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Catherine D. Merrill
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Introduction

Optical systems are used just about everywhere today, in systems that both image and illuminate. From eyeglasses to machine vision/robotics to automotive uses, from commercial reprographic equipment to medical instrumentation to the production of integrated circuits, and from telecommunications through Earth observations, Space exploration, interferometers, nullers, and weaponry, optical systems are making a difference in our world. this conference is part of a sequence of similar conferences held in prior years that are dedicated to the optical modeling of these evolving imaging and non-imaging systems and the associated test-equipment needed to bring them forward with performance certainty. Note that models continue to be increasingly important as time-to-market pressures escalate and new missions are at times extending beyond the ability to accurately pre-test performance.

To predict performance over such a broad range of optical systems and engineering disciplines, there are a great many mathematical methods and tools that are needed. Some need to correctly model nano-scale systems with feature sizes comparable to the wavelengths of illumination, while others may need to address precise representations of controlled LED light leakage out of purposely roughened fibers or the fluorescent behavior of specific phosphors. Still others need to contend with components ranging from meta-materials with negative refractive index and cloaking to quantum dots, to special prisms or gratings, to large deployable telescopes where accuracies are measured in picometers or at levels approaching 1/10,000th wave RMS WFE. When we add in wavelengths and configurations that range from X-Rays to THz, and environmental aspects spanning HEL through cryogenic in configurations from the laboratory to under-water and outer-space, the number of modeling developments needed to accurately predict optical performance is immense.

Electro-optical modeling and performance predictions also often require integrating many interdisciplinary techniques and mathematical methods with underlying physics that build-upon and/or utilize (arranged by similarity, of-sorts):

Optical Models, Methods, and Performance Estimates

- geometrical and physical optics
- diffractive optics and holographic systems
- beam propagation
- meta-materials (including negative index, photonic crystals, cloaking)
- plasmonics

- polarization
- adaptive optics
- radiometry
- narcissus
- fiber-optics and photonics
- interferometers and nullers
- image doubling
- illumination (including lasers, LEDs, OLEDS, solar)
- stray light/ghosts
- quantum dots
- optimization
- phase/prescription retrieval
- tolerancing and probabilistic design.

Electro-optical Models Including Relating Factors
- detector quantum efficiency
- charge diffusion
- EMI/EMC influences on E-O performance.

Optical Coating Performance
- filters
- laser damage resistance.

MEMS and MOEMS
- electrostatics; Casimir forces
- structures.

Structural and Opto-mechanical Modeling
- ultra-lightweight optics, nano-laminates, membrane mirrors
- mounting stresses, G-Release, and /or launch and deployment
- high impact/shock and pressure loadings
- influence functions
- vibration and damping
- micro-dynamics and influences of piece-part inertia; friction/stiction
- mechanical influences such as scanning deformations and special zoom/servo effects
- thermo-elastic effects
- stress birefringence
- fracture mechanics, and/or micro-yield
- proof testing models
- aspects such as lay-up anisotropy and material inhomogeneity
- nodal accuracy; meshing.

Thermal and Thermo-optical Modeling
- effects of energy absorption with depth in transmissive elements

- thermal run-away in IR elements
- aircraft/UAV/Instrument windows, missiles, and domes
- solar loading
- thermo-optical material characterizations over new wavelengths and/or temperatures
- system sterilization
- hole drilling, welding, and laser heat- treating
- HEL effects including survivability and hardening
- recursive models where thermo-elastic changes in-turn impact heating
- effects of joint resistance on conduction changes
- effects on LEDs
- meshing.

Integrated Models
- closely coupled thermal-structural- optical models
- optical control systems
- global optimizers
- acquisition, pointing, and tracking
- end-to-end simulations.

Space-borne (and/or Microlithographic) Factors
- contamination control
- particulate/NVR models
- photopolymerization
- radiative damage, atomic O2
- spacecraft charging
- micro-meteoroid modeling, including spalling.

Aero-optics
- boundary layer and shock wave effects
- convective effects and air-path conditioning/self-induced turbulence.

Modeling of Vision Systems
- HUDs
- HMDs.

Application-specific Unique Optical Models and Performance Predictions
- adaptive optics
- bio and medical optics/sensing
- lasers/laser communication systems
- LEDs/solid state lighting
- MEMs/nano technology
- existing/evolving photonic devices and systems
- photonic devices
- solar technology.

Other

- phenomenology
- reliability
- rules of thumb and scale factors of use to individual disciplines
- cost models of optical systems.

This conference brought forward new work in several of these areas. Our intent was to provide special attention to new methods of analysis that would help "anchor" various models and/or also provide parametric relationships to help correlate results with predictions. In this regard, several authors have helped to advance the state of the art by contributing work that provides new insight into different aspects of optical modeling and predicting performance. Abstracts, some as originally submitted, are shown below; please note that some were modified in the final version of the papers presented. Note also that some presentations were followed by a relatively lively discussion, so stay tuned, as further work in the areas noted may well be presented at a future date.

Finally, the conference chairs recognize and thank the conference committee for their effort and support in helping bring this new material to light for the benefit of us all.

Mark A. Kahan
Marie B. Levine-West

(Note: In the following Section of this Introduction, the chair has attempted to show the presenting author's name and affiliation as well as paper titles and numbers, in a **Bold** font, and to *italicize* items, or added comments, where added emphasis or post-presentation discussion(s) took place. The affiliation and full names of all the authors is not shown here as it is available in the full presented papers or was not formally submitted.)

