Conference Program

Imaging and Applied Optics

OSA Optics & Photonics Congress

Adaptive Optics: Methods, Analysis and Applications (AO)
Applied Industrial Optics: Spectroscopy, Imaging & Metrology (AIO)
Computational Optical Sensing and Imaging (COSI)
Fourier Transform Spectroscopy (FTS)
Imaging Systems and Applications (IS)
Propagation Through and Characterization of Distributed Volume Turbulence (pcDVT)
Quantitative Medical Imaging (QMI)

Renaissance Arlington Capital View
Arlington, Virginia, USA

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AluS3 • AOD Performance
Metrics Discussion — Continued
AOD has become increasingly commonplace across a diverse range of applications. Maturation of AOD methods along with technology developments have pushed the performance limits of both laboratory and commercial AOD systems. With these developments there is increasing need for simple, yet effective metrics to assess AOD performance. This is particular pressing for commercial applications, as for example in clinical ophthalmology, where the systems are operated by non-technical personnel. While different applications may require different AOD metrics, use of the same AOD fundamentals suggests there may also be much commonality. These issues will be explored in this session through a panel led discussion of leading AOD experts. Please come with your own AOD metric questions for the panel.

AluS3.2 • 15:10
New Iterative Algorithms for Multi-Angle Lidar
Gary G. Goultter1, David Roberts2
1Electro-Optical Systems Laboratory, Georgia Tech Research Inst., USA. New algorithms are shown for inverting data from angle-scanning lidars. In contrast to algorithms for finding the atmospheric extinction coefficient, the new algorithms find the range-dependent atmospheric transmittance. Great simplifications result from this new approach.

AluS3.3 • 15:50
Space-based Lidar and Interplanetary Laser Ranging
and Communication Experiments Performed by NASA GSFC, Chief Investigator: Laser Remote Sensing Lab, NASA Goddard Space Flight Center, USA. NASA Goddard Space Flight Center (GSFC) has developed a series of space lidar and successfully reprocessed Mars, Earth, Mercury and Moon. Interplanetary laser ranging and communications were also conducted from Earth to those space objects.

ChuS3.4 • 15:50
Compensative Effects of Positiveity in Cohen- causan Retrieval, Zhengyan Zhang, George Babaktsoglou
1Singapore-MIT Alliance for Research and Tech (S-MaTr) Singapore, Mechanical Engineering, Massachusetts Inst of Technology, USA. Positivity is often used in coherence retrieval to improve reconstruction fidelity and enforce physical plausibility of the result. We show that its use induces compensation errors like behavior when the mutual intensity matrix has low rank.

FluS3.4 • 15:50
Performance of a Cryogenic 21 meter-path Herriot cell conceived to probe a Raman 1632 nm system, Kazunari Sagi, K. Yoshifumi, J. Masayoshi, M. Y. H. Smith, J. C. Crawford, H. H. K. Sherlock, M. Y. D. V.enty, Science Division, Jet Propulsion Lab/Caltech, USA. Dept. of Physics, Astronomy and Geophysics, University College, USA: Science Directorates, NASA Langley Research Center, USA; Dept. of Physics, The College of William and Mary, USA. A cryogenic 21 meter-path Herriot cell designed for a broad-band Fourier transform infrared spectrometer, a Bruker 125HR, was recently developed at Connecticut College. The cell interferometer system has excellent temperature and photometric stability over a wide temperature range.

FluS3.5 • 15:50
Fiber probe for the spectral range of 5-45 µm for IR Fourier spectrometer, Liya V. Zel'manov, Alexander S. Korobov, Dmitry S. Vasil'kovsky, Andrey I. Chaban, Viktor S. Korobov, Sergey V. Kastor, Yildiz DFDU, Russian Federation. We report on a fiber probe (FPT-5-45 µm). The fiber is extracted from new crystals based on silver and nonvolatile thallium halide solid solutions.

FluS3.6 • 15:50
Lidar Lab Experiment—Continued
FluS3.2 • 15:50
Accurate laboratory atomic and molecular data for astrophysics applications by high-resolution Fourier transform spectroscopy, Juliet C. Pickering, Matthew Ruffin, Florence Laguioni, Annie P. Thome, Imperial College London, UK. Accurate high resolution atomic and molecular data are required for interpretation of many astrophysical spectra. The Imperial College London laboratory astrophysics program using high-resolution Fourier Transform spectroscopy is described.

