to count people or track their movements is only used rarely because of the increased complexity and cost. Setting up such systems is difficult because they often need better coverage of the area with less occlusions than standard surveillance systems. Finding a working camera setup can be a time consuming and expensive process if done in a real environment because data of different setups has to be recorded and evaluated.

We present a simulation framework that addresses this problem. It can simulate data of different camera setups in target environments with simulated moving characters. We simulate depth images as produced by structured-light or time-of-flight sensors not color images because depth data is easier to simulate realistically as it is less influences by lighting or colors of the environment. With this framework we can test algorithms efficiently by reproducing the exact same scenarios with different sensor setups. In addition we can easily evaluate the performance quantitatively because ground truth data can be generated as well.

To evaluate the framework we connect it to our self developed distributed and scalable multi-person multi-camera tracking system and visualize the results in real time directly in the simulated environment. Our tracking system uses consumer depth cameras and processing units combined in sensor nodes. Each sensor node processes the camera images internally and outputs only processed data about the tracked people which is then combined by a central server.

10219-32, Session PTue

An overview of head tracking integral imaging three-dimensional display using smart pseudoscopic-to-orthoscopic conversion

Xin Shen, Univ. of Connecticut (United States); Manuel Martínez-Corral, Univ. de València (Spain); Bahram Javidi, Univ. of Connecticut (United States)

We overview a head tracking integral imaging three-dimensional (3D) display to extend viewing angle accommodated to viewer's position without the crosstalk phenomenon. A head detection system is applied to obtain the head position and rotation of a viewer, and a new set of elemental images is then computed using the smart pseudoscopic-to-orthoscopic conversion (SPOC) method for head tracking 3D display. Experimental results validate the proposed method for high quality 3D display with large viewing angle.

10219-33, Session PTue

Recent progress in multidimensional optical sensing and imaging systems (MOSIS)

Xin Shen, Bahram Javidi, Univ. of Connecticut (United States)

We present recent progress of multidimensional optical sensing and imaging systems (MOSIS) 2.0 for target recognition and integrated visualization. The degrees of freedom of MOSIS 2.0 include three-dimensional (3D) imaging, polarimetric imaging and multispectral imaging. Each of these features provides unique information about a scene. 3D computational reconstructed images mitigate the occlusion in front of the object, which can be used for 3D object recognition. The degree of polarization (DoP) of the light reflected from object surface is measured by 3D polarimetric imaging. Multispectral imaging is able to segment targets with specific spectral properties.

10219-34, Session PTue

A 2D/3D hybrid integral imaging display by using fast switchable hexagonal liquid crystal lens array

Hsin-hsueh Lee, Ping-Ju Huang, Jui-Yi Wu, Po-Yuan Hsieh, Yi-Pai Huang, National Chiao Tung Univ. (Taiwan)

The paper proposes a new display which could display 2D and 3D images on a monitor at the same time, and we call it as Hybrid Display. In 3D display, the reduction of image resolution is still an important issue. The more angle information offer to the observer, the less resolution would offer to image resolution because of the fixed panel resolution. Take in for example, in the integral photography system, the part of image without depth, like background, will reduce its resolution by transform from 2D to 3D image. Therefore, we proposed a method by using liquid crystal component to quickly switch the 2D image and 3D image. Meanwhile, the 2D image is set as a background to compensate the resolution in the display. In the experiment, hexagonal liquid crystal lens array would be used to take the place of fix lens array. Moreover, in order to increase lens power of the hexagonal LC lens array, we applied high resistance (Hi-R) layer structure on the electrode. Hi-R layer would make the gradient electric field and affect the lens profile. Also, we use panel with 801 PPI to display the integral image in our system. Hence, the consequence of high resolution 2D background with the 3D depth object forms the Hybrid Display.

10219-35, Session PTue

3D visualization viewer (3DV2)

Kenneth Abeloe, Integrity Applications, Inc. (United States)

Multi-INT data visualization helps the IC and Services leverage disparate, heterogeneous data sources to improve situational awareness, planning, and operations. Typical data visualization applications include data fusion, battlespace planning, and network analysis.

As the IC and DoD Services has moved to modern hardware and software architectures (e.g. ICITE, AWS), the need for web-based true stereoscopic multi-INT visualization tools has emerged. Older architectures using traditional thick-client applications, true stereoscopic viewing is implemented using OpenGL interfaces allowing stereo display buffer manipulation resident on the graphics card - giving an application access to the stereo synch used by stereo graphics hardware. In newer architectures using browser web apps, a subset of the OpenGL capabilities is available through the JavaScript API called WebGL. Although WebGL exposes many of the rendering routines found in OpenGL, it does not provide explicit methods needed to construct a true stereographic view. Due to these limitations with WebGL in current browsers, web-based applications cannot get access to the stereographic interfaces needed to display true stereo.

3D Visualization Viewer (3DV2) provides a software bridge solution to enable web-based applications to render natively in stereo. In order to access interfaces provided by stereo-capable graphics cards, 3DV2 provides a browser-specific plugin to connect between web-based applications and specialized hardware. 3DV2 provides plugins with an open interface where any web-based application natively renders stereoscopic views. The 3DV2 capabilities benefit users employing true stereoscopic viewing through the web for various multi-INT applications such as data mining, data fusion, and ground/maritime/space situation awareness.

10219-36, Session PTue

Integral display for non-static observers

Adrián Dorado, Seokmin Hong, Genaro Saavedra, Manuel Martínez-Corral, Univ. de València (Spain); Bahram Javidi, Univ. of Connecticut (United States)

We propose to combine the Kinect and the Integral-Imaging technologies for the im-plementation of Integral Display. The Kinect device permits the determination, in real time, of (x,y,z) position of the observer relative to the monitor. Due to the active condi-tion of its IR technology, the Kinect provides the observer position even in dark envi-ronments. On the other hand SPOC 2.0 algorithm permits to calculate microimages adapted to the observer 3D position. The smart combination of these two concepts per-mits the implementation, for the first time we believe, of an Integral Display that pro-vides the observer with color 3D images of real scenes that are viewed with full parallax and which are adapted dynamically to its 3D position.

10219-37, Session PTue

Security authentication with a three-dimensional optical phase code using random forest classifier: an overview

Adam S. Markman, Bahram Javidi, Univ. of Connecticut (United States)

We overview an authentication scheme using three-dimensional (3D) optical phase tags. A 3D optical phase tag is illuminated by a coherent light source generating a unique pattern. This pattern can be captured using an imaging sensor. Features are extracted from this signature such as mean, variance, skewness, kurtosis and entropy. The extracted features are then inputted into a pre-trained random forest classifier for classification. The results show we can uniquely authenticate a 3D optical phase tag based on the recorded signature.

10219-39, Session PTue

Expansion method of the three-dimensional viewing freedom of autostereoscopic 3D display with dynamic merged viewing zone (MVZ) under eye tracking

Ki-Hyuk Yoon, Sung Kyu Kim, Korea Institute of Science and Technology (Korea, Republic of)

We studied expansion method of the three-dimensional viewing freedom of autostereoscopic 3D display with dynamic MVZ under tracking of viewer's eye. The dynamic MVZ technique can provide three dimensional images with minimized crosstalk when observer move at optimal viewing distance (OVD). In order to be extended to movement in the depth direction of the observer of this technology, it is provided a new pixel mapping method of the left eye and the right eye images at the time of the depth direction movement of the observer. When this pixel mapping method is applied to common autostereoscopic 3D display, the image of the 3D display as viewed from the observer position has the non-uniformed brightness distribution of a constant period in the horizontal direction depending on depth direction distance from OVD. It makes it difficult to provide a three-dimensional image of good quality to the observer who deviates from OVD.

In this study, it is simulated brightness distribution formed by the proposed pixel mapping when it is moved in the depth direction away OVD and confirmed the characteristics with the captured photos of two cameras on observer position to simulate two eyes of viewer using a developed 3D display system. As a result, we found that observer can perceive 3D images of same quality as OVD position even when he moves away from it in the developed 3D display system.

10219-40, Session PTue

A study on the GPU based parallel computation of a projection image

HYUN JEONG LEE, Miseon Han, Jeongtae Kim, Ewha Womans Univ. (Korea, Republic of)

Fast computation of projection images is crucial in many applications such as medical image reconstruction and light field image processing. To do that, parallelization of the computation and efficient implementation of the computation using a parallel processor such as GPGPU(General Purpose computing on Graphics Processing Units) is essential. In this research, we investigate methods for parallel computation of projection images and efficient implementation of the methods using CUDA (Compute Unified Device Architecture). We also study how to efficiently use the memory of GPU for the parallel processing.

10219-41, Session PTue

Method for self reconstruction of holograms for secure communication

Craig W. Babcock II, Eric Donkor, Univ. of Connecticut (United States)

Holograms are commonly used in the security field for securing sensitive information and for credential verification. Advancements in holographic methods ensures the effectiveness of holograms as a security tool. In this paper we present the theory and experimental results behind using a 3D holographic signal for data encryption and an identical hologram for data decryption. In our method the holographic signal is Fourier transformed and the transformed holographic signal modulated for data encryption. In order to decrypt the information an identical hologram is need to demodulate the carrier signal. This method of producing a self-reconstructing hologram ensures that the pieces in use are from the same original hologram, providing an extremely difficult system to counterfeit.

10219-42, Session PTue

Combining texture-based and difference-identification assessment for 3D printing quality control

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

Additive manufacturing is a rapidly growing industry. Despite the proliferation of 3D printers, of numerous types, limited attention has been paid to quality control. Some printers incorporate limited mechanisms to validate various parts of the printing process. For example, MakerBot uses print head-area sensors to identify filament problems. Others have proposed sensing the melting pool of sintering-based printers to ascertain if this process is working correctly. While process control is needed, this is not a complete solution. Even for printers with low failure rates, user/consumer-affecting problems (such as the shrinkage and warping of cooling printed objects) exist.

Fastowicz and Okarma suggested the use of the sensing of 3D printing texture as a “blind” approach to quality assessment. They proffer that abnormalities in printing patterns may assist in the identification of a defect. Prior work by the author of this article has demonstrated the effectiveness of comparison-based defect identification. However, the difference-based approach generates false positives and false negatives. This paper seeks to determine if incorporating the pattern-based approach suggested by Fastowicz and Okarma can aid in the reduction of misidentifications.

To this end, several tests were performed and are reported on. Texture-matching was performed (separately, for purposes of comparison) both before and after the difference-based detection. The difference in error rate is reported. The number of textures used for training is varied and these tests are performed for each. After analyzing these results, the paper concludes with a discussion of the future of 3D printing and quality assessment’s role therein.

10219-43, Session PTue

Passive long-wave infrared three-dimensional integral imaging for face detection and position estimation

Satoru Komatsu, Adam S. Markman, Univ. of Connecticut (United States); Abhijit Mahalanobis, Kenny Chen, Lockheed Martin Missiles and Fire Control (United States); Bahram Javidi, Univ. of Connecticut (United States)

We propose a passive three-dimensional (3D) imaging technique known as integral imaging (II) using a long-wave infrared (LWIR) camera for face detection and position estimation under low light conditions. Integral imaging records multiple two-dimensional images of a scene, each having a different perspective of the scene, and combines this information to generate 3D reconstruction of the scene. The face detection system reconstructs the scene over different depth planes using II, which is able to remove occlusions in front of the object. After a plane is reconstructed, face detection is achieved using correlation filters to find regions of interest and a support vector machine (SVM) for classification. Experimental results validate the proposed method of detecting a human face correctly and estimating the distance is from the camera array.

Thursday 13 April 2017

Part of Proceedings of SPIE Vol. 10220 Dimensional Optical Metrology and Inspection for Practical Applications VI

10220-21, Session PWed

A combined system for 3D printing cybersecurity

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

In previous work, Zeltmann, et al. and others have discussed the prospective impact of a cybersecurity breach on 3D printed objects. Multiple attack types that could weaken objects, make them unsuitable for certain applications and even create safety hazards have been discussed. Given the proliferation of 3D printing, numerous locations within the printing ecosystem represent prospective vulnerabilities for a would-be attacker to exploit. Securing the entirety of the ecosystem is impractical and would rely on multiple security technologies (which, themselves, would represent additional prospective points of attack).

This paper considers the efficacy of a visible light sensing-based verification system as a means of thwarting cybersecurity threats to 3D printing. Specifically, this system will detect discrepancies between what should be printed (given the pristine and independently acquired CAD model) and what is being printed. The ability for this system to detect multiple different types of attacks is considered. These attacks may, for example, change the position, composition, material, orientation and/or fill level of the object. They may also introduce defects (of various sizes) into the object. The ability to detect combined attacks and multiple simultaneous attacks in different object areas is a key area of consideration. Also considered is whether reliance on the independent CAD model is appropriate, or if additional security and/or verification measures must be taken. The future of 3D printing is projected and the importance of cybersecurity in this future is discussed. The paper concludes with a discussion of future avenues for this work and the challenges presented.

10220-22, Session PWed

3D printing cybersecurity: detecting and preventing attacks that seek to weaken a printed object by changing fill level

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

Prior work by Zeltmann, et al. has demonstrated the impact of small defects and other irregularities on the structural integrity of 3D printed objects. This prior work posited that such defects could be introduced intentionally by 'hackers' with nefarious purposes. The current work looks at the impact of changing a critical setting, the fill level, on object structural integrity. It then considers whether the existence of an appropriate level of fill can be determined through visible light imagery-based assessment of a 3D printed object. This assessment technique, instead of simply assuring that the setting is not changed, provides assurance that the printed object has the correct parameter. This allows assurance to be focused on one area instead of having to ensure the end-to-end software/file/hardware transmission infrastructure that could be required to assure the correct setting (depending at what point in a given printer infrastructure's process this is set at and what can be changed subsequent to this). Additionally, this approach also assures the absence of printing defects in this crucial structural element.

This paper presents a technique for assessing the quality and sufficiency of quantity of 3D printed fill material. This technique is assessed experimentally and results are presented and analyzed. The impact of different environmental variables and filament types is also considered and results with different lighting levels and types and filament types are presented and analyzed. Finally, the paper assesses the assurance benefits of this approach and discusses the need for 3D printing cybersecurity, more generally, before concluding.

10220-23, Session PWed

Fast 3D NIR system for facial measurement and lip-reading

Anika Brahm, Roland Ramm, Fraunhofer-Institut für Angewandte Optik und Feinmechanik (Germany); Stefan Heist, Fraunhofer-Institut für Angewandte Optik und Feinmechanik (Germany) and Friedrich-Schiller-Univ. Jena (Germany); Peter Kühmstedt, Fraunhofer-Institut für Angewandte Optik und Feinmechanik (Germany); Gunther Notni, Fraunhofer-Institut für Angewandte Optik und Feinmechanik (Germany) and Technische Univ. Ilmenau (Germany)

Structured-light projection is a well-established optical method for the non-destructive contactless three-dimensional (3D) measurement of object surfaces. In particular, there is a great demand for accurate and fast 3D scans of human faces or facial regions of interest under motion in medicine, safety, face modeling, games, virtual life, or entertainment. New developments of facial expression detection and machine lip-reading can be used for communication tasks, future machine control, or human-machine interactions. In such cases, 3D information may offer more detailed information than 2D images which can help to increase the power of current facial analysis algorithms.

In this contribution, we present our newest 3D sensor technology based on structured-light projection realized with near-infrared radiation for fast, accurate, and irritation-free measurements of human face motions for emotion recognition and machine lip-reading. In this way, disturbing glare effects of current pattern-based 3D systems which operate in the visible spectrum can be avoided for the persons. Consequently, emotion and face data is not affected by the measurement.

Furthermore, we explain the measurement principle of our 3D NIR sensor and give an overview of the technical setup and performance parameters. We show some experimental measurement results of human face motions and application examples for machine lip-reading and emotion recognition.

10220-1, Session 1

Polarized metrology systems *(Invited Paper)*

Rongguang Liang, College of Optical Sciences, The Univ. of Arizona (United States)

Polarization is a unique property of light, providing a number of advantages in optical metrology. In this talk, I will discuss principles and experimental results of polarization techniques in fringe project metrology and interferometric measurement.