Session 1 – Stray Light, Propagation, Phase Effects, and Polarization

Simple but accurate variance reduction techniques for Monte Carlo ray tracing of stray light from optical surface scatter; Paper No.: 10743-1; Mr. Alan W Greynolds, Retired (USA)

Because of its relative simplicity, Monte Carlo ray tracing is the most popular technique for computing stray light in optical systems. In the basic method, all rays have the same never-changing flux and what a ray does at each interaction is determined by the probabilities of the possible physical processes there. However, for a low probability process such as polished surface scatter (including particulate contamination), it requires a prohibitively large number of initial rays to get a sufficient ray density at a typical focal plane area. The details of several simple modifications that require far fewer rays for the same or better accuracy will be presented. These include universal techniques applicable also to illumination patterns such as smart binning (also called 'pixel interpolation') and the use of quasi-random (instead of pseudo-random) number generators. In addition, there is the 'tweaked' Monte Carlo method developed specifically for veiling glare (light from bright regions in an image bleeding into dark regions and thus reducing contrast). However, most available software for computing out-of-field stray light in general optical systems uses importance sampling in the form of preferred scattering towards predetermined 'importance areas' of usually modest solid angles. For nearly all optical surfaces, micro-roughness scatter (and particulate forward scatter) in direction-cosine space is rotationally symmetric about the specular direction. In this case, an *efficient and accurate* (even for large solid angles) version called an 'importance sector' is proposed as a replacement.

Bidirectional reflectance measurement of black absorber layers for use in optical instrument design; Paper No.: 10743-2; Miss Deepali Shirsekar, Miss Yifei Wang, Prof. J. Robert Mahan, Dr. Kory J Priestley, **Prof. Vinh Q Nguyen** (Contact Author, **Virginia Polytechnic Institute and State Univ**., **USA)**.

The bidirectional reflectance distribution function (BRDF) is a fundamental quantity for the optical characterization of an object and it correspondingly is important in a large variety of applications. The BRDF is a measure of the amount of light scattered by a medium from one direction into another. Integrating it over specified incident and reflected solid angles defines the reflectance, which can be related to the absorptance (or emissivity) of a surface. We have employed the Monte Carlo ray-trace (MCRT) method to split an incident ray into a group of reflected rays with their power and direction determined by the BRDF. The simulation is applied to simulate the performance of a telescope conceived to monitor clouds and the Earth's radiant energy budget. Low-reflection surfaces inside the telescope are coated with Z302, a commercial optical coating material widely used in optical instruments. Modeling the BRDF can thus provide valuable information about the importance of knowing the bidirectional behavior of coated surfaces and their impact on optical performance of the instrument. *Results presented were monochromatic and on a plane surface, but the paper and future work will treat these other aspects.*

Integration of optomechanical system models with DIRSIG; Paper No.: 10743-3; Mr. Keegan S McCoy, Rochester Institute of Technology (USA), Dr. John P. Kerekes, Dr. Scott D. Brown, Dr. Adam A. Goodenough, Dr. Rolando V. Raqueño, Mr. Jared D. Van Cor, Mr. Ryan G. Irvin

Stray light, any unwanted radiation that reaches a focal plane, presents a significant challenge for both airborne and satellite remote sensing systems by reducing image contrast, creating false signals or obscuring faint ones, and ultimately degrading radiometric accuracy. These detrimental effects can have a profound impact on the usability of collected data, which must be radiometrically calibrated to be useful for scientific applications. Understanding the full impact of stray light on data scientific utility is of concern for lower cost, more compact satellite systems which inherently provide fewer opportunities for stray light control. To address these concerns, we present a general methodology for integrating an optomechanical system model with the Digital Imaging and Remote Sensing Image Generation (DIRSIG) model. The results reported in this paper describe the collection of necessary raytrace data from an optomechanical system model (in this case, using FRED optical engineering software), and include the initial demonstration of the integration method by imaging DIRSIG test scenes. By integrating a high-fidelity optomechanical system model with a physics-driven, synthetic image generation model like DIRSIG, we are now able to explore system trade studies and conduct sensitivity analyses on parameters of interest, including those that influence stray light, by analyzing their effects on realistic test scenes. This new capability *(which can be used with reasonable levels of sampling/fidelity and which has been used by industry)* further aids in demonstrating the quantitative linkage between system trade studies and impact to scientific users, which will enhance the writing of system requirements.

Optimization of aspheric geometric-phase lenses for improved field-of-view; Paper No.: 10743-4; Ms. Kathryn J. Hornburg, North Carolina State Univ. (USA), Mr. Xiao Xiang, Dr. Michael W Kudenov, Dr. Michael J Escuti

In optical thin-films and surfaces, geometric phase is utilized to control the phase beyond that possible through optical path differences. Geometric phase lenses, which are significantly thinner than refractive lenses for the same numerical aperture (NA), most commonly use a spherical phase profile. This is especially effective for normally incident light, but like other thin lenses the performance degrades noticeably for off-axis incidence and wider fields-of-view. In this study, we investigate if various aspheric designs provide better off-axis performance. We simulate aspheric singlet and doublet liquid crystal geometric phase lenses (24.5 mm diameter, 40 mm back focal length at 633 nm), aiming to optimize spot size performance at field angles of 0, 3, and 7, using Zemax and a simple ray tracing algorithm in MATLAB. By using different phase functions, including Zernike fringe and polynomial expansions, we find conditions which provide improved off-axis performance. We show improved performance of a compact lens system utilizing these polarization-dependent optics, while maintaining low loss and substantially improved leakages over prior holographic lenses. *(Discussions also included selected considerations related to lateral chromatic aberration and clarification of some Figure labels.)*