FluS3.3 • 15:50
Development of an FT-S-based Spectral Responsivity Comparator, Joseph P. Rice, Jorge Nies, NIST, USA. We have developed a method of measuring the absolute spectral responsivity of infrared detectors using a Fourier Transform Spectrometer (FTS) coupled to a liquid-helium-cooled Electrically-Stabilized Boltzmann (ESB) as a reference detector.

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These concurrent sessions are grouped across two pages. Please review both pages for complete session information.

**Ti5E • Military Applications—Continued**

**Flu3.E • 15:10**
Rapid focal shifting for inline 3D Image Capture, Daniel C. Georg, Hunghang Chen, Joseph Czechowski, Kevin Harding, "US Global Research, USA. We present a novel lens system with high-resolution and wide field-of-view for 3D image capture. A depth-from-focus algorithm is implemented to reconstruct 3D object and matched with a fixed image to create a 3D view.

**Flu3.E • 15:30**
Color image formation for multiscale gigapixel imaging, Zheng He, John A. Galash, Qian Gong, Kevin Kelly, "David Kittle, Steve Rollins, David I. Bray, "Michael Gehman, "Univ. of Arizona, USA; Duke Univ., USA. We present the current development of the image formation pipeline for color gigapixel images obtained by the ARIEAL-10 multiscale camera. We introduce a camera simulator, the modifications to the scalable pipeline, and the challenges for creating seamless color gigapixel panoramas.

**Flu3.E • 15:50**
Quantitative monoscopic objective lens, Igor Stanimirov, Dmyt P. Agapov, Joseph Ford, "Univ. of California San Diego, USA. Monoscopic lenses enable panoramic, high-resolution imaging, but have not been fully explored. We present algorithms for systematic optimization of monoscopic objectives, and show the tradeoff between lens complexity and focal length, numerical aperture and spectral bandwidth.

**Ti5F • 15:10**
Detection of Orbital Angular Momentum in Optical Waves Propagating through Distributed Volume Turbulence, Denis W. Oudsh, Darryl Sanchez, Anita Gallagher, Jason Holman, Terry Ferguson, "Julie Smith, "William Gibson, "Tom C. Farrell, "Patrick R. Kelly, "US Air Force Research Laboratory, USA; "US Air Force Research Laboratory, USA; "US Air Force Research Laboratory, USA; "US Air Force Research Laboratory, USA. We demonstrate the use of optical vortices to track the propagation of photonic orbital angular momentum in wave front sensing measurements of beams propagating through distributed volume turbulence.

**Ti5F • 15:30**
The creation of photonic orbital angular momentum by molecular clouds, Darryl J. Sanchez, Denis W. Oudsh, Patrick R. Kelly, "US Air Force Research Laboratory, USA; "US Air Force Research Laboratory, USA. Here we establish that galactic atomic and molecular clouds create photonic orbital angular momentum (POAM). Then, summarize a set of on-sky experimental observations which corroborate the laboratory results.

**Ti5F • 15:50**
Photonic Orbital Angular Momentum from HR 1895, Denis W. Oudsh, Darryl J. Sanchez, Patrick R. Kelly, "Science Applications International Corp., USA; "Auburn University, USA; "Observatory of HR 1895 for photonic orbital angular momentum captured two significantly different signals in three separate measurements. Here we show the outlying point is a strong photonic orbital angular momentum signal.

**QF3G • 15:10**
Numerical simulation of the influence of optical absorption of tumor on laser induced ultrasound in soft tissue, rengang sun, "Shansun Liu, "Zhonghao Shen, "School of Science, Nanping Uni. of Science and Technology, China. The use of a pulsed laser for the generation of the elastic waves in soft tissues containing tumors with different optical absorption in the thermoelectric regime is investigated through the finite element method and experiments.

**QF3G • 15:30**
High-throughput quantitative fluorescence lifetime imaging based on active wide-field illumination, Lingling Zhao, "Ken Abe, "Margaret Barrows, "Xavier Intar, "Rensselaer Polytechnic Inst., USA; "Auburn Medical College, USA. We developed an active illumination strategy to acquire fluorescence signals over large fluorescence concentration distributions. It can improve the S/NR and weak signal sensitivity for enhanced accuracy of lifetime estimation at high acquisition speed.

**QF3G • 15:50**
Determination of detection limitation of NIRF device using Quanta Bio directed fluorescence labeled phantoms, Naigou Zhai, "John C. Ramseyer, "Ivo M. Smith, "Research, "UT Health Science Center, USA. Solid fluorescence phantoms were constructed to assess detection limitations of investigational NIRF imaging devices. The phantoms enabled the quantitative assessment of the fluorescent status of lymph nodes following resection from breast cancer patients.