10220-2, Session 1

3D shape measurement using image-matching-based techniques *(Invited Paper)*

Zhaoyang Wang, Hieu Nguyen, The Catholic Univ. of America (United States)

In the human eye system, the mind combines two separate images to build a 3D stereo picture by matching up similarities and adding in differences. This natural vision-matching mechanism is commonly employed in the

3D machine vision field. The main limitation of the conventional 3D vision technique is the incapability of providing full-field 3D information of scenes or objects with high accuracy. In this paper, accurate 3D shape measurements using the image-matching-based techniques are presented. The measurements use two or multiple images captured from different viewpoints, at different time, and/or by different cameras. The process contains two crucial steps: (1) calibrate the cameras to get the intrinsic and extrinsic parameters; (2) perform matching of pixel points to detect the location disparities of the same physical points in the involved two or multiple images. The relative accuracy of the measurement can reach 1/50,000, and the field of view can cover a range from a few millimeters to hundreds of meters. The measurement speed can be real-time or be identical to the camera capturing speed. A number of experiments are shown to demonstrate the applications, which include the 3D shape measurements of various objects, 3D scene digitization, 3D deformation and strain measurements, motion detection, audio extraction, vibration measurements, etc.

10220-3, Session 1

High-speed 3D surface measurement with mechanical projector

Jae-Sang Hyun, Song Zhang, Purdue Univ. (United States)

In spite of the development of digital fringe projection technologies over last decades, the commercially available digital projectors typically have the limitations of speed, maximum illumination, and their footprints. Specifically, the projection speed is mainly a limiting factor for measuring quickly moving objects. Numerous methods have been developed to overcome this limitation by developing different algorithms for digital video projection devices including using binary images, and reducing the number of images for 3D reconstruction. Yet, they are typically tailored to specialized development kits of digital light processing (DLP) technologies. Those DLP kits are either expensive or less powerful. This paper proposes a method to overcome this limitation by developing a mechanical slider projector. The mechanical projector, conventionally, used as an encoder for closed-loop control systems, is employed here because of its availability and affordability. The rapidly spinning disk with binary structures, blocking light (OFF) or passing light (ON), can generate rapidly changing light at a frequency of 10 kHz or higher with a single DC motor. The binary structured pattern passing through the projector is then collected by a lens and projected onto the object. By precisely synchronizing the camera with the projector, phase-shifted fringe patterns can be accurately captured, and phase-shifting algorithms can then be applied for 3D shape reconstruction. This paper will examine the accuracy of using such a mechanical projector and a single camera for high-speed shape measurement.

10220-4, Session 1

Large dynamic 3D measurement in high resolution and high accuracy using structured light system

Yatong An, Song Zhang, Purdue Univ. (United States)

Large dynamic 3D measurement is of great interests in many fields. In past years, many methods have been developed including stereo vision, laser triangulation, time of flight (e.g., Microsoft Kinect 2), structured light (e.g., Intel RealSense) and shape from focus/defocus. According to whether requiring active illumination or not, those methods can be classified into passive ones (e.g., stereo vision) and active ones (structured light, laser triangulation etc.). Passive methods can work well if an object has rich texture, but their accuracy will be comprised for uniform surface or low texture variations. Active methods are less sensitive to object surface properties. Among active methods, structured light methods becomes more and more popular because of its high resolution, high accuracy and fast speed. However, this method is only typically used in close or small range measurement. Its potential in large dynamic 3D measurement has not been fully explored yet. Due to the advancements of easy-to-use calibration methods, using the structured light system for accurate large dynamic 3D measurement becomes more and more practical and feasible. This paper will adopt recent developed calibration methods and explore the application of structured light system to large scale dynamic 3D measurement. Furthermore, other relevant questions including color texture mapping, motion artifact reduction, will be also explored. This paper will conduct a comparison with other state-of-the-art 3D measurement methods, and evaluate the resolution, accuracy and speed of different large dynamic 3D measurement methods.

10220-5, Session 1

Design and implementation of an electronic system to real-time capture and processing speckle interference patterns

Antonio Barcelata-Pinzón, Cruz Meneses-Fabian, Benemérita Univ. Autónoma de Puebla (Mexico); Rigoberto Juarez-Salazar, Instituto Politécnico Nacional (Mexico); Javier Andrey Moreno Guzmán, Univ. Tecnológica de Puebla (Mexico); Manuel Durán-Sánchez, Ricardo Iván Álvarez-Tamayo, Instituto Nacional de Astrofísica Óptica y Electrónica (Mexico); Carlos Rangel-Romero, Univ. Tecnológica de Puebla (Mexico); Carlos Ignacio Robledo-Sánchez, Benemérita Univ. Autónoma de Puebla (Mexico)

The design and implementation of an electronic system to real-time capture and processing speckle interference patterns is presented. Because of the random and instability speckle patterns nature, is very useful a system wich allows obtaining and visualizing interference patterns in the shortest time possible. Proposed system captures the first speckle pattern as steady image while captures subsequent patterns from the same source. Images are electronically transformed separately into value arrays and subtracted to obtain real-time interference speckle patterns, these patterns are automatically archived for later analysis. System consist of a CCD camera, a computer interface that makes capturing and a transparent objects 4f interferometric system whose source is a laser that passes through diffuser glass in order to obtain speckle effect. Experimental result and analytic explanation is showed bellow.

10220-6, Session 2

Wavelength dependency of optical 3D measurements at translucent objects using fringe pattern projection

Chen Zhang, Maik Rosenberger, Andreas Breitbarth, Gunther Notni, Technische Univ. Ilmenau (Germany)

In optical 3D measurements based on active triangulation with structured light it is generally assumed that the object features a non-transparent Lambertian surface. However, this requirement cannot be satisfied in many applications, e.g. measurements at objects with translucency. In this case, the light penetrates into the subsurface and is scattered in the objects volume, what causes a blurring effect of projected patterns on the object surface and angle dependant camera observation errors by pattern decoding. As a result, there arise systematic errors and a higher probability of artifacts in the correlation of image coordinates, which lead to systematic measurement errors and a minor measurement stability.

At translucent objects, the wavelength of light has an impact on the surface reflection behavior, the material refractive index and the light penetration depth. Hence, there is a wavelength dependancy of the surface scattering behavior, and consequently of the pattern blurring and decoding error. In this work, the influence of wavelength on 3D

measurements was investigated at a stereoscopic system using fringe pattern projection. The experimental setup consists of two filter wheel cameras with narrowband optical bandpass filters in 25 nm FWHM and a GOBO projector with wide-band light source. It is ensured with an exposure time adjustment that all measurements were performed under the same conditions. The first experimental results at a plastic hemisphere with 450, 525 and 625 nm wavelength show a decrease of the measured diameter for major wavelengths and an increase of the standard deviation of sphere reconstruction.

10220-7, Session 2

Influence of the measurement object's reflective properties on the accuracy of array projection-based 3D sensors

Stefan Heist, Peter Kühmstedt, Gunther Notni, Fraunhofer-Institut für Angewandte Optik und Feinmechanik (Germany)

Increasing the measurement speed of 3-D sensors that are based on the structured-light technique has become one of the main tasks in the field of optical metrology. As high-speed cameras are commercially available, this includes, in particular, the development of high-speed pattern projectors.

In 2014, we introduced the so-called array projector which allows pattern projection at several 1,000 fps. In contrast to conventional projectors like DLP projectors, the array projector does not realize pattern switching by changing the image generator of one single-aperture projector, but by switching on and off the light sources of multiple slide projectors. When using LEDs, switching times of 100 μs or less can be achieved.

However, as each pattern originates from a different projection center, a new difficulty arises: When measuring glossy objects, the ratio of the intensities detected by the stereo camera pair at a certain object point may slightly vary from pattern to pattern. Hence, subpixel correlation can yield slightly shifted corresponding points.

In this contribution, we theoretically investigate the resulting 3-D point deviation by simulating the measurement of an object with varying BRDF. Furthermore, we propose a procedure for compensating for this deviation. Finally, we experimentally verify the theoretical results by means of two identical plane objects with different, previously determined BRDF.

10220-8, Session 2

Absolute phase unwrapping for dual-camera system without embedding statistical features

Chufan Jiang, Song Zhang, Purdue Univ. (United States)

Phase unwrapping has always been a challenging problem in phase-based 3D shape measurement technologies. Existing phase unwrapping algorithms are generally divided into two categories: spatial and temporal phase unwrapping. A Spatial unwrapping algorithm can only produce relative phase maps because it refers to the phase value of a pixel. A temporal phase unwrapping algorithm produces absolute phase maps by acquiring additional fringe images, yet it is at the cost of reducing the measurement speed. To avoid acquiring additional images, researchers add the second camera to assist in phase unwrapping. The idea is that the wrapped phase value from two cameras should be the same. By combining epipolar geometry constraints, the number of candidates is limited. Because a global backward and forward checking is required for finally selecting the correct corresponding point out of all candidates, the computation speed is slow. An alternative approach is to speed up the searching by embedding statistical patterns into original fringe patterns. While the correspondence refinement process is still very slow. This paper proposes an absolute phase unwrapping algorithm that addresses these problems from two camera approaches. The first step is to calibrate all three devices including both cameras and the projector. Then the rough pixel matching is performed by a standard stereo matching algorithm to provide additional constraints. Given all these constraints, a rough absolute phase map in projector space can be obtained for phase unwrapping. Experimental results will be provided to demonstrate the performance of the proposed method.

10220-9, Session 2

Consideration of the impact of imaging technique on the efficacy of 3D printing quality assessment

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

Visible light sensing-based quality assessment has been previously proposed for identifying prospective defects in 3D printed objects. The proposed technique focused on detecting, identifying and making decisions upon the identification of discrepancies between a captured image and an ideal one. In real world operations, however, a number of considerations impair a simple comparison being used to identify discrepancies between images. Among these are background changes, lighting issues, movement of parts of the 3D printer itself and the techniques used for collecting the images that are used for comparison purposes. This paper focuses, in particular, on this last point (while considering, briefly, all of the others as well – particularly in conjunction with the imaging technique question).

Several different approaches to imaging of the object can be undertaken. These can include techniques that require moving the camera, moving the object on the build plate or having a printer designed to print the object on a non-moving platform (while the print head is moved for all three axes of movement). Many printers have the print head move for only two of the axes of movement; only a limited number support a stationary object. This stationary approach is compared to prior work imaging an object where the build plate returned to an imaging position and the approach where the camera moves to keep a consistent perspective with regards to the object being printed. The results from the different approaches are assessed and conclusions are drawn.

10220-10, Session 2

Measuring optical phase digitally in coherent metrology systems

Damien P. Kelly, Technische Univ. Ilmenau (Germany); James P. Ryle, John T. Sheridan, Univ. College Dublin (Ireland)

The accurate measurement of optical phase has many applications in metrology. For biological samples, which appear transparent, the phase data provides information about the refractive index of the sample. In speckle metrology, the phase can be used to estimate stress and strains of a rough surface with high sensitivity. In this theoretical manuscript we compare and contrast the properties of two techniques for estimating the phase distribution of a wavefield under the paraxial approximation: (I) A digital holographic system, and (II) An idealized phase retrieval system. Both systems use a CCD or CMOS array to measure the intensities of the wavefields that are reflected from or transmitted through the sample of interest. This introduces a numerical aspect to the problem. For the two systems above we examine how numerical calculations can limit the performance of these systems leading to a near-infinite number of possible solutions.

10220-11, Session 3

Visual servoing based on fringe pattern projection *(Invited Paper)*

Jing Xu, Rui Chen, Tsinghua Univ. (China)

In the traditional stereo visual servoing methods, the positions of features in the two cameras are obtained by feature extraction and matching, which costs large calculation amount, leading to low real-time control capability. Moreover, the feature extraction depends on environment illumination and target texture, resulting in low reliability. To this end, a stereo visual servoing method based on fringe pattern is proposed in this paper, where the positions of features are obtained by pattern decoding, which reduces the calculation amount and enhances feature extraction reliability, allowing for real-time control capability. The proposed visual servoing system is composed of a camera and a projector, instead of two cameras, where the relative position between the camera and projector is obtained through system calibration. In the proposed method, firstly, the series of coded fringe patterns are shot to the target by the projector, and reflected deformed patterns are captured by the camera; secondly, the decoded phase map is obtained by using dual-frequency phase shift method, which contains the coordinate information of both the camera and the projector; thirdly, the features of the object are detected from the phase map, where the phase intensity changes dramatically due to the 3D shape of the object, by using image processing algorithm; finally, the robot is controlled to move from the initial to goal configuration by using the coordinate information of features. The validity of the proposed method is demonstrated through computer simulations and real experiments.

10220-12, Session 3

Accurate 3D fingerprint reconstruction using optical and digital aberration compensation in a digital holographic system

Thanh C. Nguyen, The Catholic Univ. of America (United States); Ujitha A. Abeywickrema, Univ. of Dayton (United States); Georges Nehmetallah, The Catholic Univ. of America (United States); Partha P. Banerjee, Univ. of Dayton (United States); Akhlesh Lakhtakia, Stephen E. Swiontek, The Pennsylvania State Univ. (United States)

Fingerprint identification and analysis is extremely important in law enforcement and security, including commercial applications such as in smartphones. The 3D reconstruction of a fingerprint hologram can reveal detailed information about every ridge, pore, and minutiae that is unique to a certain finger. We propose optical and digital automatic phase aberration compensation techniques for accurate 3D reconstruction of fingerprint holograms recorded using a multi-wavelength digital holographic system. This recording configuration compensates for most of the parabolic phase distortion due to the microscope objective and the phase tilt due to the reference beam. The digital techniques use Zernike polynomials and/or principal component analysis to enhance the visibility of the reconstructed hologram and to cancel chromatic and higher order aberrations. These methods are fully automatic and do not require knowledge of the object or the optical setup. Experimental results employing 3D fingerprints visualized using columnar thin-film coatings and imprints are also presented. Finally, the analysis of 3D fingerprints could help in improving both optical sensor manufacturing and 3D fingerprint matching algorithms which lead to improvements in security.

10220-13, Session 3

Optimized measurement of gaps

Kevin G. Harding, Rajesh Ramamurthy, GE Global Research (United States)

Gaps are important in a wide range of measurements in manufacturing, from the fitting of critical assemblies to cosmetic features on cars. There are a variety of potential sensors that can measure a gap opening, each with aspects of gap measurements that they do well and other aspects where the technology may lack capability. This paper provides a review of a wide range of optical gages from structured light to passive systems and from line to area measurement. The technologies reviewed include triangulation line sensors, stereo viewing, chromatic confocal and phase shifting 3D methods. Each technology is considered relative to the ability to accurately measure a gap, including issues of edge effects, edge shape, surface finish, and transparency. Finally, an approach will be presented to creating an optimize measurement of gap openings for critical assembly applications.

10220-14, Session 3

Temporal speckle correlations for optical alignment

Florian Schurig, Damien P. Kelly, Technische Univ. Ilmenau (Germany)

It is possible to use of 3D lateral and longitudinal static speckle fields to determine the lateral location of the optical axis in a system. In this manuscript we examine a variation of this idea where we use the 3D temporal correlation properties of multiple speckle fields to perform the same task. The characteristics of both approaches are contrasted, experimental results are compared with the theoretical predictions and we present some conclusions.

10220-15, Session 4

On-machine metrology system

Hsiang Nan Cheng, Katherine Overend, Yu Zhang, Rongguang Liang, College of Optical Sciences, The Univ. of Arizona (United States)

Diamond turning is the powerful fabrication method for optics. Current process is very time consuming due to the lack of on-machine metrology. In this talk, we will first discuss the challenges and requirement of in-situ metrology, then we will present chromatic confocal on-machine metrology system developed in our lab and demonstrate its performance.

10220-16, Session 4

Assessing the quality of 3D printing: combining difference-based and structural similarity metrics

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

Quality assessment for 3D printing is an area of growing interest, due to the dramatic growth in the deployment and use of 3D printers, worldwide. While several process-based efforts have been commercially implemented, these approaches fail to provide a holistic picture of the quality of the object being produced. For safety- or mission-critical parts, process assurance (which doesn't fully assure the product being produced) falls short of requirements.

The potential for printers to be deployed to point-of-sale locations (the UPS Store, for example, currently make 3D printing available in some locations)

for customized object printing or the sale of mass-customization-based products heightens the need for automated quality assurance. A retail clerk, typically, is not trained in in-depth quality control techniques and may be frequently distracted by the environment and the demands of his or her job, resulting in prospective quality lapses.