Optical propagation through multilayered anisotropic media; Paper No.: 10743-5; Mr. Hammid Al-Ghez, **Univ. of Dayton (USA)**, Mr. Rudra Gnawali, Dr. Partha P. Ban

Anisotropic materials can comprise multilayer stacks made from uniaxial-uniaxial or isotropic-uniaxial layers. These structures can be used to achieve unique optical filters and can be modeled as a bulk structure using effective medium theory. The optical properties of these anisotropic media can be described in terms of effective parameters such as permittivity and permeability tensors. In this work, optical propagation through such layered media is analyzed using Berreman 4 × 4 matrix along with appropriate boundary conditions. Reflection and transmission are investigated as functions of the incident angle and wavelength *(which covers the angular effects seen in F/No-driven convergent or divergent cones of light)*. The effective medium theory is validated by varying the number of layers and the thickness of layers. Results are compared with those obtained using the transfer matrix approach, where the constituent uniaxial layer is itself composed from dissimilar isotropic materials. This analysis can be extended to Gaussian beam propagation through such anisotropic materials using angular plane wave approach.

Polarization ray tracing and polarization aberration compensation in reflective, astronomical telescopes; Paper No.: 10743-6; Dr. Derek Sabatke, Ball Aerospace (USA)

Polarization aberrations degrade image quality. Although are frequently neglected in the design of conventional systems, they are important in systems with highly demanding image quality requirements, such as telescopes and coronagraphs for exoplanet missions. Assessing and optimizing polarization performance in the context of a ray-based optical design program can be challenging. We describe an approach to this problem that decouples the polarization effects of Fresnel reflections and coatings from the optical system geometry. Each surface's polarization properties are parameterized in terms of their impact on retardance and diattenuation in the small angle-of-incidence limit. This decouples assessment of polarization impact from the task of coating design. A low-resolution ray trace of the system is adequate to determine ray geometry at each interface, which can then be interpolated to rapidly evaluate net Jones Matrix pupil functions. Coating behavior can be easily varied using the ellipsometric angles Psi and Delta as parameters to investigate impacts and compensation. Desired values of these parameters can then be specified as constraints in coating design. Initial investigation with telescope optical designs for

LUVOIR show promising possibilities for compensation using a purpose-designed coating on the secondary mirror. *Measurements are planned but are currently TBD.*
Using lightfields to simulate the performance of optical systems; Paper No.: 10743-7; Dr. Jim Schwiegerling, College of Optical Sciences, The Univ. of Arizona (USA)

The lightfield describes the radiance at a given point provide by a ray coming from a particular direction. Integrating the lightfield for all possible rays passing through that point gives total irradiance. For a static scene, the lightfield is unique. Cameras act as integrators of the light field. The irradiance at each camera pixel can be mapped to the points in the entrance pupil of the camera lens and a series of directions defined by the wavefront error associated with the lens. Consequently, if the lightfield is known at the entrance pupil, then the camera image can be created simply from the aberrations associated with the camera lens. The advantage of this technique is that the lightfield only needs to be calculated once for a given scene. Images of this scene for any lens can then be simulated as long as the lightfield is known at its entrance pupil. Here, an array of ideal pinhole cameras was placed in a 50mm x 50mm region of a 3D scene created in freeware rendering software. The pinhole camera images encode the ray directions for rays passing through the pinholes. The set of images from this array then describes the lightfield. Images for real camera lenses with different types of aberrations are then simulated directly from the lightfield. Images from different types of camera lenses and the consequences of different aberrations can be compared with this technique.

Session 2 – Materials and STOP I

New moldable glasses for multispectral optics; Paper No.: 10743-8; Dr. Shyam S Bayya, U.S. Naval Research Lab. (USA), Dr. Daniel Gibson, Dr. Vinh Nguyen, Dr. Jasbinder Sanghera, Mr. Mikhail Kotov, Mr. Collin McClain, Dr. Jay Vizg

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 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 (*e.g. doublets, etc.,* offering lower Fresnel reflection losses *and reasonably broad temperature ranges*). 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. The glass database is now available for distribution. Some of the NRL glasses are also available commercially. This presentation will cover discussions on the new optical materials, multispectral designs, as well fabrication and characterization of new optics.

Optothermal stability of large ULE and Zerodur mirrors; Paper No.: 10743-9; Mr. Thomas E Brooks, NASA Marshall Space Flight Ctr. (USA), Mr. Ron Eng, Dr. H. Phillip Stahl

Marshall Space Flight Center's (MSFC) X-ray and Cryogenic Test Facility (XRCF) has tested two high-quality, large aperture mirrors in a thermal vacuum chamber. The mirrors deformed due to a variety of *(real-world)* conditions such as: thermal gradients, thermal soaks, coefficient of thermal expansion (CTE) gradients, CTE mismatch between the mirror and its bond pads, CTE mismatch between the mirror and the mount's back plane, and stiction in the mirror's mount. This paper focuses on how the conditions affected the surface figure of the large optics while in vacuum at temperatures ranging from 230 to 310 K (-43 to 37 ˚C). The presented data *(which are at accuracies/repeatability's of ~ 6 nm, and which tracked both focus and higher order aberration)*, conclusions, and taxonomy are useful for designing mirrors and support structures for telescopes operating in any temperature regime. The data is particularly useful for telescopes that require extreme dimensional stability and telescopes that operate at very low temperatures.