**Ti5F • 15:10**
Advective digital holography for gain-enhanced imaging, Abbie T. Watten, Paul S. Lehner, "US Naval Research Laboratory, USA. An iterative feedback loop using a spatial modulated probe provides wavelength-shaping in a holography experiment. In addition to hardware components, an algorithmic technique to provide uniform illumination to the target prevents image overlapping.

**Flu5.F • 15:10**
Propragation of the Optical Rotational Correlation Field and Orbital Angular Momentum through Turbulence, Missouri Nature, "David Wadell, "New Mexico State University, USA. We consider a general formulation that describes the propagation of the rotational correlation field through atmospheric turbulence. The associated influence on spatial distribution of the orbital angular momentum of a single photon is analytically determined.
JfuA.23 
Raman Scattering Method for Fiber Bundle Microscopy Using Interpolation Based on Overlapping Self-Shielded Images, Chen Tang; Jie Li; Sheng-Min Chi; Jie-Hue Han; Korea Tech. Univ., Republic of Korea. A method for using fiber bundle microscopy incorporating honeycomb artifacts is demonstrated based on interpolating pixels using overlapping images. The imaging result with biological specimen shows improved image quality with minimal degraded sharpness as well.

JfuA.24 
Fiber Scanning Array for 3 Dimensional Topographic Imaging, Barry Carbonell; David Babst; Domenico Pizzuto; Bryan Blair; Paul R. Szymczak; Richard Key; Greg Clarke; Jack Walkera: NASA Goddard Space Flight Ctr., USA; Physics, American Univ., USA; Global Science Tech, USA. This design presents a 35 beam switched fiber optic array 3-D LIDAR. The instrument distributes 35 pulses over a target and assembles the return into 3 D images for Earth and planetary monitoring.

JfuA.25 
The optimization of PPIX formation at different skin layers using ALA evaluated by widefield fluorescence imaging and fluorescence spectroscopy, Prathapa Muanzsi, Optics, INSA; USA; Brazil. The PDT using P.ALA as a precursor to PIPX has been used in the skin cancer treatment. This work aims to evaluate the influence of negative pressure reduction in the PPIX formation using imaging and spectroscopy fluorescence analyses.

JfuA.26 
Single Source Stereoscopic Camera for Robot Navigation, Chong Wook Park; Seung Ho Jun; Korea Electronic Technology Inst., Republic of Korea. This paper presents a new stereoscopic camera system to acquire depth information from robot operating environments with obstacles, human bodies, and home facilities.

JfuA.27 
Improving retinal images by avoided-based ocular point spread function estimation, Xinna Min; IEEE, T. Blide; Physics, Technion - Israel Inst. of Technology, Israel. In vivo retinal imaging is often limited by high optical aberrations. We demonstrate a method to enhance the contrast of retinal cells by estimating the ocular PSF, this is done by retinal cells’ modeling.

JfuA.28 
Aperture design in wedge projection display for on-axis imaging system, Chang Kian Lee; Youngro Jeong; Sung-Wook Min; Byungho Lee; School of Electrical Engineering, Seoul National Univ., Republic of Korea. We analyze the relation between the aperture and wedge angle parameters. We derive the numerical equation for on-axis imaging with prism structure. Experimental results show that proposed structures enhance image quality and expand expressible area.

JfuA.29 
Multi-parameter Sensing Based on Graded-index multimode fiber, Jianpeng Zhang; Harbin Engineering Univ., China. We demonstrate a smart optical fiber sensor unit, based on combing a Bragg grating in graded-index multimode fiber and a flexure cavity, to realize a multi-parameter sensing of temperature, curvature, strain or displacement.

JfuA.30 
Development of a Fast Measurement System for Microstructured Surfaces, Renate Scheur, Thomas Museler, Edward Kelmheim; Inst. of Measurement and Automatic Control, Leibniz Univ. Hannover, Germany. This paper describes the development of a measurement system for fast analysis of microstructured surfaces. The main component is a high-speed video camera with a telecentric lens. Measurement speed of 1000 mm/min can be achieved.