Okarma, Fastowicz and Teclaw proposed the use of structural similarity-based techniques to perform an untrained and object-unaware quality control process. Under this approach, it is presumed that the object has repeating common elements. Departures from homogeneity may represent quality issues. The author of this paper has performed related prior work using difference-detection based techniques, where a model of the object and the produced object are compared. This paper combines the structural similarity techniques and difference detection-based techniques. It compares the combined algorithm to the use of the techniques independently. These results are analyzed before the paper concludes with a discussion of the next steps in 3D printing quality control.

10220-17, Session 4

Dimensional metrology for printed electronics

Vadim Bromberg, Kevin G. Harding, GE Global Research (United States)

Novel materials and printing technologies can enable rapid and low cost prototyping and manufacturing of electronic devices with increased flexibility and complexity. However, robust and on-demand printing of circuits will require accurate metrology methods that can measure micron level patterns to verify proper production. This paper presents an evaluation of a range of optical gaging tools ranging from confocal to area 3D systems to determine metrological capability for a range of key parameters from trace thickness to solder paste volumes. Finally, this paper will present a select set of optimized measurement tools detailing both capabilities and gaps in the available technologies needed to fully realize the potential of printed electronics

10220-18, Session 4

Measurement of material thickness in the presence of a protective film

Rajesh Ramamurthy, Kevin G. Harding, GE Global Research (United States)

Many sheet products from plastic to structural composites are produce in tightly controlled thickness needed for functional applications. There are many methods that have been used to measure such sheeting from mechanical rollers to optical micrometers. However, many materials are produced with a thin protective film on either side that may not have critical dimensional controls. This paper addresses the challenge of measuring sheet products to critical thickness values in the presence of protective plastic films using high speed optical gaging methods. For this application, the protective films are assumed to be transparent though not necessarily scatter free, and have thickness variations that are comparable to the tolerances of the sheet product. We will examine the pros and cons of a number of different optical measurement methods in light of resolution, speed and robustness to the film thickness variation and present an approach able to address the desired sheet measurement tolerances.

10220-19, Session 4

Physical security and cyber security issues and human error prevention for 3D printed objects: detecting the use of an incorrect printing material

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

A wide variety of characteristics of 3D printed objects have been linked to impaired structural integrity and efficacy for various uses. These have included object printing orientation, the presence of defects (of various sizes) and introduced design changes. The material used for printing can also have a significant impact on the quality, utility and safety characteristics of a 3D printed object. Material issues can be created by vendor issues (e.g., material fabrication issues, labeling issues and picking issues), physical security issues and human error. Material selection, for a printer having material selection automation, can also represent a target for cyber attackers, as well. Job requirements metadata could also be changed (even absent automation), leading to the use of an incorrect material.

The automated detection of the use of incorrect material can save money on rework and prevent object failure mishaps, among other potential problems. This paper, thus, presents and evaluates a system that can be used to detect the use of an incorrect material in a 3D printer, using visible light imaging. Specifically, it assesses the ability to ascertain the difference between different color materials, for a printed object, as well as materials of different types with similar coloration. The impact of lighting on material correlation identification and the use (and juxtaposition) of imagery collected under multiple lighting conditions for comparison is also considered. The paper discusses the prospective uses for this system in at point of sale 3D printers and in large-scale manufacturing facilities, among other uses, before concluding.

10220-20, Session 4

A microscope automatic image fusion system for unregistered multi-focus images with sensor focusing technique

Yunzhi Yu, The Univ. of Southern California (United States); Haiyang Zhou, Zhejiang Univ. (China)

An image with all depth objects in focus is desired for microscope application. The multi-focus image fusion technique provides a promising way to extend the thick pathological section depth of defocused images by combining multiple images with diverse focuses into a single focused one. The conventional method is to rotate the microscope fine focusing knob with the connected electrically controlled motor. Different microscopes will need different connection mechanics. These will need the high precision control and increase the system complexity with no common applications.

In this paper, a new method is proposed to overcome this difficulty. Through the careful calculation, a sensor plane movable camera is designed. The camera then is connected to the microscope camera adapter to get the proper focused image. Through the movement of the image sensor, different tissue plane images are captured. Because of the magnification effect, the movement accuracy requirement is decreased, but the captured images may have different levels of scales, translations and rotations.

To fuse these captured images, we present a robust and automated algorithm including image registration based on phase correlation and image fusion based on an improved fast Fourier transform and synthesis in the space domain (FFDSSD) algorithm. After registration, fast Fourier transform and image content adaptive Gaussian low-pass filter are applied for accurate clarity determination. Finally, a weighting combination scheme consisted of divergence and clarity factors, and a noise clipping model is used to choose the pixels from these captured images and reconstruct the final fused image.

The experimental results prove that the proposed system achieves better

performance on extending the depth-of-field, and it is especially robust to scale, rotation and translation compared with traditional direct fusion method.

10220-24, Session 4

Dimensional metrology of micro structure based on modulation depth in scanning broadband light interferometry

Yi Zhou, Yan Tang, Qinyuan Deng, Lixin Zhao, Song Hu, Institute of Optics and Electronics (China)

Dimensional metrology for micro structure plays an important role in many science and industrial applications, such as integrated circuits (IC), medical cure, and chemistry. Broadband light interferometry is widely utilized in topography measurement due to its large measurement range, noncontact and high precision. In this paper, we propose a spatial modulation depth-based method to reshape the surface topography through analyzing the characteristics of both frequency and spatial domains in the interferogram. Due to the characteristics of spatial modulation depth, the method could effectively suppress the negative influences caused by light fluctuations and external disturbance. Both theory and experiments are elaborated to confirm that the proposed method can greatly improve the measurement stability and sensitivity with high precision. This technique can achieve a superior robustness with the potential to be applied in online topography measurement.

10221-1, Session 1

State-space based modeling for imaging system identification

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

State-space (SS) based modeling for imaging electro-optical (EO) systems representing various states facilitates a method for system estimation. Traditionally linear shift-invariant (LSI) systems are modeled using Fourier analysis (FA). However models based on FA may introduce stability issues over the SS based models. In this paper, we introduce three methods to estimate system parameters for LSI EO imaging system using SS based modeling. These methods include batch processing version of least squares (LS) estimation, recursive version of LS estimation, and sliding window LS estimation. The accuracy of the developed methods was tested using input and output signals of simulated LSI systems. First, LSI systems with various system parameters (poles and zeros) were simulated, which were then used to generate output signals for a set of random input signals, with each input signal value representing the average of an image. Then, these input and output signals were used to estimate system employing SS and FA based modeling. Further, the estimated systems were used to generate output signals for a new set of input signals. For any given input signal, output signals generated by both systems were compared for similarities and signal-to-noise ratio (SNR). Results show that SS based models generate output signals that have higher SNR values. In addition, developed methods were tested against the simulated data and results show promise for development of models for estimating more complicated systems (e.g., non-linear system).

10221-2, Session 1

Race classification from face images using fusion technique of fast Fourier transform (FFT) and discrete cosine transform (DCT)

Hawkar Ahmed, Univ. of Sulaimani (Iraq)

Race Classification from Face Images using Fusion Technique of Fast Fourier Transform (FFT) and Discrete Cosine Transform (DCT)

Abstract

Ethnicity identification and recognition is a key biometric technology with a wide range of applications related to homeland security, safety, access control, and automatic annotation. In this paper, we propose a method in multi-level fusion schema for ethnicity identification by using two global features fast Fourier transform (FFT) and discrete cosine transform (DCT) on the pre-processed face image of size 128 * 128 in YCbCr color space. A database is consisting of 750 face image of three different ethnicities (Kurd 300, Oriental 300 and African 150). The query image feature is compared with a database image features using k – nearest neighbor classifier using City block distance for evaluating similarity measurement. The experimental result shows good accuracy and demonstrate the effectiveness of the combined features. On our database 96.22% of classification accuracy was obtained.

10221-3, Session 1

Data independent dimensionality reduction for pattern recognition using Hadamard submatrices

Tahir Hassan, The Univ. of Buckingham (United Kingdom); Abdulbasit Al-Talabani, Koya Univ. (Iraq); Azhin T. Sabir, Nadia Al-Hassan, Sabah Jassim, The Univ. of Buckingham (United Kingdom)

Random projection is a powerful dimensionality reduction tool. However, designing a desirable random projection matrix P for pattern recognition applications relies on achieving high probability of preserving distances within a tolerable error. In this paper, we focus on projection matrices that are independent of application sampled data. In particular, we test the performance of differently constructed over-complete Hadamard mxn (m<<n) submatrices, using Sylvester and Walsh-Paley methods, for certain pattern recognition applications. We shall demonstrate that these matrices perform as well, if not better, dataset dependent dimensionality reduction techniques. Moreover, we shall show that by sampling the top rows of Walsh Paley matrices outperform matrices constructed more randomly. Our experiments cover 3 different Pattern recognition applications: human gait recognition, Emotion recognition from speech, and face recognition.

10221-4, Session 1

Fast and accurate face recognition based on image compression

Yufeng Zheng, Alcorn State Univ. (United States)

Image compression is greatly desired for many image-related applications especially for online applications. The body of literatures reported the effect of image compression on face recognition. The wavelet-based face recognition methods such as EBGM (elastic bunch graph matching) and FPB (face pattern bye) are of high performance but run slowly due to their high computation demands. The PCA and LDA algorithms run fast but perform poorly in face recognition. In this paper, we propose a novel face recognition method based on standard image compression algorithm, which is both accurate and fast. First both probe and gallery images are compressed by the selected compression algorithm and compute their compression ratios. Second a mixed image is formed with both probe and gallery images then compressed. Third a composite compression ratio (CCR) is computed with three compression ratios from: probe, gallery and mixed images. Finally compare the CCR values and the smallest CCR corresponds to the matched face. The time cost of each face matching is about the time of compressing a face image. We initially tested the proposed method on the “ASUDC face database” (visible images) from 96 subjects. The face recognition accuracy is 100% by using 90% of image quality (IQ) compressed with JEPG algorithm. On the same JPEG dataset (of 100% IQ), the accuracies of two wavelet algorithms were reported as: FPB = 97.92%, EBGM = 93.75%. More extensive research and comparisons will be conducted and presented in the full paper.

10221-5, Session 1

Autonomous facial recognition based on human visual system-based image quality measure

Qianwen Wan, Karen Panetta, Tufts Univ. (United States); Sos S. Agaian, The Univ. of Texas at San Antonio (United States)

In the past several decades autonomous facial recognition system has been considered as one of the high priority topics and is most widely applied in identification and authentication. This is because human faces can be easily captured by any imaging sensors or surveillance devices. Some of the most concerned challenges of a real-time facial recognition system are the image quality, the illumination problem, the pose variation and the facial

expressions. The contributions of this research paper are: a) human visual systembased image quality measure is for the first time introduced as a feature extraction concept for facial recognition system due to its efficiency, robustness and low-cost; b) a novel automatic facial recognition system utilizing our human visual system based image quality measures coupled with Logical Binary Pattern feature descriptors and our region weighted model is presented. Three widely used facial image databases such as Yale, ATT and FERET databases are used for prototype systemaccuracy and efficacy testing. We believe our proposed system has many potential applications for law enforcement, homeland security.

10221-6, Session 1

Pattern recognition algorithm using descriptors combined infrared and visible spectra

Vyacheslav V. Voronin, Vladimir I. Marchuk, Don State Technical Univ. (Russian Federation)

Recent advances in imaging technologies have increased the usage of cameras working at different spectral bands (e.g infrared and visible). Novel solutions to classical problem of pattern recognition allow to improve the results that can be obtained when we consider combination of images in infrared and visible spectra. Extraction of information from multispectral images is a complex task, mainly due to the manifold combinations of surface materials and the diversity of size, shape and placement of the objects composing a typical image scene. Interest point detectors or descriptors are the basis of many applications within pattern recognition. This manuscript evaluates the behavior of classical feature point descriptors when they are used in images from infrared spectral band, compare them with the results obtained in the visible spectrum and their combination. We analyze proposed descriptor to robustness to changes in rotation and scaling. Experimental results using a cross-spectral image data set are presented. Proposed descriptor provides effectiveness for recognition images in infrared and visible spectra.

10221-8, Session 2

Automatic pelvis segmentation from x-ray images of a mouse model

Omar Al Okashi, Hisham Al-Assam, Hongbo Du, The Univ. of Buckingham (United Kingdom)

The automatic detection and quantification of skeletal structures has a variety of different applications for biological research. Accurate segmentation of the pelvis from X-ray images of mice in a high-thoughput project such as the Mouse Genomes Project not only saves time and cost but also helps achieving an unbiased quantitative analysis within the phenotyping pipeline. This paper proposes an automatic solution for pelvis segmentation based on structural and orientation properties of the pelvis in X-ray images. The solution consists of three stages including preprocessing image to extract pelvis area, initial pelvis mask preperation and final pelvis segmentation. Experimental results on a set of 100 X-ray images showed consistent performance of the algorithm. The automated solution overcomes the weaknesses of a manual annotation procedure where intra- and inter-observer variations cannot be avoided.

10221-9, Session 2

Computer Aided solution for accurate segmentation of the Region of Interest in Hippocampal microscope images in relation Alzheimer's disease

Tahseen Albaidhani, Hisham Al-Assam, Sabah Jassim, The Univ. of Buckingham (United Kingdom)

The brain Hippocampus component is responsible for memory and spatial navigation. Its functionality depends on the activities of different blood vessels within it, and is severely impaired by Alzheimer's disease as a result blockage of increasing number of blood vessels by access of amyloid-beta (A?) protein. Evaluating the number of functioning vessels within the Hippocampus of mice brain, from microscopic images, is an active high throughput research task for the understanding of Alzheimer. In this paper we report on our work on automatic detection of the ROI, i.e. region were the blood vessels are located, between the border and the line of neurons within the Hippocampus. Our solution is based on a Trainable segmentation approach, Morphological operations based on variation in colour and intensity values, and Texture values. Experimental results on a sufficiently large number of images demonstrate the effectiveness of the developed solution in preparation of vessel counting.

10221-10, Session 2

Medical image segmentation using 3D MRA data

Vyacheslav V. Voronin, Vladimir I. Marchuk, Evgeny A. Semenishchev, Don State Technical Univ. (Russian Federation); Sos S. Agaian, The Univ. of Texas at San Antonio (United States)

Precise segmentation of three-dimensional (3D) magnetic resonance angiography (MRA) image can be a very useful computer aided diagnosis (CAD) tool in clinical routines. Accurate automatic extraction a 3D component from images obtained by magnetic resonance angiography (MRA) is a challenging segmentation problem due to the small size objects of interest (e.g., blood vessels, bones) in each 2D MRA slice and complex surrounding anatomical structures. Our objective is to develop a specific segmentation scheme for accurately extracting parts of bones from MRA images. In this paper, we use a segmentation algorithm to extract the parts of bones from Magnetic Resonance Angiography (MRA) data sets based on modified active contour method. We propose a robust tool for segmentation of medical images instead 2D model-based methods. Currently the using of three-dimensional models, primarily made possible by breakthroughs in automatic detection of shape correspondences. We show that due to the multimodal nature of MRA data, blood vessels, bones can be accurately separated from the background in each slice using a voxel-wise classification based on precisely identified probability models of voxel intensities. As a result, the proposed method demonstrates good accuracy in a comparison between the 2D and 3D segmentation approaches on real and simulated MRA data. We conclude with a survey of applications in the medical field and a discussion of future developments in 3D printing.

10221-11, Session 2

Trainable segmentation of multilocular cysts based on local basic pixel features

Dheyaa Ahmed Ibrahim, Sabah Jassim, Hongbo Du, Hisham Al Assam, The Univ. of Buckingham (United Kingdom)

Ultrasound imagery has been widely used for ovarian tumour diagnoses.