Influence of core and hexapod geometry, and local reinforcement on the performance of ultra lightweight ULE mirror; Paper No.: 10743-10; Dr. William R Arnold, NASA Marshall Space Flight Ctr., **Dr. H. Phillip Stahl, NASA Marshall Space Flight Ctr, (USA)**

During several design iterations for the HABEX project *(error budgeted using Zernike's)*, a number of point designs were done *(using the so-called Arnold Mirror Modeler that feeds into Ansys)* with edge mounted, 85 percent diameter and 75 percent diameter hexapod suspension systems. A trend was noted that no matter the first free-free frequency, the mounted mirror always had very low first mode frequency. To identify the major players in this phenomenon, the strut axial stiffness was varied by several orders of magnitude with negligible effect. By zooming in upon the deformations (static in the various directions corresponding to the lower mode shapes) it was determined that highly localized bending at the zone of attachment was the culprit. As the light weight process drives the design to thinner and thinner elements, this makes sense. The next step in the process was to determine the best way to apply local stiffness (essentially thickening the webs around the attachment). So, the value function for the trade study becomes highest increase in frequency for the minimum additional weight (that being defined as the difference between un-reinforced weight and final reinforced mirror weight). Both hexagon core patterns and isogrid core patterns were included. To keep the run numbers within reason, a six-point exterior mount hexapod was the baseline. Both one zone and two zone (first zone heavily reinforced and second zone lightly reinforced) were studied. Results show an interaction between cell size and reinforcement zone(s) which appear to have definite optimal combinations – *and where stiffness appears more important than simply adding mass for real/fabricated configurations.* Each optimum would depend on mirror outer diameter and core depth.

Design and development of stress relieving mechanism for TMT primary mirror segments; Paper No.: 10743-11; Mr. Alikhan Basheer, Indian Institute of Astrophysics, Mr. S. Sriram, Dr. Vineeth Valsan, Mr. Krishna Murthy, Mrs. Janani Varadhachari, Mr. Viswanatha Narasimhiah, Prof. G.C. Anupama *(The Chair's notes show this paper was not presented; the abstract is included for completeness given potential reader interest.)*

The Thirty Meter Telescope (TMT) adopts a recently developed technology known as Stressed Mirror Polishing for the polishing of its 492 mirror segments. In this process, first the meniscus type spherical shape glass blanks are converted in to a desired aspheric shape by the application of forces around the edges using warping arms followed by spherical polishing in the stressed condition. After that, the blank edges will be cut in to its final hexagonal shape. These warping as well as the hex cutting process generate significant stress within the glass which in later stage, will cause the propagation of micro cracks and results in blank breakage. So prior and after the hex cutting process, it is essential to ensure that the glass blanks are free from stress accumulation. Hence the glass blanks need to be stress relieved before its usage into the telescope. To achieve this stress relaxation, the glass blanks need to be kept over a platform or a support system which will provide a zero-gravity condition for a time period of at least 48 hours. In this paper, we designed and simulated two support system (One for roundel and one for hexagon) which will sense the reaction force at each support point and nullify the gravity effect by giving equal and opposite counter acting forces. This stress relieving mechanism which additionally gives optimized support for the glass blank which in turn minimizes the surface deformation due to its self-weight sagging. First, we have calculated the optimum support points and support point locations using an optimization tool called PLOP. Then to simulate the stress relieving mechanism, we have used FEA Modeling tool. With the FEA Software, first we modeled an FEM Model of the mirror segment and calculated the mirror deformation due to 1G gravity inertial load when supported at the 27 support point locations. Keeping the segment surface RMS as critical design parameter, we have done the sensitivity and tolerance analysis of the support point locations. We have also calculated the reaction forces at each of the 27 support points, which later used for the sensitivity and tolerance analysis for reaction force. In Later stage, these 27 support points are connected in a pair of 3 to become 9 triangles. And finally, all the 9 triangles are again connected in a pair of 3 to become 3 triangles. This will basically form a whiffletree structure. By forming whiffletree structure, the entire segment weight will experience on the 3-large bottom whiffletree support points, which will help to control the reaction forces with much ease rather than controlling at 27 points.

Session 3 – Materials and STOP II

Projection x-ray microscopy beamline mirror cooling and optomechanical analysis; Paper No.: 10743-12; Dr. Ming-Ying Hsu, National Synchrotron Radiation Research Ctr. (Taiwan), Dr. Gung-Chian Yin, Dr. Bo-Yi Chen, Mr. Chien-Yu Lee, Dr. Han-Chao