JfuA.31 
Dynamics phase contrast of a thin film using a single-shot polarizing phase shifting interferometry, Noel Jinnio-Tsai; Daniel Serrano-Garcia; Luis Garcia-Lechuga; Juan Marco Miranda Gómez; Germán Benardó López; Angelica Contreras Rosas; Optica y Fotónica, Universidad Tecnológica de Tultepec, Mexico; Laboratorio de Mecanometría III, Centro de Investigaciones en Optica, A.C. Mexico. In this paper, we propose a Quasi Constant-Path interferometer based on using two beams configuration using stigmator phase shifting interferometry modulated by polarization that shows high sensitivity against external vibration. Experimental results are also given.

JfuA.32 
3D Optical Metrology of Finite sub-20 nm Dense Arrays with sub-nanometer Parametric Uncertainty, Eng Qin; Hai Zhiou, Bryan Banard; Donald Voss; Richard M. Scheller; Semiconductor and Dimensional Metrology Division, NIST, USA. A new approach that involves parametric fitting of 3-D scattered field with electromagnetic simulation, Fourier domain normalization, and uncertainties analysis is presented to rigorously analyze 3-D through-focus optical images of targets that scatter a continuum of frequency components.

JfuA.33 
Random optical scatter filters for spectrometers: Implementation and Estimation, Woenig Ji Lee; Oliver Jansen; Seung Chul Kim; Hyoung-No Lee; Department of Information and Communications, Konkuk Inst. of Science and Technology, Republic of Korea. In this paper, we introduce an implementation of filters with random transmittance for miniature spectrometers with limited number of CCD elements. We also present a method for estimating the random transmittances, which are needed for recovering the signal spectrum.
Random optical scatter filters for spectrometers: Implementation and Estimation

Woong-Bi Lee, J. Oliver, Seung-Chul Kim, and Heung-No Lee
School of Information and Communications, Gwangju Institute of Science and Technology, South Korea. wblee@gist.ac.kr, oliver@gist.ac.kr, kscmail@hanmail.net, heungno@gist.ac.kr

Abstract: In this paper, we introduce an implementation of filters with random transmittance for miniature spectrometers with limited number of CCD elements. We also present a method for estimating the random transmittances, which are needed for recovering the signal spectrum.

OCIS codes: (300.6320) Spectroscopy, high-resolution; (120.2440) Instrumentation, measurement, and metrology, filters

1. Summary

Miniature spectrometers play a major role in various academic and industrial applications such as bio-medical, chemical, and environmental engineering [1]. A family of spectrometers that are built with an array of optical filters offers miniaturization, superior portability, and cost effectiveness [2]. The spectrometers measure properties of light source over various spectral components [3].

The state of the art filter-array based spectrometers are equipped with digital signal processing (DSP) algorithms to alleviate distortions and to reconstruct the original signal spectrum. The resolving ability of these spectrometers is determined by the number of filters in the filter array and the shapes of the transmittance functions (TF) of these filters [4]. In practice, due to low-cost integrated-array fabrication, the number of filters in miniature spectrometers is fixed (and hence the CCD elements) and the shape of the TF of each of the filters is non-ideal as in [5]. A signal spectrum passing through these non-ideal filters is severely distorted. Hence, digital signal processing of the spectrum measured by the spectrometer is necessary. In [5], the $L_1$ norm minimization-based DSP algorithm is used for processing the signal spectrum obtained from the spectrometer. In [6], filters with random TFs are proposed that was used along with the DSP algorithm in [5] for recovering the input signal spectrum. The random filters have two main properties. First, the transmittance of a filter at one wavelength is completely different and uncorrelated with that at the other wavelength. Second, the shape of each filter’s transmittance is uncorrelated with other filters in the filter-array. With these random TFs, in [6], a mercury signal spectrum was shown to be successfully recovered better than using filters with non-ideal TFs in [5]. However, in [6], the TFs of random filters are generated by randomly varying the thickness of the layers in thin-film filters.

In this paper, we propose a new implementation of the random transmittance filter-array by attaching scatter filters with random TFs to the existing grating in a spectrometer. Our approach is different from [6] in that now the estimation of the random TFs is necessary to recover the original signal spectrum using the DSP. We estimate the random TFs by modeling the raw spectrum from the spectrometer and show through real world experiments that random filters can be implemented and aid in the recovery of an input signal spectrum.