Ultrasound scanning is safe and non-intrusive; thus, it is repeatedly used to discriminate between various types of ovarian tumour such as benign from malignant. However, the size and number of cysts are good indicators to discriminates benign from malignant and even the subtypes of them. This is typically done by counting the number of cysts and measuring their size manually. This task involves multiple subjective decisions, which might lead to inaccurate diagnosis. Therefore, computer- based systems need to be developed to help radiologists to analyse ovarian ultrasound images and identify various types of tumours. This paper proposes a new approach to automatically segment and extract a loculary of the cyst from static B-mode ultrasound images by exploiting image texture features. A trainable segmentation based on Two-class machine learning is proposed to learn the actual distribution of image features without prior knowledge. The segmentation task is then performed by the trained classifier followed by filtering unwanted objects based on morphology operations. We evaluated the effectiveness of the proposed solution by comparing the automatic size measurements and a number of the segmented cyst against the manual measurements

10221-12, Session 3

Detection of chaotic dynamics in human gait signals from mobile devices *(Invited Paper)*

Stephen P. DelMarco, Yunbin Deng, BAE Systems (United States)

The ubiquity of mobile devices offers the opportunity to exploit device-generated signal data for biometric identification, health monitoring, and activity recognition. In particular, mobile devices contain an Inertial Measurement Unit (IMU) that produces acceleration and rotational rate information from the IMU accelerometers and gyros. These signals reflect motion properties of the human carrier. It is well-known that the complexity of bio-dynamical systems gives rise to chaotic dynamics. Knowledge of chaotic properties of these systems has shown utility, for example, in detecting abnormal medical conditions and neurological disorders. Chaotic dynamics has been found, in the lab, in bio-dynamical systems data such as electrocardiogram (heart), electroencephalogram (brain), and gait data. In this paper, we investigate the following question: can we detect chaotic dynamics in human gait as measured by IMU acceleration and gyro data from mobile phones? To detect chaotic dynamics, we perform recurrence analysis on real gyro and accelerometer signal data obtained from mobile devices. We apply the delay coordinate embedding approach from Takens' theorem to reconstruct the phase space trajectory of the multi-dimensional gait dynamical system. We use mutual information properties of the signal to estimate the appropriate delay value, and the false nearest neighbor approach to determine the phase space embedding dimension. We use a correlation dimension-based approach to make the chaotic dynamics detection decision. We investigate the ability to detect chaotic dynamics for the different one-dimensional IMU signals, across human subject and walking modes, and as a function of different phone locations on the human carrier.

10221-13, Session 3

3D indoor scene reconstruction and change detection for robotic sensing and navigation

Ruixu Liu, Univ. of Dayton (United States)

A new methodology for 3D scene reconstruction for scene change detection, which can support e?ective robot sensing and navigation in an indoor environment, is presented in this paper. We register the RGB-D images acquired with an untracked camera into a globally consistent and accurate point cloud model. This word introduces a robust system that detects camera position for multiple RGB video frames by using a modified structure from motion (SFM) algorithm. A cross bilateral filter smooths the surface and fills the holes as well as keeps the edge details on depth image. Utilizing iterative closest point (ICP) algorithm to establish geometric constraints between the point cloud as they become aligned. For the change detection part, we use 2D corresponding points in 2D key frames to match the current frame with the previous frames. Then combining key frame translation and ICP to align the current point cloud with reconstructed 3D scene. Meanwhile, camera position and orientation are used to aid robot navigation. After preprocessing the data, we create a Staggered Voxels Model to detect the scene change measurements. The experimental evaluations performed to evaluate the capability of our algorithm show the robot's location and orientation accurately and provide promising results for novel change detection indicating all the object changes with very limited false alarm rate.

10221-14, Session 3

Visible spectrum-based non-contact HRV and dPTT for stress detection *(Invited Paper)*

Balvinder Kaur, J. Andrew Hutchinson, U.S. Army Night Vision & Electronic Sensors Directorate (United States); Vasiliki Ikonomidou, George Mason Univ. (United States)

ABSTRACT

Stress is a major health concern that not only compromises our quality of life, but also affects our physical health and well-being. Despite its importance, our ability to objectively detect and quantify it in a real-time, non-invasive manner is very limited. This capability would have a wide variety of medical, military, and security applications. We have developed a pipeline of image and signal processing algorithms to make such a system practical, which includes remote cardiac pulse detection based on visible spectrum videos and physiological stress detection based on the variability in the remotely detected cardiac signals. First, to determine a reliable cardiac pulse, principal component analysis (PCA) was applied for noise reduction and independent component analysis (ICA) was applied for source selection. Then to determine accurate cardiac timings for heart rate variability (HRV) analysis, a blind source separation method based lease squares (LS) estimate was used to determine signal peaks that were closely related to R-peaks of electrocardiogram (ECG) signal. In addition, a new metric called differential pulse transit time (dPTT), defined as the difference in arrival time of remotely acquired cardiac signal at two separate distal locations, was derived. Further, it was demonstrated that the remotely acquired metrics, HRV and dPTT, have potentials for remote stress detection. The developed algorithms were tested against human subject data collected under two physiological conditions using the modified Trier Social Stress Test (TSST) and the Affective Stress Response Test (ASRT). This research provides an evidence that the variability in remotely-acquired BW signals can be used for stress (high and mild) detection and a guide for further development of a real-time remote stress detection system based on remote HRV and dPTT.

10221-15, Session 3

Automatic Identification of ovarian tumours using B-mode ultrasound images: classified mature teratomas from other types of benign tumours

Dhurgham Al-karawi, Sabah Jassim, Hisham Al-assam, Hongbo Du, The Univ. of Buckingham (United Kingdom)

Developing ovarian cysts is very common in women of all ages with 5-10% of cases are in need for surgical intervention to remove the cyst. Accurate characterization of ovarian masses is essential for optimal management of the condition. Patients with benign ovarian masses can be managed

conservatively if they are asymptomatic. Mature teratomas are common benign ovarian cysts that occur in premenopausal women in most of the cases. If they are causing no symptoms, they can be harmless and may need no surgery. The aim of this study is to develop a computerized technique to characterize mature teratomas from other types of benign ovarian tumours from ultrasound images. Following the pre-processing phase whereby images were enhanced via different steps, Histogram of Oriented Gradient (HOG) are used to represent texture features which we shall establish to be specific in distinguishing teratomas when Neural Networks (NN) are used as a classifier. A sample dataset of 130 B-mode static ovarian ultrasound images (41 mature teratoma tumour and 89 other types of benign tumours) was used to test the effectiveness of the proposed technique. Test results have shown an average accuracy rate of 98.63% with a sensitivity of 100% and specificity of 97.61%. This study demonstrates the effectiveness of using texture-based image features can provide reliable discriminating models of different types of ovariatin tumours from static 2D B-mode ultrasound images.

10221-16, Session 3

Automatic quantification of epidermis curvature in H&E stained microscopic skin image of mice

Saif Hussein, The Univ. of Buckingham (United Kingdom)

Changes in the curvature of the epidermis layer is often associated with many skin disorders, such as ichthyoses and generic effects of ageing. Therefore, methods to quantify changes in the curvature are of a scientific and clinical interest. Manual methods to determine curvature are both laborious and intractable to large scale investigations but specific computational methods are not currently available.

This work documents an automatic algorithm to quantify curvature of microscope images of H&E-stained murine skin. The algorithm can be divided into three steps. Firstly, color deconvolution has been used to separate image into three channels equivalent to the actual colors used. This allows the algorithm to accurately measure the area for each stain separately. Secondly, the segmentation algorithm divides an image into multiple layers, namely epidermis, dermis and subcutaneous layer. The algorithm then identifies the cornified epidermis sub-layer by filtering the cornified mask. Finally, the measurements of curvature of epidermis layer are used to find the interesting genes.

10221-17, Session 4

Privacy of audio-visual documents for cloud services: challenges and potential approaches *(Invited Paper)*

Sabah Jassim, The Univ. of Buckingham (United Kingdom)

No Abstract Available

10221-18, Session 4

Topological image texture analysis for quality assessment *(Invited Paper)*

Aras Asaad, The Univ. of Buckingham (United Kingdom); Rasber Dh. Rashid, Koya Univ. (Iraq); Sabah Jassim, The Univ. of Buckingham (United Kingdom)

Image quality is a major factor influencing pattern recognition accuracy and help detect image tampering for forensics. We are concerned with investigating topological image texture analysis techniques to assess different type of degradation. We use Local Binary Pattern (LBP) as a texture feature descriptor. For any image construct simplicial complexes for selected groups of uniform LBP bins and calculate persistent homology invariants (e.g. number of connected components). We investigated image quality discriminating characteristics of these simplicial complexes by computing these models for a large dataset of face images that are affected by the presence of shadows as a result of variation in illumination conditions. Our tests demonstrate that for specific uniform LBP patterns, the number of connected component not only distinguish between different level of shadow effects but also help detect the infected regions. We shall also present the result of our experiments on the effect of image blurring.

10221-19, Session 4

Key exchange for biometric-based encryption (KE-BIOIBE) in the cloud computing

Waleed K. Hassan, Hisham Al-Assam, Sabah Jassim, The Univ. of Buckingham (United Kingdom)

The main problem associated with using symmetric keys/asymmetric key is how to securely exchange the key between the parties over open networks particularly in the open environment of the cloud. Currently, available key exchange protocols depend on using trusted couriers or secure channels. Diffie-Hellman is one of most convenient protocol for key exchange. In its general form, DH is secure against eavesdropping but not secure against man-in-the-middle attacks. Existing solutions to overcome the man-in-the-middle attack incorporate authentication of two trusted parties, which cannot be adopted in the cloud due to the absence of an agreeable trust model in the cloud. Our proposed protocol give to the parties an ability to securely exchange keys even an adversary is monitoring the communication channel between the parties. The proposed protocol combines user biometric with Identity-Based Encryption (IBE) in order to provide a secure exchange of symmetric keys even in the case of unsecure channel.

KE-BIOBE protocol States that, a Message encrypts using a symmetric key before outsourcing to the cloud storage. Then, encrypt the symmetric key using user's biometric. Our protocol exploits Fuzzy Identity-Based Encryption proposed by Sahai and Waters to encrypt the symmetric key between the parties.

10221-20, Session 4

Person re-identification based on feature propagation

Sergey Makov, Vladimir I. Marchuk, Vyacheslav V. Voronin, Don State Technical Univ. (Russian Federation)

Person re-identification is essential task within multi-camera surveillance systems. Re-identification algorithm supposes to determine which pictures are belonging to the same person. The most important aspects of robust person re-identification framework are discriminative feature representation and appropriate distance metric. But this feature usually is non-stationary. It related with flexible form of human picture. Also we have perspective distortions which affect the feature. In most cases we are able to track persons on one-view video even if the person was overlapped in few frames by some other object. It allows us to re-identify the person after its appearing after overlapping. Another problem is to re-identify person in multi-camera system. When we have overlapped views and information about camera positions we can compute feature for the person when one present in both cameras. More difficult case when camera's views have not common areas. In this paper we propose method of person feature propagation. For pair of cameras using autoencoder we get some feature transformation law. When person disappear from the one camera field of view we trying to find propagated feature for all persons appeared in the other cameras fields of views. We use several discriminative features to compare results of re-identification efficiency with and without applying of our approach. We have tested proposed approach on several re-

identification benchmarks. Obtained results are on the level of current state-of-the-art methods and give promising results.

10221-7, Session PTue

Forensic print extraction using 3D technology and its processing

Srijith Rajeev, Shreyas Kamath K. M., Karen Panetta, Tufts Univ. (United States); Sos S. Agaian, The Univ. of Texas at San Antonio (United States)

Biometric evidence plays a crucial role in criminal scene analysis. Forensic prints can be extracted from any solid surface such as a firearm, doorknob, mug, etc. Prints such as fingerprints, palm prints, footprints etc., can be classified into patent, latent, and three-dimensional plastic prints. Traditionally, law enforcement officers capture these forensic traits using an electronic device or extract them manually by means of ink and paper, and save the data electronically using special scanners. The reliability and accuracy of the method depends on the ability of the officer or the electronic device to extract and analyze the data. Furthermore, the 2-D acquisition and processing system is laborious and cumbersome. This can lead to the increase in false positive and true negative rates in print matching. In this paper, a method and system to extract visible fingerprints from any surface, irrespective of its shape is presented. First, a suitable 3-D camera is used to capture images of the forensic print, and then the 3-D image is processed and unwrapped to obtain 2-D equivalent biometric prints. Computer simulations demonstrate the effectiveness of using 3-D technology for biometric matching of fingerprints, palm prints, and footprints. This system can be further extended to other biometric and non-biometric modalities.

10221-21, Session PTue

Palm print authentication system using various image detectors

Shreyas Kamath K. M., Srijith Rajeev, Karen Panetta, Tufts Univ. (United States); Sos S. Agaian, The Univ. of Texas at San Antonio (United States)

In the field of biometrics, palm print authentication has been an important research topic over the last fifteen years. In conventional palm print authentication system, matching is based on flexion creases, friction ridges and minutiae points. Contactless palm print images tend to involve fluctuations in the image quality, texture loss including variations viz. illumination conditions, occlusions, noise, pose etc. These variations decrease the performance of the authentication systems. Furthermore, real-time palm print authentication in large databases continues to be a challenging problem. To overcome these problems, additional features along with the conventional features are required. In this paper, we propose a method to detect different local characteristic features of the images using Difference-of-Gaussian, Hessian, Hessian Laplace, Harris Laplace, Multiscale Hessian, Multiscale Harris along with Scale Invariant Feature Transformation (SIFT) descriptor to provide additional features for matching. Computer simulations were conducted on IITD and PolyU 2D3DPalmprint database. Experiments demonstrate that the accuracy of the system has increased effectively and are comparable to that of the state of the art algorithms.

10221-22, Session PTue

A rotation invariant palm print stitching and authentication

Shishir Paramathma Rao, Rahul Rajendran, Karen Panetta, Tufts Univ. (United States); Sos S. Agaian, The Univ. of Texas at San Antonio (United States)

Although not as popular as fingerprint biometrics, palm prints have garnered interest in scientific community for the rich amount of distinctive information, such as stable (heart, head and life) lines, wrinkles, and ridges features, available on the palm. Palm image is also known as a consistent/permanent human identifier because the palm features are not repeated in other people, including twins. It is natural to ask can a computer automatically catch/recognize by using above palm features whether two palm –images are from the same person or not. In this paper, a novel method for touchless palm print stitching in order to increase the effective area is presented. The method is not only rotation invariant but also able to robustly handle many distortions of touchless systems like illumination variations, pose variations, partial palm prints etc. The stitched images are then used for authentication using an improved palm print matching technique. Furthermore, the quality of stitching algorithm is determined by extensive computer simulations and visual/statistical analysis of the stitched image. In addition, images are generated by rotating and rescaling the image. Experimental results confirm that the stitching significantly increases the number of interest points, the results are very robust performance when the palm is embedded in different backgrounds and also increase the efficiency of authentication.

10221-23, Session PTue

Method for stitching microbial images using a neural network

Evgeny A. Semenishchev, Vyacheslav V. Voronin, Don State Technical Univ. (Russian Federation)

Currently an analog microscope has a wide distribution in the following fields: medicine, animal husbandry, monitoring technological objects, oceanography, agriculture and others. Stepper motors are used to move the microscope slide and allow to adjust the focus in semi-automatic or automatic mode view with transfer images of microbiological objects from the eyepiece of the microscope to the computer screen. Scene analysis allows to locate regions with pronounced abnormalities for focusing specialist attention. This paper considers the method for stitching microbial images, obtained of semi-automatic microscope. The method allows to keep the boundaries of objects located in the area of capturing optical systems. Objects searching are based on the analysis of the data located in the area of the camera view. We propose to use a neural network for the boundaries searching. The stitching image boundary is held of the analysis borders of the objects. To auto focus, we use the criterion of the minimum thickness of the line boundaries of object. Analysis produced the object located in the focal axis of the camera. We use method of recovery of objects borders and projective transform for the boundary of objects which are based on shifted relative to the focal axis. Several examples considered in this paper show the effectiveness of the proposed approach on several test images.

10221-24, Session PTue

Face recognition based on parametric multilevel Weber local descriptor

Shishir Paramathma Rao, Karen Panetta, Tufts Univ. (United States); Sos S. Agaian, The Univ. of Texas at San Antonio (United States)

Face recognition has been one of the most important research field in the past two decades due to the growing need for security in the society. Variation of skin color with varying illumination conditions, presence of eye-wears, different viewpoints, difference in facial expressions, partially covered faces are few of the key challenges that prevail in automatic face recognition systems. To address these issues, a new multiscale parametric based Weber local descriptors for face recognition is introduced. The novelty of the method lies in its ability to automatically select the parameters based on the statistics of each block and thus making the algorithm more robust to the challenges discussed. Computer simulations illustrate a) the multilevel

parametric Weber local face descriptor added an extra/upgrading feature to face recognition by increasing insensitivity to illumination; b) the proposed method can handle rotation variation problems and significantly improve the recognition rate; c) the presented method outperforms many state-of-the-art face recognition algorithms in both accuracy and efficiency. Moreover, two widely used facial image databases such as Yale and FERET databases are used for computer simulations and efficacy testing.