(Chair's paraphrasing used to hopefully help clarify abstract.) The X ray beam line Projection X-ray Microscopy (PXM) is used *(with a)* wiggler insert part in *(a)* Taiwan Photon Source. The PXM system has two mirrors and one Double Crystal Monochromator (DCM). The Vertical Collimating Mirror (VCM) is the first mirror *(seen by the)* wiggler, thus the thermal absorption is an important issue. Meanwhile, the DCM sees very high-power density *(Chair's note - ~ solar loading in Earth orbit),* so the DCM uses liquid nitrogen cooling. The X ray optical foot print can be calculated by SHADOW software on the VCM and DCM. The X-ray thermal load can be weighed and input to a Finite Element Method (FEM) model used to calculate thermal deformation. The mirror surface deformation can be fit by a B-spline and fed-back to *the* SHADOW software so as to evaluate system performance differences introduced by thermal deformation, and help the designer determine mirror tolerances. *(Mirrors are polished Si & 3-point mounted.)*

Beamed-energy propulsion: optical phase noise in 1064nm fiber amplifiers; Paper No.: 10743-13, Dr. Prashant Srinivasan, Univ. of California, Santa Barbara, **Dr. Peter Krogen, (Univ. of California, Santa Barbara, USA)**, Mr. Nicholas. Blasey, Mr. Will. Hettle, Gary Hughes Dr. Philip. M Lubin

Effective transfer of beamed optical energy to a spacecraft requires that the source have a sufficiently small angular divergence to contain the beam within the area of the spacecraft collector. Such a directed energy system could be achieved by coherently combining many small optical sources distributed throughout a large-scale array. The fundamental unit of such a system is a MOPA (master oscillator power amplifier) which consists of a frequency stabilized laser source distributed to many amplifiers distributed through the array. The primary challenge in long baseline coherent beam combination is that each source be combined with sub-wavelength accuracy over the entire array. In addition to perturbations due to mechanical and atmospheric disturbances, phase noise introduced by the amplifiers and seed distribution network must also be accounted for to achieve the necessary accuracy. This work investigates the excess phase noise introduced by the amplifier stages and fiber optic links and locking schemes that could be used to synchronize such an array. The test bed used to interrogate phase noise is based on an all polarization maintaining fiber-based Mach-Zehnder interferometer with FPGA based digital I/Q quadrature detection at 1 MS/s yielding direct measurement of amplitude and phase with servo control for phase locking. Results for various MOPA and fiber link configurations based on Yb-doped fiber amplifiers operating at 1064nm and link lengths up to kilometer scale will be presented. (Accuracies of□□v/10,000 are considered.)

Basic practical mechanical hints for designing space-based optical instruments using the KISS Principal (Keep It Simple Stupid); Paper No.: 10743-14; Mr. Phil Pressel, Quartus Engineering Inc. (USA)

Based on nearly 50 years of experience designing optical instruments, including the design of the stereo cameras for *(one of)* America's best and last film space based spy satellite called Hexagon, here are topics that will be covered: Detailed list of recommendations • A brief discussion and explanation of the Hexagon spy satellite and its importance in keeping the peace during the cold war • Material properties for glass (strength) and heat treatment for invar to maintain CTE stability • outgassing of various materials (adhesives, oils, paints), good or unacceptable for use in space • coatings and friction, venting • motors and bearings • importance of flexures • preloading assemblies to maintaining alignment after launch loads (gravity release) • guidelines for locking hardware.*(Heat-treating of various metallic materials/parts was also discussed.)*

Session 4 – Optical Systems

HabEx Telescope WFE stability specification derived from coronagraph starlight leakage; Paper No.: 10743-15, Brian Nemati, The Univ. of Alabama in Huntsville, **Mr. Mark T Stahl, The Univ. of Alabama in Huntsville (USA)**

The next generation of space-borne coronagraph instruments will use large collecting apertures which allow small inner working angles, bringing for the first-time earth-class terrestrial planets within view for direct imaging. Since the planet flux ratio for an Earth-sized planet will be only a few times 1e-10, the requirements on the allowed starlight leakage will be very tight. One of the most important categories of error will be the instability of starlight speckle background, which will limit the effectiveness of differential imaging in bringing the background well under the planet signal level. Telescope structural modes excited by thermal and dynamic disturbances will be the major source of speckle instability. In this paper, we present simulation results on the sensitivity of the coronagraph speckle to error modes of the telescope and make first estimates of the expected error for the HabEx baseline architecture.

Performance modelling of the fine lateral and longitudinal sensor (FLLS) for ESA's PROBA-3 mission; Paper No.: 10743-16; Dr. Miranda J. Bradshaw, Univ. of Surrey (UK), Prof. Yang, Gao, Prof. Kevin P. Homewood

PROBA-3 is a European Space Agency (ESA) mission, due to launch in 2020. The aim of the mission is two-fold: to study the solar corona, and to demonstrate formation flying technology. Two satellites will fly in formation, 150 m apart, to form a coronagraph instrument. The relative displacement between the two satellites must be known to within 300 µm in order to produce an accurate coronagraph. The instrument that will provide this high-accuracy measurement is FLLS – the Fine Lateral and Longitudinal Sensor. Built by Neptec UK and Neptec Design Group, FLLS uses a retro-reflected laser beam to monitor the position of one satellite with respect to the other. Phase measurements of the reflected signal are used to compute the longitudinal displacement between the two satellites. The lateral displacement is measured from the position of the returning beam on a CMOS sensor. FLLS is currently in preliminary testing, in collaboration with Surrey Space Centre. To support the testing, the performance of the lateral system of FLLS has been modelled. A computational model of the full optical system has been produced, including key predicted noise sources, and several calibration routines have been tested on the modelled beam images. The results of these routines have enabled predicted performance analysis of the FLLS instrument. The paper and presentation will provide an overview of the method, model, and results of the performance modelling of FLLS, including pertinent test results. *(Audience discussions noted some related/prior NASA cube-corner work on ALSEP, LAGEOS, and PAMS that treated polarization effects in solid cube-corners.)*