![Fig. 1. Schematic of the proposed filter-array based spectrometer](image)

We consider a spectrometer that consists of a planar filter array (filter elements attached to a grating) with $M$ filters and its corresponding CCD array as shown in Fig. 1. Each filter randomly selects (transmits) the input wavelength components which are recorded by the CCD. The output of the CCD is sampled in analog-to-digital converter (ADC) and fed into a DSP unit to estimate the spectrum. The data model for the raw spectrum, $y \in \mathbb{R}^{M+1}$, which is an input to the DSP algorithm can be represented as a system of linear equations:

$$ y = Dx + w, \quad x \geq 0 \quad (1) $$

where the $N \times 1$ vector $x$ contains the samples of the original signal spectrum, the matrix $D$ is an $M \times N$ TF matrix, and $w$ is $M \times 1$ noise vector. Each row of $D$ is a TF of a filter. Since the number of spectral components of $x$ is greater than the number of filters, the value of $N$ is greater than $M$, i.e., $N > M$. 
In order to estimate TFs, we observe $L$ number of raw spectrum by applying monochromatic light sources with various wavelengths. The observed $L$ raw spectrums can be put together as a single matrix equation as

$$ Y = DX + W \quad \text{where} \quad X \geq 0. $$

where the matrix $X$ is $N \times L$ input signal spectrum whose columns are signal spectrum of various light sources, the matrix $Y$ is $M \times L$ raw spectrum, and $W$ is $M \times L$ noise matrix. The goal of the TF estimator is to obtain an estimate $\hat{D} \in \mathbb{R}^{M \times N}$ of $D$ from the raw spectrum $Y$, given the matrix $X$. We obtain the estimate $\hat{D}$ as

$$ \hat{D} = Y \cdot \text{pinv}(X) $$

where $\text{pinv}(\cdot)$ represents the pseudo-inverse.

Once we obtain the TFs of the random filters, we rewrite Eq. (1) using sparse representation. Any natural signal or a vector $x$ in Eq. (1) can be represented as sparse in a certain basis, i.e., $x = Gs$. The basis $G \in \mathbb{R}^{N \times \ell}$ is called kernel matrix and the signal $s \in \mathbb{R}^{N \times \ell}$ is $K$-sparse vector, i.e., only $K$ components of $s$ are non-zero values and $N - K$ components are zero, where $K << N$. Each column of the matrix $G$ contains spectrum of a monochromatic light sources. That is, any signal spectrum can be represented by linear combinations of monochromatic light sources. With the sparse representation of the input signal spectrum, Eq. (1) can be rewritten as

$$ y = DGs + w = As + w \quad \text{where} \quad s \geq 0. $$

The DSP algorithm aims to obtain an estimate $\hat{s}$ of $s$ from the raw spectrum $y$, given the estimated TF matrix and $G$.

A recovery algorithm in [6] is based on a DSP optimization tool called $L_1$ norm minimization. The $L_1$ norm minimization for the recovery of the sparse signal $s$ in Eq. (4) can be expressed as

$$ \hat{s} = \min_s \|s\|_1 \quad \text{subject to} \quad \|DGs - y\| \leq \varepsilon, \quad s \geq 0 $$

where $\varepsilon$ is a small positive constant.

In the experiment, we have solved the problem in Eq. (5) for sparse signal recovery. We implement a filter-based spectrometer with following parameters: $M = 40$, $N = 800$, and $L = 255$.

As shown in Fig. 2, we generate 255 numbers of monochromatic light sources range from 428 nm to 682 nm. A monochromatic light source is divided into two sources. One is inserted into a spectrometer with random transmittance and the output $y$ is obtained. The other is inserted into a high resolution spectrometer which measure the input signal spectrum $x$. We repeat this experiment for $L$ times with different monochromatic light sources in order to model the raw spectrum as in Eq. (2) and estimate $\hat{D}$ as per Eq. (3).

![Fig. 2. Experimental setup of the proposed spectrometer](image)

Three of the estimated TFs are shown in Fig. 3. Each random filter captures holistic and independent information about the signal spectrum.
With the estimated TFs, $\hat{D}$, we verify the ability of the spectrometer with only 40 CCD elements in recovering the fluorescent light spectrum of 3 dominant wavelengths. As shown in Fig. 4, the spectrometers with random filter array can detect three distinct peaks of the source. We did not do much to the effect of noise in Eq. (2) and (4). In our future work, we aim to measure the statistical properties of the noise and use them to improve the results.

In conclusion, we have shown that the optical filters with random TFs in [6] can be implemented in the real world by placing randomly scattering filters between gratings and CCD array. The role of random filters is to acquire global information about the signal spectrum, rather than localized information which was the target of traditional designs. The set of global information captured by each filter helps the DSP algorithm to recover the input signal spectrum in detail. We demonstrated through experiments the signal spectrum recovering ability of the proposed random filters after estimating their transmittances.

Acknowledgement

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4. References