10221-25, Session PTue

A versatile human vision based segmentation technique for medical based applications

Rahul Rajendran, Shreyas Kamath K. M., Karen Panetta, Tufts Univ. (United States); Sos S. Agaian, The Univ. of Texas at San Antonio (United States)

In the field of vision-based systems for object detection and classification, segmentation is a key preprocessing step. Image data is of immense importance in the field of medicine. Segmentation of medical images, such as Computed Axial Tomography (CAT), Magnetic Resonance Imaging (MRI), X-Ray, Phase Contrast Microscopy, and Histopathology images, present problems like high variability in terms of the human anatomy and variation in modalities. Detection and extraction of region of interest such as tumors, lesions, cell structure, etc., is an arduous task. A possible solution to these problems is to develop an automated segmentation technique which aims at extraction of vital information. This paper describes a novel adaptive segmentation technique which aims at segmenting important region of interest for different clinical images. The result of the segmentation can further be used by radiologists to perform effective diagnosis. Possible applications are automatic extraction of tumor regions, analysis of cell network growth, and detection of infectious regions in dental X-ray images. Quantitative and qualitative computer simulations show that the technique is efficient in segmenting critical information.

10221-26, Session PTue

Automated classification of histopathology frozen section prostate cancer images using transfer learning framework

Arleen Kaur, Sos S. Agaian, Paul Rad, The Univ. of Texas at San Antonio (United States); Michael A. Liss, The Univ. of Texas Health Science Ctr. at San Antonio (United States)

Prostate Cancer (PC) is the most common non-cutaneous malignancy in American men with over 200,000 new cases diagnosed every year. Currently, skilled pathologists manually grade the prostate tissues biopsies using the Gleason grading schema. However, the quality of the cancer diagnosis significantly depends on the skills, observations, samples, knowledge and experience of the pathologist. At present, pathology is facing an increasing desire to develop a system that can support pathologist to make quick and precise diagnosis, to get fast second opinion by maximizing patient's safety. One such solution could be digital pathology based whole-slide imaging. Most of the automated PC diagnosis methodologies used in the literature to address this issue utilizes the gland based and lumen based segmentation and exploits textural features for grading purpose.

Conventionally, the state-of art methods use histopathology images in grading cancer. At the same time, frozen section (FS) examination is the central procedure performed by the pathologists during their practice occasionally. There are a very few cases of computerized examination of frozen section images. The reason could be the low quality of the FS images, so using them directly for feature extraction would result in misclassification unlike the normal histopathology images. As a result of insufficient availability of FS database to train the developed system, using the generic classification algorithm for FS biopsy and normal histopathology images may produce an incorrect grading of cancer. Traditional machine learning is based on availability of a large number of graded images to train a model in the same feature space which is not in the case of FS, hence, expanding the learning across different feature domains can help in decreasing the classification efforts. Consequently, the background motivated the designing of a system which deals with both frozen and normal biopsy PC images classification using MATLAB software and transfer learning framework.

The specific goals of this paper are: (1) classification of regular and frozen prostate biopsy images either as cancerous or non-cancerous using textural and graphical features using modified bag-of-words system. (2) Develop a classification system for both histopathology and frozen section biopsy images that distinguishes different grades of cancer using transfer learning framework and (3) development of a complete automatic classification system that is able to combine the classification of frozen section and normal biopsy cancerous and non-cancerous images and further grading them as per Gleason grading using Transfer Learning.

10221-27, Session PTue

Nuclei based automated classification system of prostate biopsy images using Fibonacci P-patterns

Foram M. Sanghavi, Sos S. Agaian, The Univ. of Texas at San Antonio (United States)

Gleason Grading is commonly utilized by pathologists for diagnosing prostate cancer and is subjective to variation, even by the same pathologists. Training, individual interpretation skills, fatigue, and application of Gleason grading to only small portions of prostate biopsy tissue samples are the various factors that affect the precision of the pathologist's reports. Thus, to support and improve the efficacy and precision of the pathologist's analysis, a computer-aided classification system can be used. Several approaches of classification system have been proposed in the past, to classify prostate histopathology images. However, very few systems utilize the nuclei information for classification purposes. Cell especially the nucleus and changes in its structure have been studied to play a significant role in both detecting and grading prostate cancer. Thus, generating a requirement of a classification system to classify the entire Gleason grading scale using the nuclei information. In this article, a Fibonacci p-patterns based automated Gleason Grading System is introduced. The proposed Gleason grading system, on computer simulation, classifies the prostate biopsy tissue samples either as normal or abnormal or as the grade of abnormality. Moreover, the CAD system may represent a useful educational tool for the pathologist.

Conference 10222: Computational Imaging II

Sunday - Monday 9 –10 April 2017

Part of Proceedings of SPIE Vol. 10222 Computational Imaging II

10222-1, Session 1

Active illumination computational imaging for optical super resolution, 3D topography, and indirect imaging *(Invited Paper)*

Marc Christensen, Prasanna Rangarajan, Southern Methodist Univ. (United States)

Structured illumination has been utilized to super-resolve microscopic objects and provide topographic information in computer vision applications. Motivated by the achievements in these fields and leveraging techniques found in astronomical sparse aperture systems, an approach is developed to super-resolve macroscopic objects in typical real world scenarios. The challenges of super-resolving uncontrolled 3D environments are addressed. An approach is presented which enables the collection of 3D topographic information while super-resolving. These techniques use incoherent illumination to resolve spatial detail in an intensity image. For indirect imaging scenarios, this approach is adapted with structured coherent illumination to super-resolve phase at a distance.

10222-2, Session 1

Computational phase space measurements using multiplexed coded apertures

Hsiou-Yuan Liu, Nicholas R. Boyd, Fanglin Liu, Benjamin Recht, Laura Waller, Univ. of California, Berkeley (United States)

Phase-space refers to simultaneous space-frequency information (e.g. Wigner functions, light fields), which is directly related to spatial coherence properties (e.g. Mutual Intensity). We introduce a binary pupil masking technique that allows us to computationally reconstruct the phase space distribution of optical beams from a series of images. Previous work has shown phase space to be useful for 3D imaging and localization in a multiple scattering environment. Binary masks are easy to implement compared to gray masks or phase masks and the proposed scheme requires no interferometry. After designing the masks with nonredundant arrays, we measure an intensity image for each aperture mask and reconstruct the phase space through an auxiliary coherence function. We demonstrate experimentally the reconstruction of the phase space of a collection of 3D incoherent sources.

10222-3, Session 1

Feature-enhanced computational infrared imaging

Alper Gungor, H. Emre Guven, ASELSAN A.S. (Turkey)

We present a resolution enhancement method based on sparsity priors in the image domain and gradient using total variation. Focal plane array (FPA) sizes are generally limited due to cost and system design considerations. Moreover, some pixels in large FPAs have imperfections due to the nature of the production process and require correction via post-processing. Also, optical components in the imaging chain typically cause blurring. Hence a super-resolution method is desirable for practical infrared imaging systems.

An approach suggested by Marcia and Willet uses a coded aperture to mask the image in Fourier domain, and solve an optimization problem for image reconstruction. Another approach is to collect different linear measurements of the same scene using a digital micro-mirror device, and solve an optimization problem for image reconstruction. These approaches require the optical system to be modified, and imperfections cause different problems in the reconstructed images.

In this study, we propose a model-based super-resolution method for infrared cameras. We propose using the inherent point spread function (PSF) of the camera to enhance image resolution. The proposed method includes solving a deconvolution-like optimization problem with the objectives of linear combination of Total Variation and l1-norm with a data fidelity constraint including possible missing pixels and the convolutional forward model, using alternating direction method of multipliers. We then test our algorithm on both simulated and experimental data, and compare against the coded-aperture based approach. We show that the proposed method improves the resolution and performs close to the coded-aperture approach in some cases.

10222-4, Session 2

Computational imaging: Beyond the limits imposed by lenses *(Invited Paper)*

Ashok Veeraraghavan, Rice Univ. (United States)

No Abstract Available

10222-6, Session 2

Single-shot hyperspectral multiplexed imaging using a computational imaging array

Joseph H. Lin, MIT Lincoln Lab. (United States)

We show experimental results from a prototype multiplexed imaging spectrometer. Spectral information is encoded via a dual-dispersive architecture using a digital micromirror spatial light modulator (SLM) and decoded on-chip at the focal plane with a computational imaging array. Light from the scene is dispersed through a first prism and imaged onto the SLM, which applies a unique time-varying binary (1,0) encoding to each spectral bin. The encoded light is then recombined through a second prism and imaged onto a computational imaging array, where the multiplexed image is decoded on-chip. The computational imaging array is comprised of a 32x32 array of pixels with the capability of acquiring eight concurrent measurements that can be modulated with a time-varying duo-binary signal (+1,-1,0) at MHz rates. This results in eight decoded images per frame at a maximum frame rate of 1600 frames per second. The frame rate of the system depends on the number of encoded spectral bins. At the high end it is limited by the switching speed of the DMD SLM, and at the low end it is limited by the readout rate of the imaging array. We explore these trades as well as discuss areas for future improvement.

10222-7, Session 2

Lensless computational imaging using 3D printed transparent elements

Gabriel C. Birch, Charles F. LaCasse IV, Amber L. Dagel, Bryana L. Woo, Sandia National Labs. (United States)

Lensless imaging systems have the potential to provide new capabilities and use cases that have potential to operate in a lower size and weight configuration than traditional imaging systems. Lensless imagers frequently utilize computational imaging techniques, which moves the complexity of the system away from optical subcomponents and into a calibration process whereby the system transfer function is estimated.

We report on the design, simulation, and prototyping of a lensless imaging system that utilizes 3D printed optically transparent random scattering elements. Development of complete system simulations, which includes

simulations of the calibration process, as well as the data processing algorithm used to generate an image from the random data are presented. Complete system simulations utilize GPU-based raytracing software, and parallelized minimization algorithms to bring complete system simulation times down to the order of seconds.

Hardware prototype results are presented, and practical lessons such as the effect of sensor noise on reconstructed image quality are discussed. System performance metrics are proposed and evaluated to discuss image quality that is relatable to traditional image quality metrics. Various specific hardware instantiations are discussed.

10222-24, Session 2

Toward depth estimation using coded mask-based lensless camera

Salman Asif, Univ. of California, Riverside (United States)

Coded masks have been used in various imaging systems to achieve different capabilities. For instance, coded masks are used in X-ray and Gamma-ray imaging because lenses are either infeasible or very expensive at those wavelengths; coded masks have also been used along with lenses to capture 4D light field or depth and texture information.

Recently, coded masks have been used to demonstrate a thin form-factor lensless camera, FlatCam, in which a single or multiple masks are placed on top of a bare, conventional image sensor. In a coded mask-based camera, light coming from different scene locations is modulated by shifted copies of the mask and the sensor records a multiplexed image. A computational algorithm is then used to reconstruct the scene from the multiplexed recordings.

In this paper, we present an algorithm to jointly estimate depth and intensity information in the scene from a single image of FlatCam. We first represent image formation using a light field representation in which light rays originating from different depths yield different modulation patterns. Then we present a greedy pursuit algorithm that estimates the depth and intensity of each pixel from the available coded measurements. We demonstrate the performance of our algorithm using a suite of experiments with FlatCam model. We also discuss an application of our method for continuous estimation of depth from a sequence of sensor measurements.

10222-8, Session 3

Computational imaging through scattering media *(Invited Paper)*

Laura Waller, Univ. of California, Berkeley (United States)

This talk will describe new computational imaging methods for reconstruction of 3D objects embedded in scattering media. We demonstrate experimental schemes that employ both illumination-side and detection-side coding of angles (Fourier space) in order to capture large-scale 4D phase space (e.g. light field) data with fast acquisition times. Using a multi-slice forward model, wave-optical and multiple scattering effects are incorporated, so results are applicable to both coherent and incoherent imaging systems. Sparsity-enforcing algorithms can further exploit available prior information in order to improve resolution, field of view or speed of capture. Such computational approaches to imaging add significant new capabilities to existing systems without significant hardware modification.

10222-9, Session 3

Using MODIS data and Saastamoinen model for atmospheric effect reduction in interferometry

Arlinda Saqellari-Likoka, Vassilia Karathanassi, National Technical Univ. of Athens (Greece)

In this study, a method for reducing the atmospheric effects on the interferometric phase signal is proposed. The method exploits MODIS data and the Saastamoinen model for the estimation of the atmospheric component and the generation of spatially continuous data for this component.It generates spatially continuous data for the atmospheric phase component and it recovers the unwrapped interferometric phase signal from atmospheric path delays.

More analytically, it uses MODIS Atmosphere Water Vapor (05_L2) and MODIS/Terra land surface temperature products, as well as historical data for the air pressure. MODIS data are scaled to SAR image resolution, converted to the slant range geometry and introduced to the Saastamoinen model which provides the phase delay due to the atmospheric conditions for the date that a SAR image is acquired. Then the atmospheric path delay between the master image and slave image for the interferometric pairs can be estimated and subtracted from the unwrapped phase.

The method has been implemented over the Attica area of Greece, and has evaluated using Envisat images. MODIS data have been validated using meteorological data from four meteorological stations.

Performance of the method depends on MODIS data resolution; however, it always improves the produced interferometric DEM.

10222-10, Session 3

An efficient algorithm for model based blind deconvolution

Melih Bastopcu, Alper Gungor, H. Emre Guven, ASELSAN A.S. (Turkey)

We propose a method for blind-deconvolution with prior information on the lens characteristics. There is a permanent demand for higher resolution for applications such as tracking, recognition, and identification. Limitations of available methods for practical systems are generally due to computational cost and power. Therefore a computationally efficient method for blind-deconvolution is desirable for practical systems.

Total-variation (TV) minimization method proposed by Acar and Vogel is used to recover the edges of the images and eliminate some of the blurs. Another approach called split augmented Lagrangian shrinkage algorithm uses alternating direction method of multipliers (ADMM) in which an unconstrained optimization problem including l2 data-fidelity and a non-smooth regularization term is solved. Although successful, the excessive computational requirements present a challenge for practical usage of these methods.

Here, we propose a parametric blind-deconvolution method with prior knowledge on the point spread function (PSF) of the camera lens. We model the PSF of the circular optics as Jinc-squared function and determine the best PSF by solving optimization problem containing TV-norm along with Wavelet-sparsity objectives using an ADMM based algorithm. We use a convolutional model and work in Fourier domain for efficient implementation, and avoid circular effects by extending the unknown image region. First, we show that PSF function of the lenses can be modeled with Jinc function in experimental data. Next, we point out that our algorithm improves resolution of the image and compared to classical blind-deconvolution methods while remaining feasible in terms of computation time.

10222-11, Session 3

Isogeometric Approach to 3D tomographic reconstruction in optical imaging

Vahid Bateni, Robert L. West, Virginia Polytechnic Institute and State Univ. (United States)

No Abstract Available

10222-12, Session 3

Atmospheric effects estimation on SAR Images using a pure statistical method

Arlinda Saqellari-Likoka, National Technical Univ. of Athens (Greece)

The values of the unwrapped phase produced by interferometric pairs can be parameterized for phase components, such as height, atmospheric path delay and deformation term, and estimated through DInSAR techniques. In this study, a method is proposed which estimates the atmospheric path delay using a single interferometric pair and an atmospheric path delay estimator. The estimator relies on the minimization of the outage probability, which is the probability that the Mean Square Error (MSE) of the estimated atmospheric component exceeds a desired MSE value. Outage minimization is equivalent to the minimization of the MSE of the atmospheric component for a fixed outage probability. The minimization of the MSE of the atmospheric component is determined by the second-order statistics of the topography and atmospheric components. For a specific SAR image geometry, second-order statistics of the topography component are satisfactorily approximated by the mean squared height errors of a high quality InSAR DEM for various height and slope classes, whereas second-order statistics of the atmospheric component are approximated by the inverse coherence value of the dataset which provides the high quality InSAR DEM. The proposed approach is validated to real satellite images and meteorological measurements.