Optical design of dual-mode seeker for long wave infrared and mid-wave infrared in missile application); Paper No.: 10743-18; Mr. Dogan Ugur Sakarya, Roketsan A.S. (Turkey) [*as combined with original submission: Compact seeker design by using piezo actuator in missile applications; Paper No.: 10743-17]*

In missile applications, there are many parameters to be optimized. One of these is *the* diameter of the seeker and the related need to lower its profile as a countermeasure. Compact seeker design also ties to the drag force, w*hich in-turn ties to the* mass and flight motor. All these factors *need* to be optimized. However, because of the vibration of missiles, *the* gimbal part is *especially* important. Old fashioned gimbal approaches increase missile diameter. New proposed methods are vulnerable to jitter *of the* image. There should be some tradeoff between methods. To eliminate increasing *the* seeker diameter, *the* gimbal is removed from *the* seeker part. Also, *so as* not to *impact image jitter, a* piezo actuator system is used. In this technique, detector and objective stay stable out of gimbal mechanism and light is focused in front of the objective. Later, *a* virtual image is created at the detector. *In* this way, diameter of the objective and detector don't affect diameter of the seeker and give more free space to put another detector for dual wavelength into system to be immune to countermeasures. In this study; an optical design and production of the camera module is conducted. Performance of the camera module is tested both in simulation and laboratory. After that, target is simulated in the collimator system to illustrate performance of the module. Later, camera module performance under the vibration profile of the missile is tested with automatic target acquisition algorithm to compare results of the system objectively. Finally, analyzes are performed to show piezo actuator effects *of a* vibration profile of the missile. (Porro prisms were also discussed.)

Weighted raised cosine waveform with reduced peak to average power ratio for optical transmission; Paper No.: 10743-19; Mr. Bishara Shamee, The Univ. of Southern California (USA), Mr. Amirhossein Mohajerin-Ariaei, Mr. Ahmed Almaiman, Mr. Yinwen Cao, Ms. Fatemeh Alishahi, Prof. Alan Wilner

The raised cosine is a bandwidth efficient pulse shaping waveform with relatively high peak to average power ratio (PAPR). Reducing the PAPR while maintaining waveform integrity and bandwidth efficiency increases the over*(all)* transmission rate by utilizing the spectrum more effectively. We modify the raised cosine by reducing the adjacent symbol contribution to the PAPR while maintaining the Error Vector Magnitude integrity at a relatively small increase in required bandwidth over the raised cosine waveform. The attained PAPR reduction is on the order of 1.5 dB for the smaller excess bandwidth.

Development of an inverse approach for the characterization of in-vivo optical properties of human skin based on artificial neural networks; Paper No.: 10743-20; Dr. Alexander Doronin, Yale Univ. (USA), Prof. Holly Rushmeier, Dr. Alexander Bykov, Prof. Igor Meglinski

Due to the complex and inhomogeneous structure of biological tissues, the analysis of imaging data collected with various optical biopsy methods is often complicated and time consuming. The major challenge here is to understand the peculiarities of light propagation and link it with advanced image/data classification pipelines. This presentation considers the application of the novel Artificial Intelligence (AI) based methods to the inverse problem of light transport in scattering media such as human skin. A spectral image classification pipeline based on Artificial Neural Networks (ANNs) has been developed by implementing and training several configurations of ANNs classifiers that fit for the scattering and absorption properties of the tissues. The training of the ANNs has been performed by the further developed unified Monte Carlo-based computational framework for light transport in scattering media. The hyperspectral data is acquired at each pixel as a function of time, by varying the illumination/detection wavelength and polarization of light. The results of nearly real-time chromophore mappings for parameters such as distributions of melanin, blood vessels, oxygenation, simulation of BSSRDFs, reflectance spectra of human tissues, corresponding colors and 3D rendering examples of human skin appearance will be presented and compared with the exact analytical solutions, phantom studies, traditional diffuse reflectance spectroscopic point measurements and *an* advanced Spatial Frequency Domain Imaging (SFDI) technique. Computer simulation and training are accelerated by parallel computing on Graphics Processing Units (GPUs) using Compute Unified Device Architecture (CUDA) and *a* Cloud-based environment. Open-source machine learning frameworks (e.g. Tensorflow) are used to measure and validate each ANN's performance. *(Discussion also included information on a free-access website for scattering data, and a relevant PhD thesis related to melanoma.)*

Effect of detection posture on performance of prediction model for an apple's soluble solid content using online near-infrared spectroscopy; Paper No.: 10743-21; Ms. Xiao Xu, Zhejiang Univ. (China), Prof. Lijuan Xie, Prof. Yibin Ying (Contact Author)