10222-13, Session 3

Combination of correlated phase error correction and sparsity models for SAR

Toby Sanders, Theresa Scarnati, Arizona State Univ. (United States)

Direct image formation in synthetic aperture radar (SAR) involves processing of data modeled as polar spaced Fourier data. Often in such data acquisition processes, imperfections in the data cannot simply be modeled as additive or even multiplicative noise errors. In the case of SAR, errors in the location of the Fourier data points can exist due to imprecise estimation of the round-trip wave propagation time, which manifests as phase errors in the image domain. To correct for these errors, we propose a phase correction scheme that not only relies on smoothness characteristics of the image, but also on the phase corrections associated with neighboring pulses, which are possibly highly correlated due to the nature of the data offsetting. Our model takes advantage of these correlations and smoothness characteristics simultaneously for a new autofocusing approach, and our algorithm for the proposed model alternates between approximate image feature and phase correction minimizers to the model.

10222-14, Session 4

Computational imaging systems for measurement-limited applications *(Invited Paper)*

Mark A. Foster, Johns Hopkins Univ. (United States)

Imaging systems can become measurement limited under various conditions resulting in strict limits to the amount of acquired image information. For example, a high-speed imager is limited in the number of measurements that can be acquired per second. Similarly, an ultra-small imager such as a micro-endoscope is limited by the number of measurements that can be acquired in a given cross-sectional area. In this talk, we will discuss our recent research in applying optical signal processing and computational imaging to enhance imaging performance in measurement-limited applications. Specifically, we will discuss our research into high-throughput flow microscopes for imaging flow cytometry and ultra-small fiber imagers for minimally-invasive micro-endoscopy.

10222-15, Session 4

High-speed holographic imaging using compressed sensing and phase retrieval

Zihao Wang, Northwestern Univ. (United States); Donghun Ryu, California Institute of Technology (United States); Kuan He, Northwestern Univ. (United States); Roarke Horstmeyer, Humboldt-Univ. zu Berlin (Germany); Aggelos K. Katsaggelos, Oliver Cossairt, Northwestern Univ. (United States)

Digital in-line holography serves as a useful encoder for spatial information. This allows three-dimensional reconstruction from a two-dimensional image. This is applicable to the tasks of fast motion capture, particle tracking etc. Sampling high resolution holograms yields a spatiotemporal tradeoff. We spatially subsample holograms to increase temporal resolution. We demonstrate this idea with two subsampling techniques, periodic and uniformly random sampling. The implementation includes an on-chip setup for periodic subsampling and a DMD (Digital Micromirror Device) -based setup for pixel-wise random subsampling. The on-chip setup enables direct increase of up to 20 in camera frame rate. Alternatively, the DMD-based setup encodes temporal information as high-speed mask patterns, and projects these masks within a single exposure (coded exposure). This way, the frame rate is improved to the level of the DMD with a temporal gain of 10. The reconstruction of subsampled data using the aforementioned setups is achieved in two ways. We examine and compare two iterative reconstruction methods. One is an error reduction phase retrieval and the other is sparsity-based compressed sensing algorithm. Both methods show strong capability of reconstructing complex object fields. We present both simulations and real experiments. In the lab, we image and reconstruct structure and movement of static polystyrene microspheres, microscopic moving peranema, macroscopic fast moving fur and glitters.

10222-16, Session 4

Controlled aberrations for snapshot compressive imaging

Esteban Vera, Pontificia Univ. Católica de Valparaíso (Chile); Pablo F. Meza Narvaez, Univ. de la Frontera (Chile)

Compressive imaging aims to capture optical images using fewer measurements, or measurement elements, than what is needed to naively sample the image at a given resolution. It is feasible by using compressed sensing, which has been demonstrated by the single-pixel camera where each measurement is a randomly coded version of the whole scene. Nonetheless, since in many imaging modalities there are array detectors available, the challenge for snapshot compressive imaging is the optical generation of simultaneous projections that fulfill the compressed sensing reconstruction requirements. In this work, we propose the use of controlled aberrations through wavefront coding to produce simultaneous projections for compressive imaging. In contrast to the idea that aberrations are indeed jeopardizing the image quality, we use optical aberrations to produce point spread functions that can simultaneously code and multiplex different parts of the scene on the available imaging detector in a variety of ways. Apart from light efficiency, the main advantage of controlled phase aberrations in comparison with random coded apertures is that we can analytically obtain the corresponding system matrix response, thus avoiding cumbersome calibration procedures. Further, we explore different aberrations by combinations of Zernike modes and analyze the compression ability by means of the coherence parameter. Simulation results using natively sparse and natural scenes demonstrate the feasibility of employing controlled aberrations for compressive imaging. Now, once we are able to acquire snapshot compressed images, how to efficiently reconstruct large-scale

images from compressive measurements becomes a challenging but exciting problem.

10222-17, Session 4

Compressive video sensing with side information (Rising Researcher Presentation)

Xin Yuan, Alcatel-Lucent Bell Labs. (United States); Yangyang Sun, Sean Pang, CREOL, The College of Optics and Photonics, Univ. of Central Florida (United States)

High-speed longitudinal imaging is a powerful revealing tool for study of dynamics in biological research and material science. Many fundamental processes, such as neural activities, are on the time scale of millisecond and sub-millisecond. To observe such processes, the system requires a frame rate over 1000 Hz. However, most imagers on the consumer market only. Recently developed compressive imaging system in time domain reconstructs high-speed image sequence from a single, coded snapshot. The reconstruction quality, similar to that of other compressive sensing system, often depends on the structure of the measurement, as well as the choice of regularization. In this paper, we report a compressive video system that also captures the side information to aid the reconstruction of high-speed scenes. The inclusion of the side information not only improves the quality of reconstruction, but also reduces the dependence of the reconstruction on regularization. We have implemented a system prototype, which splits the field of view of a single camera into two channels: one channel captures the coded, low-frame-rate measurement for the typical high speed video reconstruction; the other channel captures a direct measurement without coding as the side information. A joint reconstruction algorithm is developed to recover the high-speed videos from the two channels and a 4-time temporal compressive video acquisition and reconstruction were experimentally demonstrated. By analyzing both the experimental and the simulation results, the reconstructions with side information have demonstrated superior performances in terms of both peak signal-to-noise ratio (PSNR) and structural similarity (SSIM).

10222-18, Session 4

Unified optimization framework for L2, L1, and/or L0 constrained image reconstruction

Masayuki Tanaka, Masatoshi Okutomi, Tokyo Institute of Technology (Japan)

In computational imaging, reconstruction-based image processing is widely used. The image reconstruction is formulated as an optimization problem. The optimization algorithm has had to be developed for each application. In this paper, we propose a unified optimization framework for L2, L1, and/or L0 constrained image reconstruction. One can get a reconstructed image by applying the proposed optimization framework to their cost function.

First, we generalize the cost functions for image reconstruction, which consist of a fidelity term with L2 norm and constraint terms with L2, L1, and/or L0 norms. This generalized cost function covers many types of existing cost functions for image reconstruction. Then, we show that this generalized cost function can be optimized by the alternating direction method of multipliers (ADMM). The ADMM is a well-known iterative optimization approach for convex and non-convex problems. For the non-convex problem like L0 constrained image reconstruction, the initial guess estimation has a crucial role in practice. We also propose the initial guess estimation for the ADMM approach. The order of ADMM procedure is changed assuming that we have reasonable initial guess.

We solve the sub-problem of the ADMM in the frequency domain. The Fourier transform implicitly assumes that the image is periodical. This assumption degrades the image quality especially around image borders. We also propose the algorithm which reduces the border effect.

Experimental results demonstrate that the proposed unified optimization framework is applicable to a wide range of applications. It is also shown that the initial guess estimation accelerates the calculation for optimization.

10222-19, Session 4

Near-field millimeter wave imaging calibration method

Xinyu Yin, Alexander G. Denisov, Jinghui Qiu, Harbin Institute of Technology (China)

In the system of passive millimeter wave imaging, the mechanism is the use of electromagnetic energy radiated by the target scene itself, the process by the receiving terminal receives and further processed. The main contents of this article is based on a focal plane of the linear array scanning system of passive millimeter wave imaging systems theory, and introduce this system in the near-field imaging calibration method.

According to the millimeter-wave imaging process, combining with the basic principles of millimeter wave imaging, in this article the focal plane imaging line scan imaging methods is used. A mathematical model of the spatial variation of the imaging process is used to influence the types of spatially variable factors on the expression generated imaging during imaging process.

Based on the above mathematical model of the imaging process, I will introduce of two near-field imaging calibration methods, namely the internal calibration and external calibration, which is the core of this thesis. Which the internal calibration uses a linear relationship between the input criteria temperature and output voltage. By the two-point method 70 radiometer arrays is calibrated in the system. Eventually in the input array radiometer with the same temperature conditions, it is possible to output the same voltage. Using the external calibration standards for the point spread function (PSF) of the image is estimated. Here I use wiener filtering algorithm, the image formed by further calibration, which effectively improve the passive millimeter wave imaging resolution of the image.

10222-20, Session 5

A stick-shaped multi-aperture camera for intra-oral diagnosis *(Invited Paper)*

Jun Tanida, Hirotsugu Akiyama, Osaka Univ. (Japan); Keiichiro Kagawa, Shizuoka Univ. (Japan); Chizuko Ogata, Makoto Umeda, Osaka Univ. Dental Hospital (Japan)

Multi-aperture imaging systems are useful as a universal platform of computational imaging owing to their flexibility in optical system design. A compound-eye imaging system TOMBO (thin observation module by bound optics) is a simplified instance of the multi-aperture imaging system. In the TOMBO an image sensor is divided into several sections by a signal separator, and the individual microlenses image the objects on them. This configuration enables to reduce the thickness of the hardware and to integrate different properties of optics in the same module.

As a variation of the TOMBO, a stick-shaped camera module was designed for intra-oral diagnosis. The module consists of 3 x 3 individual imaging units which are customized to capture different optical signals. Embedded functions are stereo 3D monitoring, depth estimation with combination of pattern projection and stereo pattern matching, and tissue component estimation. Illumination equipment for visible and IR lights and a pattern projector are also integrated on the module.

Teeth and gingiva of several subjects were observed by the stick-shaped TOMBO. 3D shape of gingiva was retrieved from a couple of unit images to monitor swelling. Areal distributions of melanine, hemoglobin, and oxyhemoglobin saturation were estimated by multiple regression analysis on the captured RGB image. The reconstructed information is expected to be useful for diagnosis in odontotherapy.

10222-21, Session 5

In-situ stress imaging of photoelasticity induced birefringence using transport of intensity equation (TIE)

Yunhui Zhu, Ziling Wu, Virginia Polytechnic Institute and State Univ. (United States)

We demonstrate a fast stress retrieval method for birefringence materials using Transport of Intensity Equation (TIE). Transport of intensity equation (TIE) has been a popular and robust phase imaging method that obtains phase retrieval from the measurements of intensity differentials. Here, we adapt TIE to birefringence imaging for stress mapping. The method is applied to materials that lose physical isotropy and demonstrated birefringence under stress or deformation, such as polymer and glass. The propagation of light waves in such a material is governed by two refractive indices for the ordinary and the extraordinary polarizations, respectively. By injecting a circular polarized light, and comparing the defocused intensity profiles of the object for orthogonal polarizations, we demonstrate a TIE based method to retrieval the birefringence induced phase shift, which is proportional to the maximum shear stress. Compared to conventional interference measurement, TIE based birefringence imaging is linear, thereby can better resolve singular areas with stress-concentration. This method also eliminates the iterative phase compensation process and allows for instant stress retrieval from intensity measurement, thus can be operated with an unprecedented speed that is only bounded by the frame rate of the camera. The TIE method is also compatible with incoherent illumination, which further enhances the spatial resolution at the diffraction limit. The ease of implementation, fast speed and fine spatial resolution make this method appeal in study of in-situ stress transformation such as fatigue and crack propagation. Our simulation results have demonstrated robust and fast stress retrieval with a variety of loading conditions.

10222-22, Session 5

Fluorescence lifetime estimation using a dynamic vision sensor

Fengqiang Li, Nathan Matsuda, Marc Walton, Oliver Cossairt, Northwestern Univ. (United States)

Art conservation research frequently requires a means to identify the materials, such as oil paints or pigments, used in a work of art. Since many of these materials are fluorescent, measuring the fluorescence lifetime following an excitation pulse is a useful non-contact method to identify pigments. One such pigment, calcium copper silicate, commonly known as “Egyptian Blue”, has an identifiable fluorescence decay signature previously characterized using x-ray imaging. This signature can be used without the need for destructive chemical analysis to study usage of the pigment in antiquities. X-ray imaging techniques, however, are usually impractical due to cost and complexity. An efficient, low cost technique for measuring fluorescence lifetime has the potential to bring the tool to a wider range of art conservators throughout the world.

In this project, we proposed a method using the low-cost Dynamic Vision Sensor (DVS) to efficiently characterize the fluorescence lifetime of Egyptian Blue. We implemented a simple setup pairing the DVS with a modulated laser diode. By synchronizing the diode modulation with the DVS clock, we are able to record the time at which the fluorescence drops below a pre-calibrated threshold level relative to the excitation pulse. We demonstrate that the decay time for Egyptian Blue measured using this technique closely matches the accepted fluorescence lifetime as measured by x-ray techniques.

We believe that our technique provides a fast and cost-effective method to characterize fluorescence lifetime in materials of interest to art conservation researchers.

10222-5, Session 6

Matrix sparsification and non-negative factorization for task partitioning in computational sensing and imaging

David G. Stork, Rambus Inc. (United States); Neda Rohani, Northwestern Univ. (United States); Aggelos K. Katsaggelos, Northwestern Univ. (United States) and Rambus Inc. (United States)

We address the mathematical foundations of a special case of the general problem of partitioning an end-to-end sensing algorithm for implementation by optics and by a digital processor for minimal electrical power dissipation. Specifically, we present a non-iterative algorithm for factoring a general k ? k real matrix A (describing the end- to-end linear pre-processing) into the product BC, where C has no negative entries (for implementation in linear optics) and B is maximally sparse, i.e., has the fewest possible non-zero entries (for minimal dissipation of electrical power). Our algorithm achieves a sparsification of B—i.e., the number s of non-zero entries in B—of $s \leq 2k$, which we prove is optimal for our class of problems.

10222-23, Session 6

Pupil engineering design by optimization of two dissimilar metrics *(Invited Paper)*

Abbie T. Watnik, U.S. Naval Research Lab. (United States); Jacob Wirth, Grover A. Swartzlander Jr., Rochester Institute of Technology (United States)

For the application of incoherent imaging in the presence of nuisance laser light, two mutually independent objectives are desired: spreading of the laser illumination across the sensor to avoid high-intensity pixels and image recovery via deconvolution of the incoherent image. Simultaneous recording of coherent and incoherent illumination in a single image can be separated after detection based on properties of the pupil function of the imaging system. We describe a differential evolution approach to estimate a pupil phase mask that jointly optimizes these dissimilar metrics. Calculated phase masks are presented with results of the final reconstructed imagery.

10222-25, Session 6

Modular time of flight imaging system for ranging development

Eric C. Breitbach, Mohit Gupta, Andreas Velten, Univ. of Wisconsin-Madison (United States)

The interest in time of flight (ToF) imaging has increased in the past years, driven in part by applications such as autonomous vehicles and augmented reality, and availability of low-cost devices such as the Microsoft Kinect. Most existing continuous-wave ToF systems use sinusoidal modulation and demodulation signals, i.e., the light source emits light whose intensity is modulated as a sinusoid over time. The radiance received at the camera (after reflection from the scene) is correlated with a sinusoidal signal (demodulation) as well to determine the depth of the scene.

There is great interest in exploring different strategies for illumination and detection schemes, such as varying time modulation functions, spatial illumination patterns, illumination and detector technologies, polarization, and other parameters for optimized scene reconstruction. Unfortunately commercial LiDAR devices do not provide the flexibility to allow computational researchers to test and apply those new detection schemes.

Here we introduce a modular point scanning tabletop system that can produce and utilize arbitrary modulation waveforms and spatial patterns for both illumination and detection. We show performance improvements in

ranging using new illumination and detection patterns.

The intent of this system is to be open and easily reproducible, thus all of the equipment is purchasable off the shelf. The system consists of an avalanche photodiode, a laser diode capable of being modulated by an external signal, and a scanning system.

10222-26, Session 6

Source diversity for contrast transfer function imaging

Tonmoy Chakraborty, Jonathan C. Petruccelli, Univ. at Albany (United States)

Propagation-based phase imaging enables the quantitative reconstruction of a beam's phase from measurements of its intensity. Because the intensity depends on the time-averaged square of the field the relationship between intensity and phase is, in general, nonlinear. In order to simplify phase reconstruction, approximate linear models have been proposed. The transport of intensity equation (TIE), arises from restricting the propagation distance to be small. However, the propagation distance limits the spatial frequencies that can be reliably reconstructed using the TIE to those below some cutoff. On the other hand, the low frequency components suffer from poor signal to noise ratio (SNR) unless the propagation distance is sufficiently large, which leads to low frequency artifacts in the reconstruction. We have previously examined the use of incoherent primary sources of illumination to enhance the low frequency performance of the TIE. However, this method does not address the high frequency cutoff.

To avoid this cutoff, for objects with slowly varying phase, the contrast transfer function (CTF) model can be used to recover phase. By allowing the use of longer propagation distances, the CTF also improves SNR at low frequencies. The CTF transfer function presents propagation-distance-dependent nulls which introduce artifacts in phase retrieval unless multiple distances are used. Here we demonstrate the effect of finite, incoherent sources of illumination on the CTF to improve low frequency performance at any defocus distance. In addition, when combining measurements from multiple distances, source shape provides an additional parameter that can be used to optimize reconstruction performance.

Conference 10223: Real-Time Image and Video Processing 2017

SPIE. DCS COMMERCIAL+SCIENTIFIC SENSING AND IMAGING

Monday - Tuesday 10–11 April 2017

Part of Proceedings of SPIE Vol. 10223 Real-Time Image and Video Processing 2017

10223-1, Session 1

Structured learning via convolutional neural networks for vehicle detection

Ana I. Maqueda, Carlos R. del Blanco, Narciso García, Fernando Jaureguizar, Univ. Politécnica de Madrid (Spain)

New intelligent transportation systems based on vision-based technologies are becoming very important for traffic monitoring and flow analysis, advanced driver assistance, surveillance, or autonomous vehicles. One of the main tasks is the detection of vehicles in real conditions: day and night operation, diversity of road configurations, arbitrary camera position, occlusions, etc. Recently, deep neural networks have been successfully applied to vehicle detection, outperforming other machine-learning techniques. However, the projective geometry of a typical road scene is usually not considered in the detection process, which originates dramatics changes in the vehicle appearance depending of its location over the image plane. Another challenge is the detection of partially visible vehicles, either because they are outside the image boundaries, or occluded by different traffic related objects (streetlights, crash barriers, bridges, etc.). In this paper, a new real-time vision-based system for vehicle detection based on deep learning is proposed, which explicitly considered the previous challenges to be able to detect vehicle in a wide range of real traffic situations. Input frames are analyzed by a new design of Convolutional Neural Networks (CNN) that generates a spatially structured output that discretely encodes detected vehicle locations. In addition, the proposed CNN can learn that vehicle appearance can change according to its image location, and due to background occlusions, which improves the detection capability. These characteristics allow to the proposed deep learning based system successfully operate in real traffic situations. Moreover, the implementation of the proposed approach in a GPU allows a real time operation.

10223-2, Session 1

Real-time smoke detection using a moving camera

Ahmet E. Çetin, Bilkent Univ. (Turkey) and Univ. of Illinois at Chicago (United States); Dingli Qin, Weiye Wu, Univ. of California, San Diego (United States)

Early detection of a wildfire is extremely important to extinguish it as quick as possible before any significant damage [1-2]. Wildfires that cause major problems usually start in remote areas and can develop into catastrophic events. Drones can fly over uninhabited remote areas in a predetermined GPS based route and spot wildfires at an early stage. Smoke is clearly visible from long distances in wildfires and forest fires. Ordinary visible range cameras can detect smoke from long distances. However, current computer vision based smoke detection methods assume that the camera is stationary [1]. In this paper we will describe a real-time smoke detection algorithm that can be installed in mobile platforms. The proposed smoke detection algorithm determines SIFT features of the current image frame and compares them with the SIFT features of the next image frame of the video. The smoke appears as gray regions with different brightness levels. There are local maxima and minima points from the difference of Gaussians applied to the grayscale of the image frame, and the SIFT feature points can be detected. We mark a small window around such SIFT feature points as potential smoke regions. Once a potential region is found, we match it with a potential region in previous frame if they are close and similar. By tracking and analyzing the motion of a potential region, we can determine whether it is smoke or not. The algorithm can be implemented in an Android platform in real-time at a rate of 4 to 5 fps.

References:

[1] O. Gunay, B.U. Toreyin, K. Kose, A. E. Cetin, "Entropy-functional-based online adaptive decision fusion framework with application to wildfire detection in video," IEEE Transactions on Image Processing, 2012.

[2] A. E. Cetin,Bart Merci,Osman Gunay,Behcet Toreyin,Steven Verstockt, Methods and Techniques for Fire Detection, Signal, Image and Video Processing Perspectives, Academic Press, 2016.

10223-3, Session 1

A real-time crowds safety and comfort management framework from CCTV image

Muhammad Baqui, Rainald Lohner, George Mason Univ. (United States)

High density pedestrian flows are experienced in various places nowadays. Pedestrian safety and comfort in high density flows are very challenging. In recent years a number of tragic incidents have occurred that outline the importance of effective real time crowd management. Velocity and density of pedestrians are two fundamental features of any crowd flow. Crowds density is obtained by counting the number of people in a unit area. Cross Correlation velocity extraction and Optical flow technique are two prime ways of extracting pedestrian velocity from video sequence. However, the application of these techniques in high density crowds images is not thoroughly studied. This work presents a study of high density crowd monitoring from video and its real time application viability. The video data is captured from the Closed Circuit Television (CCTV) available at the facility. Both Cross Correlation based and Optical flow based approaches are studied. Results are presented in the forms of fundamental diagrams, velocity vectors and speed contours of the flow field.

10223-4, Session 1

Real-time text extraction based on the page layout analysis system

Mahmoud Soua, Mohammed Alae Benchekroun, Rostom Kachouri, Mohamed Akil Sr., ESIEE Paris (France)

Several approaches were proposed in order to extract text from scanned documents. However, text extraction in heterogeneous documents stills a real challenge. Indeed, text extraction in this context is a difficult task because of the variation of the text due to the differences of sizes, styles and orientations, as well as to the complexity of the document region background. Recently, we have proposed the improved hybrid binarization based on Kmeans method (I-HBK) to extract suitably the text from heterogeneous documents. In this method, the Page Layout Analysis (PLA) - part of the Tesseract OCR engine - is used to identify text and image regions. Afterwards our hybrid binarization is applied separately on each kind of regions. In one side, gamma correction is employed before to process image regions. In the other side, binarization is performed directly on text regions. Then, a foreground and background color study is performed to correct inverted region colors. Finally, characters are located from the binarized regions based on the PLA algorithm. In this work, we extend the integration of the PLA algorithm within the I-HBK method. In addition, to speed up the separation of text and image step, we employ an efficient GPU acceleration. Through the performed experiments, we demonstrate the high accuracy of the PLA algorithm. In addition, we illustrate the sequential and the parallel compared PLA versions. The Obtained acceleration measures of the parallel PLA implementation on GPU is also studied and discussed.

10223-5, Session 1

A comparison study between two neural network models for character recognition

Syrine Ben Driss, Mahmoud Soua, Rostom Kachouri, Mohamed Akil Sr., ESIEE Paris (France)

Optical Character Recognition (OCR) systems have been designed to operate on text contained in scanned documents and images. They include text detection and character recognition in which characters are described then classified.

In the classification step, characters are identified according to their features or template descriptions. Then, a given classifier is employed to identify characters. In this context, we have proposed the unified character descriptor (UCD) to represent characters based on their features. Then, matching was employed to ensure the classification. This recognition scheme performs a good OCR Accuracy on homogeneous scanned documents, however it cannot discriminate characters with high font variation and distortion.

To improve recognition, classifiers based on neural networks can be used. The multilayer perceptron (MLP) ensures high recognition accuracy when performing a robust training. Moreover, the convolutional neural network (CNN), is gaining nowadays a lot of popularity for its high performance. Furthermore, both CNN and MLP may suffer from the large amount of computation in the training phase.

In this paper, we establish a comparison between MLP and CNN. We provide MLP with the UCD descriptor and the appropriate network configuration. For CNN, we employ the convolutional network designed for handwritten and machine-printed character recognition (Lenet-5) and we adapt it to support 62 classes, including both digits and characters. In addition, GPU parallelization is studied to speed up both of MLP and CNN classifiers. Based on our experimentations, we demonstrate that the used real-time CNN is 2x more relevant than MLP when classifying characters.

10223-6, Session 1

Weighted fusion of depth and inertial data to improve view invariance for real-time human action recognition

Chen Chen, Univ. of Texas at Dallas (United States); Huiyan Hao, The Univ. of Texas at Dallas (United States) and North Univ. of China (China); Roozbeh Jafari, Texas A&M Univ. (United States); Nasser Kehtarnavaz, The Univ. of Texas at Dallas (United States)

Human action recognition based on depth cameras, in particular Microsoft Kinect, has been extensively studied in the literature for various applications including human-computer interactions, gaming and rehabilitation. A depth camera provides depth images or a 3D structure of the human body in the scene. Due to differences in performing actions from subject to subject and variations in environmental conditions, there are still challenges in achieving robust real-time human action recognition.

With the advancement of Micro-Electro-Mechanical Systems (MEMS), wearable inertial sensors such as accelerometers and gyroscopes are increasingly being utilized for action recognition. This sensor technology provides an alternative approach toward performing action recognition by utilizing 3D acceleration and rotation signals associated with an action. Considering the complementary aspect of the 3D action data provided by these two types of sensors, i.e. depth camera and inertial sensor, our research team has previously developed a number of real-time action recognition solutions by utilizing both of these sensors at the same time. As a result of fusing the data from these two differing sensor modalities, it has been shown that recognition rates are improved compared to situations when each sensor is used individually.

In this paper, an extension is made to our previous fusion framework to further cope with variations in depth images that are caused by the way a subject faces a depth camera. Similar to our previous works, a depth camera and an inertial sensor are used simultaneously irrespective of how the depth camera is placed in the scene as long as subjects appear in the camera's field of view. In the literature when a depth camera is used for human action recognition, one sees that actions are often performed in a frontal view setting and there has been limited study of the effect of changing the subject orientation with respect to the camera on the recognition outcome. Thus, the focus of this paper is on studying view variations within the context of our real-time fusion framework.

In the extension developed here, the classifiers are weighted not equally in order to gain more robustness when training data incorporate samples for subjects facing the camera at different viewing angles. To retain the computational efficiency or real-time aspect of our previous fusion framework, instead of using computationally intensive view-invariant features, a computationally simple view angle estimation is used here. The developed approach requires obtaining training data from different views. The view estimation allows using only the training samples of a specific view when examining test samples. The contributions made in this paper are two-fold: (1) the utilization of a computationally efficient view estimation based on the skeleton joint positions, and (2) a weighted fusion to assign different weights to the two classifiers that are associated with depth features and inertial features.

The paper is organized as follows. After the introduction in Section 1, Section 2 describes the two sensors used in our real-time fusion framework. Section 3 covers a computationally efficient and simple method to estimate different views by using skeleton joint positions. The weighted fusion framework is then presented in Section 4. The experimental results and discussion are stated in Section 5. Finally, the paper is concluded in Section 6.

10223-8, Session 2

Low cost high throughput affine transformation engine using FPGA

Mehmet Aktukmak, Mehmet S. Ero?lu, ASELSAN A.S. (Turkey)

Geometric transformation is widely used in image processing applications especially in the ones in which image registration is required. Electronic image stabilization, super-resolution, sensor fusion can be given as featured example applications requiring a qualitative registration. Affine transformation is a kind of geometric transformation providing sufficient solution for video streams since it covers necessary transformations such as rotation, scaling, shearing, and translation. However this transformation requires enormous matrix operations like matrix multiplications and additions which makes real time hardware implementation a challenging task. In this paper, the methodology of a fully pipelined architecture design by using FPGA is explained to meet the real time requirements of affine transformation for high resolution video streams. A fully pipelined tile based engine was created in order to perform transformation by aiming maximizing throughput. The design was implemented on Altera's Stratix V FPGA as a real-time system that has the capability of processing full HD video streams.

10223-9, Session 2

Development of an FPGA based video image frame enhancement system

Can Ugur Oflamaz, ASELSAN A.S. (Turkey); Umut Sezen, Hacettepe Univ. (Turkey)

Nowadays high resolution videos are required in applications such as security, satellite, military applications etc. Herein the resolution of detectors is one of the bottlenecks. In this study, increasing the resolution of video streams by using super-resolution technique is examined for real-time systems. For this purpose, an FPGA architecture with low cost hardware

is designed. Video frames are transmitted in real time from the camera to the screen by increasing the resolution. Basically, an FPGA processing unit with the ability to perform parallel processing is used in the center of the hardware and the multi-frame super-resolution method, which is effective in producing high quality images from a collection of low resolution photographic images, is used. The algorithm is implemented using RTL coding for motion estimation and reconstruction parts which are the sub-units of the super-resolution method. Integral projection model approach, which is similar to block matching algorithm, is used for the part of motion estimation at the subpixel level. For reconstruction part, bilinear interpolation at HR grid is applied. System parameters are identified and optimized, then simulations are carried out to determine the performance rates and the obtained results are evaluated accordingly. The results show that the performance of the generated algorithm is much better than the bilinear interpolation in the event that the input picture frames contain turbidity in all SNR values. In conclusion a low cost, real time and robust to noise video image frame enhancement system is designed and implemented. This platform can be used in vision systems to increase system performance.

10223-10, Session 2

Real-time implementations of image segmentation algorithms on shared memory multicore architecture: A survey

Mohamed Akil Sr., ESIEE Paris (France)

The real-time processing is getting more and more important in many image processing applications. Image segmentation is one of the most fundamental tasks image analysis. As a consequence, many different approaches for image segmentation have been proposed. The watershed transform is a well-known image segmentation tool. The watershed transform is a very data intensive task. To achieve acceleration and obtain real-time processing of watershed algorithms, parallel architectures and programming models for multicore computing have been developed.

This paper focuses on the survey of the approaches for parallel implementation of sequential watershed algorithms on multicore general purpose CPUs: homogeneous multicore processor with shared memory.

To achieve an efficient parallel implementation, it's necessary to explore different strategies (parallelization/distribution/distributed scheduling) combined with different acceleration and optimization techniques to enhance parallelism.

In this paper, we give a comparison of various parallelization of sequential watershed algorithms on shared memory multicore architecture. We analyze the performance measurements of each parallel implementation and the impact of the different sources of overhead on the performance of the parallel implementations. In this comparison study, we also discuss the advantages and disadvantages of the parallel programming models. Thus, we compare the OpenMP (an application programming interface for multi-Processing) with Ptheads (POSIX Threads) to illustrate the impact of each parallel programming model on the performance of the parallel implementations.

10223-11, Session 3

Dual field combination for unmanned video surveillance systems

Louise Sarrabezolles, Institut Franco-Allemand de Recherches de Saint-Louis (France); Antoine Manzanera, Ecole Nationale Supérieure de Techniques Avancées (France); Nicolas Hueber, Pierre Raymond, Maxime Perrot, Institut Franco-Allemand de Recherches de Saint-Louis (France)

Unmanned systems used for threat detection and identification are still not efficient enough for monitoring autonomously the battlefield. The limitation on size and energy makes those systems unable to use most state-of-the-art computer vision algorithms for recognition.

The bio-inspired approach based on the human's peripheral and foveal visions has been reported as a way to combine recognition performance and computational efficiency. As a low resolution camera observes a large zone and detects significant changes, a second camera focuses on each event and provides a high resolution image of it.

While such biomimetic existing approaches usually separate the two vision modes according to their functionality (e.g. detection, recognition) and to their basic primitives (i.e. features, algorithms), our approach use common structures and features for both peripheral and foveal cameras, thereby decreasing the computational load with respect to previous approaches.