Near-infrared spectroscopy has enjoyed increasing popularity in recent years with advantages of being rapid, safe, nondestructive and environmentally friendly. Consequently, this technique has been widely applied as an analytical tool for on-line grading of fruits in the agricultural industry, which demands low cost and high efficiency. In this paper, an on-line near-infrared detection system based on roller transportation was established to determine the soluble solid content of apples. However, an apple's posture cannot be ensured after its random rotation on a roller, and this results in a decrease in spectral repeatability. Therefore, there is a necessity to study *the influence of posture on* the prediction model's accuracy and robustness for the determination of apple's soluble solid content. Two categories of detection postures were compared, including a fixed posture and a random posture. Near-infrared spectra of one hundred samples were obtained by the on-line system in these two different detection postures. Then prediction models were respectively established and compared. Results showed that the performance of the prediction model constructed by spectra gained in the fixed detection posture was better than that in the random detection posture. Last but not least, methods upon compensating this influence were discussed. *(In discussions it was mentioned that the illumination source penetrates the apple by ~ 10mm-15 mm, and that the solubility measure relates to apple's sweetness.)*

Session 5 – Evolving Components and Devices (Session Number As Presented)
High-efficient, on-chip photonic filter design via objective-first algorithm; Paper No.: 10743-22; Mrs. Mediha Tutgun, TOBB Univ. of Economics and Technology (Turkey), Mr. Ahmet Masut Alpkilic, Mr. Yusuf Abdulaziz Yilmaz, Dr. Adan Yeltik, Mrs. Döne Yilmaz, Prof. Hamza Kurt

Inverse design of integrated photonic devices has recently attracted great attention owing to the effective optimization of all structural parameters, which is not possible with heuristic methods. In numerous applications, optical filters are required to isolate a band of wavelengths from the input spectrum through either selectively transmitting or blocking the incident light. The objective-first inverse design algorithm is therefore utilized for the first time to design on-chip compact optical filters with ultra-high efficiency. The algorithm providing reliable and flexible results with short-time computation is effectively revised to design high-pass, low-pass and all-pass filters operating within the range of 1200-1600 nm, *the* telecommunication wavelength spectrum, to be used for optical signal processing in photonic circuits. The obtained high-pass filter shows outstanding performance by transmitting the optical spectrum below 1425 nm with *an* efficiency up to 95.43% *while* blocking the other spectral region effectively, presenting *a* full-width half-maximum bandwidth of 110.2 nm at the center of 1310 nm. Also, the designed low-pass filter exhibits the performance of the high-pass filter with the reversed spectral characteristics. Further, the presented all-pass filter is shown to transmit the entire telecommunication spectrum with *an* ultra-high efficiency of 92.37%, suppressing the other regions effectively. Dielectric binarization of the proposed filters for manufacturable designs is also possible with very low efficiency degradation values. Performances have been successfully verified via the finite-difference time-domain method. To summarize, the proposed optical filters *have excellent* device performances *and* are promising candidates for next-generation on-chip photonic applications necessitating superior properties of miniaturized optical components. *(Audience discussion related to the sharpness of the cut-on/cut-off wavelength zones, and piece-part feature sizes.)*

Z-cut Lithium Niobate (LiNbO3) Mach-Zehnder modulator-based integrated photonic highly steerable beam-forming system for broadband airborne application; Paper No.: 10743-23; Mr. Nimish Kumar Srivastava, Indian Institute of Technology (Indian School of Mines), Dhanbad, Dr. Sanjeev Kumar Raghuw *(The Chair's notes show this paper was not presented; the abstract is included for completeness given potential reader interest.)*

In this paper, we will demonstrate a photonic based wideband true-time delay (TTD) beamforming network employing a linearly chirped fiber Bragg grating for controlling the radiation angle of phased array antenna (the main lobe radiated by the phased array antenna can be steered squint-free between ±60 ^0) suitable for continuous beam forming at microwave frequencies up-to Ku-band. Time delay variations up-to 300 ps by varying the wavelength of the optical carrier will be achieved through *the use of* gratings of 12nm bandwidth each; with length of 2mm, 4mm, 6mm and 8mm, respectively. Our setup, *ties to* linearly chirped fiber Bragg grating and Mach-Zehnder delay interferometers. The proposed work is theoretically appraised, and *the* squint-free beam steering of *a* microwave waveform is probed by simulation. The time delay applied in the optical signal translates to phase shift of the RF signal after photo-detection. In this paper, optical beamforming has been done by combination of the undelayed received signal (channel1) with its delayed copy (channels 2, 3, 4). When the phase shift between the channels is zero, i.e. when the two signals are in phase, a constructive addition of the signals occurs, and a maximum power level is received. When the 4 channels are out of phase, a destructive addition of the combined waveforms leads to a minimum received power level. Ultimately, if we make such an offset adjustment so that the phases and the amplitudes of *the* four RF signals are *the* same, a single beam *propagating* toward the straight forward direction will be formed.

Microwave optoelectronic oscillator with chirping capability; Paper No.: 10743-24; Dr. Sanjeev Kumar Raghuwanshi, Indian Institute of Technology (Indian School of Mines), Dhanbad, Mr. Ritesh Kumar *(The Chair's notes show this paper was not presented; the abstract is included for completeness given potential reader interest.)*