The proposed approach is evaluated using simulated data. Although the recognition performance is still not at the level of the best algorithms, the outcome proves particularly attractive for real time embedded systems, as the primitives (features and classifier) have already proven good performances in low power embedded systems. This first result reveals the high potential of dual views fusion technique in the context of long duration unmanned video surveillance systems. It also encourages us to go further into miming the mechanisms of the human eye. In particular, it is expected that adding a retroaction of the fovea towards the peripheral vision will further enhance the quality and efficiency of the detection process.

10223-12, Session 3

High bandwidth, real-time video transport with ARINC 818

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

Modern Avionics systems are starting to include a wide variety of sensors and camera systems for applications such as night vision, degraded vision, and other sensors. Systems that require multiple coordinated sensors (including sensor fusion) used for ISR, navigation in degraded environments, or infrared countermeasures are constantly trying to increase throughput to carry higher resolution images and video in real-time and with low latency. The need for ever higher throughput challenges system designers on every level, including the physical interface. Simply moving video efficiently from point to point or within a network in itself is a challenge. ARINC 818, the Avionics Digital Video Bus continues to expand into real-time video applications because of its low latency, robustness, and high throughput capabilities. This paper explores architectures based on both high speed coax and fiber optic ARINC 818 links, which include: time multiplexing multiple sensors onto single links, high speed regions of interest, channel bonding of video signals, bi-directional communication over a single link, and ultra-high speed (56Gbps) interfaces. Results will be presented from prototype implementations that enable all of the above technical objectives.

10223-13, Session 3

Real time video analysis to monitor neonatal medical condition

Mukul V. Shirvaikar, Premananda Indic, The Univ. of Texas at Tyler (United States)

One in eight live births in the United States is premature and these infants have complications leading to life threatening events such as apnea (pauses in breathing), bradycardia (slowness of heart) and hypoxia (oxygen de-saturation). Infant movement pattern has been hypothesized as an important predictive marker for these life threatening events. The estimation of movement along with behavioral states, as a precursor of life threatening events, can be useful for risk stratification of infants as well as for effective management of disease state. This information includes important cues such as sleep position and the status of the eyes, which are important markers for neonatal neurodevelopment state.

This paper explores the feasibility of using real time video analysis to monitor the condition of premature infants. Sample images and videos from premature infants in neonatal hospital units are analyzed to identify possible features that can be used to determine infant awareness and position. The image of the infant can be segmented into regions to localize and focus on specific areas of interest. Relational analysis of the segmented regions can be performed to identify different parts of the body including the eyes, face, hair, arms, legs and torso. A model based approach to pose estimation can then be applied to classify the infant as being in a particular pose. The same approach can also be applied for infant awareness determination. Such a monitoring system would be of great benefit as an aide to medical staff in neonatal hospital settings requiring constant surveillance.

10223-14, Session 3

Projection based video stabilization for moving platforms

Lütfi M. Gevrekçi, Mehmet Aktukmak, Can Ugur Oflamaz, Berk Ülker, Meriç Koray Karakurt, ASELSAN A.S. (Turkey)

Video stabilization is a critical component in jittery imaging platforms. Feature-based video stabilization is computationally exhaustive for low-power processors to accomplish especially in the real-time systems. Our proposed solution is suitable for platforms where video stream is roll (rotation) compansated. Remaining translational jitter is compansated using our efficient stabilization routine. In this work, horizontal and vertical projections of an image are computed and resampled to sub-pixel accuracy on FPGA device. Then, projections are transferred from FPGA to DSP, instead of the whole image, for computing shifts, which leads to minimizing bandwidth of data flow between devices. A bracketing search algorithm is proposed to detect the sub-pixel shift by comparing image projections in time. Instantenous shifts are Kalman smoothed and the undesired jitter is motion compansated. An efficient FPGA block is implemented for tranlational motion compansation on interlaced video stream with minimum system delay. Our novelty lies in the systems solution and the efficiency of the stabilization proposed framework for systems where an estimated LOS roll angle is available.

10223-15, Session 4

Pre-processing techniques to improve HEVC subjective quality

D. Guillermo Fernandez, Alberto A. del Barrio, Guillermo Botella, Carlos E. García, Manuel Prieto-Matías, Univ. Complutense de Madrid (Spain)

Nowadays, HEVC is the cutting edge encoding standard being the most efficient solution for transmission of video content. In this paper a subjective quality improvement based on pre-processing algorithms for homogeneous and chaotic regions detection is proposed and evaluated for low bit-rate applications at high resolutions. This goal is achieved by means of a texture classification applied to the input frames.

Furthermore, these calculations help also reduce the complexity of the HEVC encoder. Therefore both the subjective quality and the HEVC performance are improved.

10223-16, Session 4

Beyond the High Efficiency Video Coding Standard: an overview

Christos Grecos, Central Washington Univ. (United States)

The Joint Video Exploration Team (JVET) [1,2] was established in October 2015 to explore possibilities of improving the performance of the latest state of the art High Efficiency Video Coding Standard (HEVC or otherwise known as H265). The Joint Exploration Model (JEM) developed by JVET in February 2016 showed improvements in rate reduction by 14% in the luminance channel (Y) and 12% in the two chrominance channels (U and V) for the All Intra configuration. It further showed improvements in rate reduction by 20% in the luminance channel (Y) and around 16% in the two chrominance channels (U and V) for the Random Access configuration. Both these configurations had resolutions ranging from 720p to 4kx2k pixels.

Many tools aided these improvements [1,2] such as larger Coding Tree Unit size (CTU) up to 256X256 pixels, improved adaptive loop filters, cross component linear model predictions, sub-prediction unit level motion merging, overlapped motion vector compensation, frame rate up-conversion mode, bi-directional optical flow, affine motion vector prediction, local illumination compensation, 64x64 pixels transform, adaptive multiple core transforms (AMTs), non-separable secondary transforms (NSSTs), position dependent intra prediction, reference sample adaptive filtering, additional boundary filters for intra prediction, 4-tap interpolation for intra prediction, 65 angular intra prediction directions, neighborhood transform coefficient context modelling, temporal Context Adaptive Binary Arithmetic Coding (CABAC) initialization, CABAC update with adaptive window sizes and CABAC probability estimation using 2 windows. The addition of Quad-tree Plus Binary Tree Structure (QTBT) and further Adaptive Loop Filter (ALF) improvements promise a further 6% reduction in rate for the same quality.

This paper will describe the above tools in some level of detail

References

1) JVET B0001-B1011 (http://phenix.it-sudparis.eu/jvet/)

2) JVET C0001-C1011 (http://phenix.it-sudparis.eu/jvet/)

10223-17, Session 4

An efficient HW&SW design of H.264 video compression, storage and playback on FPGA devices for handheld thermal imaging systems

Ismail Özsaraç, Omer Gunay, ASELSAN A.S. (Turkey)

Video storage has been an essential property of new generation military imaging systems. Beside this, in many military applications playback of the stored video on the same device provides many operational benefits to the end users. H.264/AVC (Advanced Video Coding) is still one of the most used industrial video coding technique. Power consumption and device size are very important for many military imaging systems especially for handheld devices. For this reason, it became a must to process video, compress, store, decode , playback it and doing other system functions on a single programmable chip such as FPGA, DSP, GPU or ASIC. In this work, video compresion, video storage, video decode and video plackback blocks are efficiently designed on FPGA platforms using FPGA fabric and Altera NIOS II soft processor. Many subblocks which are used in video coding are also used during video decoding in order to save FPGA resources and power. Computationaly complex blocks are designed using FPGA fabric and blocks such as SD card file system write/read, H.264 syntax decoding and entropy decoding are done using NIOS processor to benefit software flexibility and ease. The design was tested using CYCLONE V FPGA which is the ALTERA's lowest power FPGA family. Designed blocks support every video resolution and frame rates which are supported by H.264 standard. Also, for low power purpose the design does not need an external memory and on the average consumes lower than %35 of CYCLONE V 5CEFA7 FPGA resources.

10223-18, Session 5

Inferring patterns in live video computing query streams

Alex Aved, Air Force Research Lab. (United States)

Collecting, aggregating and interpreting data to understand ongoing patterns and identify rare events in real time is a prerequisite for cognizant decision-making. Key information comes from video sensors; whether mounted aerial platforms or fixed structures. The vast quantity and complexity of available data is increasing, making at-a-glance processing, exploitation and dissemination infeasible without the aid of intelligent software (algorithms to learn models and the corresponding execution). This software layer provides a means for users to access and query raw data that was collected. Consumption of live video requires end users to watch the video, record activities, and take other actions as necessary (such as summarizing activities that occurred in a shift). The underlying aspiration of this research is to leverage deep learning to break the linear relationship between collection and analysis, such that people are leveraged for their synthesis and insight, and computers for calculations and memory. The specific focus is on event specification and pattern detection; analysts will conceptualize events in terms of patterns and leverage computers for video sensor fusion, real-time big data analytics and machine learning. Activities and events are specified in the form of queries, where a query is a series of declarative spatio-temporal conditions that result in a continuous data stream of query evaluations. Deep learning models and methods can then be employed to infer, predict and classify patterns exhibited in the stream, and correspondingly, events.

10223-19, Session 5

Camera network video summarization

Rameswar Panda, Amit K. Roy-Chowdhury, Univ. of California, Riverside (United States)

Networks of vision sensors are deployed in many settings, ranging from security needs to disaster response to environmental monitoring. Many of these setups have hundreds of cameras and tens of thousands of hours of video. The difficulty of analyzing such a massive volume of video data is apparent whenever there is an incident that requires foraging through vast video archives to identify events of interest. As a result, video summarization, that automatically extract a brief yet informative summary of these videos, has attracted intense attention in the recent years. Much progress has been made in developing a variety of ways to summarize a single video. However, generating a summary from a set of videos captured in a multi-camera network still remains as a novel and largely under-addressed problem.

Motivated by the fact that each video in the set may contain some information that other videos do not have, we develop a novel sparse optimization framework that can extract a single informative summary by exploring the complementarity structural information present within multiple views. We propose a novel diversity regularizer in the optimization framework to explore the complementarity within multiple videos by penalizing the condition that two correlated shots from two distinct videos are present in the summary at the same time. We then present an alternating minimization algorithm based on half-quadratic function theory to solve the proposed non-smooth and non-convex objective with strong theoretical analysis. Extensive experiments on standard multi-camera datasets well demonstrate the efficacy of our method over state-of-the-art methods.

10223-20, Session 5

Low complexity scheme with JPEG-LS for near-lossless, multi-component and selective compression

Yakup Murat Mert, TÜBITAK BILGEM ILTAREN (Turkey)

This study focuses on improving compression capability of a single band JPEG-LS encoder with preprocessing unit. Main motivation is preserving its low complexity and integrity. Although JPEG-LS standard describes near-lossless and multicomponent compression procedures, a conveniently designed preprocessor unit can easily cause a JPEG-LS encoder gain these capabilities without change on itself. Similarly, its compression performance can be improved with selective compression. Idea depends on the detection of regions with cloud, water and snow and remapping the corresponding pixels using preprocessing so that highest compression with the JPEG-LS can be yielded. These regions are detected employing their spectral bands as they have distinct spectral signature and contain no significant information. Hence, Regions out-of-interest can be compressed regardless of the outcome quality. Through analyses are achieved on satellite images for all cases with software. Besides, designed preprocessor unit is implemented with field-programmable-gate-array (FPGA) and implementation details are provided.

10223-21, Session PTue

Parallel halftoning technique using dot diffusion optimization

Javier Molina-Garcia, Volodymyr I. Ponomaryov, Rogelio Reyes-Reyes, Clara Cruz-Ramos, Instituto Politécnico Nacional (Mexico)

Digital Halftoning is the process to convert a gray-scale image into a binary one using multiple dots. This technique has many applications, in particular in compression, in processing videos and images, etc. Inverse Halftoning is used to restore a gray-scale image from a binary one and is widely applied in removal of aliasing artifacts, contrast enhancement, resizing, etc. There are many algorithms for inverse Halftoning, in which this technique is formulated as an inverse deconvolution process. These methods can be found in Wavelet Transform (WT), Multilayer Perceptron Artificial Neural Network (MLP-ANN), Sparse Representation, among others.

In this paper, a novel approach for halftone and inverse halftone images are proposed and implemented for images that are obtained by the Dot Diffusion (DD) method. Designed technique is based on an optimization of the so-called Class Matrix used in DD algorithm and it consists of dividing the original image into edges, texture and smooth regions where for each region a different Class Matrix is used in order to generate the halftone image. One of the advantages of the DD method against the state-of-the-art techniques is that this method can be parallelized when fast implementation is needed.

During the process of inverse Halftoning a Gaussian filter is employed for smoothing the halftone image and to get an approximation to the original gray-scale one. After that, informative regions such as the edges and fine details of the image are preserved using a bilateral filter. Finally, a post-processing phase is done to improve the results on the inverse halftone image. The proposed method using different architectures of parallel computing is implemented by developing two parallel frameworks utilizing all the CPU cores and GPU architecture to realize real-time processing procedure.

The obtained results are evaluated by comparing the ensued inverse halftone image and the original one in a visual subjective perception and via objective criteria via Peak Signal-to-Noise Ratio (PSNR), Structural Similarity Index Measure (SSIM) and Mean Absolute Error (MAE). Experimental results have shown that the proposed method generates a good quality in the halftone and inverse-halftone images. Also, the simulation results using parallel architectures have demonstrated the efficiency of the proposed method to be implemented in real-time conditions.

10223-22, Session PTue

Parallel steganography framework for hiding a color image inside stereo images

Volodymyr I. Ponomaryov, David Muñoz-Ramirez, Rogelio Reyes-Reyes, Clara Cruz-Ramos, Instituto Politécnico Nacional (Mexico)

In the last years, the 3D content is more accessible due to the exposure of many devices where it is possible to use hiding techniques such as steganography.

In this work, a robust steganography framework is proposed to hide a color image into a stereo image.

The designed inserting algorithm is performed via Discrete Cosine Transform (DCT) and the Quantization Index Modulation Dither Modulation (QIM-DM) hiding the secret data. Additionally, we applied Arnold Transform in order to scramble the secret image guaranteeing better security and robustness of the proposed system.

We divide the secret image in two parts, where one half is stored in low-frequency coefficients of DCT from the right image and the other half in the left image of stereo pair. Designed framework appears to demonstrate the robustness offered by the Least Significant bit (LSB) insertion algorithm. We noticed that novel framework has demonstrated better performance against JPEG compression attacks in comparison with Discrete Wavelet Transform (DWT).

The proposed scheme is developed in two variants: multi-core CPU and GPU performing parallel computing with purpose to increase the processing speed.

The designed scheme has been evaluated by the Peak Signal-to-Noise Ratio (PSNR), Structural-Similarity Index Measure (SSIM) and Bit Error Rate (BER) as quality assessments. Additionally, a visual comparison between the original stereo pair images (left and right) and the marked by hiding images stereo pair are presented. The experimental results have shown that the proposed framework can hide a digital color image into stereo images, demonstrating sufficient robustness against JPEG compression attacks and high imperceptibility.

10223-23, Session PTue

Information fusion based techniques for HEVC

D. Guillermo Fernandez, Alberto A. del Barrio, Guillermo Botella, Univ. Complutense de Madrid (Spain); Anke Meyer-Bäse, Uwe Meyer-Baese, Florida State Univ. (United States)

Aiming at the conflict circumstances of multi-parameter H.265/HEVC encoder system, the present paper introduces the analysis of many optimizations set in order to improve the trade-off between quality, performance and power comsumption for different reliable and accurate applications. The method is based on the Pareto optimization and has been tested with different resolutions on real-time encoders.

10223-24, Session PTue

Real-time depth processing for embedded platforms

Oscar M. Rahnama, Philip H. S. Torr, Univ. of Oxford (United Kingdom)

Obtaining depth information of a scene is an important requirement in many computer-vision and robotics applications. For embedded platforms, passive stereo systems have many advantages over their active counterparts (i.e. LiDAR, Infrared). They are power efficient, cheap, robust to lighting conditions and inherently synchronized to the RGB images of the scene. However, stereo depth estimation is a computationally expensive task that operates over large amounts of data. For embedded applications which are often constrained by power consumption, obtaining accurate results in real-time is a challenge. We demonstrate an efficient implementation of a stereo block-matching algorithm in FPGA. The computational core achieves a throughput of >400 fps at standard VGA resolution whilst maintaining suitably low power consumption for embedded applications.very limited amounts of power. The data is processed using an in-stream approach that minimizes memory-access bottlenecks and best matches the raster scan readout of modern digital image sensors.