Microwave oscillators are used to generate high quality microwave signals. With *a* conventional electronics circuit it is not possible to generate such signals because of *a* lack in *the* degree of spectral purity and stability. These drawbacks are mainly due to the presence of passive components giving rise to resistive loss and their frequency dependency on energy storage capability. *A* photonic based oscillator is a substantial way of generating high quality microwave waveforms with high frequencies. Here, a photonic based optoelectronic oscillator is proposed for the generation of *a* microwave signal with chirping capability. *The* proposed methodology consists of *a* laser diode, dual parallel Mach-Zehnder modulator (DPMZM), optical fiber, photodetector, RF amplifier, and electrical band pass filter (BPF). The DPMZM is the parallel combination of two Mach-Zehnder modulators (MZM). The overall model is in the form of *a* loop consisting of *an* optical and electrical path. The detected light from DPMZM is feedback to the RF port of upper MZM forming a loop. RF amplifier is used to provide sufficient gain for oscillation, and electrical band pass filter eliminates the undesired harmonics in the detected signal. The optical fiber offers better stability & spectral purity, low loss transmission, and energy decay time. In addition to lower noise and very high stability, *the* chirping capability *is* designed to *have* practical and useful characteristics for the proposed oscillator. Radar and navigation, satellite communication, and modern instruments are the expected areas *that can* benefit with the proposed oscillator.

Modeling oblique propagation of polarized light through a thick birefringent element; Paper No.: 10743-38; Mr. Ashan Ariyawansa, Univ. of Rochester, Galabada Dewag, **Dr. Thomas G. Brown (← Contact Author and Presenter, University of Rochester, USA)**

We evaluate two methods of modeling the oblique propagation and tracking the singularities of polarized light through a thick birefringent element known as a stress-engineered optic (SEO). First, we develop a continuous model based on solving a system of differential equations that governs the light propagation, and then we implement a discrete method to obtain similar results faster with much less computational complexity. Finally, we compare the numerical results with the experiment. *(Discussion centered on extending the work to multiple wavelengths, convergent/divergent beams, and cases where errors varied over the aperture/beam-footprint in some wide-angle systems using large glass boules.)*

Effects of a random process variation on the transfer characteristics of a fundamental photonic integrated circuit component; Paper No.: 10743-25; Miss Sally I El-Henawy, Massachusetts Institute of Technology (USA), Mr. Ryan Miller, Prof. Duane S Boning

Silicon photonics is rapidly emerging as a promising technology to enable higher bandwidth, lower energy, and lower latency communication and information processing, *as well as* other applications. In silicon photonics, existing CMOS manufacturing infrastructure and techniques are leveraged. However, a key challenge for silicon photonics is the lack of mature models that take into account known CMOS process variations and their effect on photonic component behavior. A key factor for the adoption of silicon photonics into high-yield manufacturing is to extend Process Design Kits (PDKs) to include photonic process variability models that are aware of the variations that may occur during the fabrication process. We study the effect of a well-known random process variation, Line Edge Roughness (LER), present in the lithography process, on the performance of a fundamental component, the Y-branch, through virtual fabrication simulations. Ideally, the Y-branch transmits the input power equally to its two output ports. However, imbalanced transmission between the two output ports is observed when LER is imposed on the Y-branch, depending on the statistical nature (amplitude and correlation length) of the LER. The imbalance can be as low as 1% for small LER amplitudes and reach up to 15% for large LER amplitudes. In addition, LER increases the excess loss compared to the nominal (smooth) case. Ensemble statistical virtual fabrication and FDTD photonic simulations across a range of LER amplitude and correlation lengths are reported. These results can be captured as worst-case corner models and included in variation-aware photonic compact models. *(Discussion included work with Coventor, Lumerical, and others.)*

Note: Beyond the oral presentations noted above, there were also several posters that were scheduled for the evening of 22 August, though logistics prevented several authors from attending and being able to post/present. Where abstracts were provided, they are included below.

Analysis and performance of non-circular polynomials in the wavefront modelling; Paper No.: 10743-26; Mr. Petr Janout, Czech Technical Univ. in Prague, Prof. Petr Páta

Imaging system design is not limited to circular aperture shapes. However, non-circular apertures require a different set of polynomials, because broadly used Zernike polynomials are not orthogonal over non-circular shapes. Applying the Gram-Schmidt orthogonalization process provides the adopted set of orthogonal polynomials over selected non-circular aperture shape. However, when the aperture shape is complicated, non-symmetrical, the resulting set of polynomials can be very complex. In the case of odd-sided polygons the analytical form of the polynomials is *generally* inappropriate due to their complexity and these polynomials have to be expressed in their numerical form. Concerning the laborious complexity of some non-circular polynomials, we analyze the desired accuracy of such polynomials and their performance *in* wavefront modeling according to classical circular Zernike polynomials.

Birefringence test for basic load case; Paper No.: 10743-27; Dr. Jan Hošek, Czech Technical Univ. in Prague, Dr. Petr Tichý, Dr. Šárka Němcová

Birefringence can be a crucial problem for many optical instruments operating with laser beams. Even for birefringence free optical elements, birefringence can be introduced due to mounting forces and torques. Highly sensitive polarimeters need to be used to reveal the limit values of linear or circular retardance introduced into the optical system. The correct assessment of a polarimeter's resolution limit needs to be done with an appropriate test sample. We propose a birefringence test sample based on a circular plate loaded with torsion stress. Such a test sample has many advantages for a low-level birefringence measurement. There is *almost* always present a zero level of stress in the middle of the circular sample. The stress level linearly increases towards the perimeter and its slope can be set arbitrarily. There is no change of either the sample volume or its shape under torsion stress. In the paper we evaluate the birefringence of a sample under torsion stress with Jones matrixes. We present finite elements models of torque load introduction into the test sample under different geometrical configurations. We assess the radius of sample evaluated area suitable for the determination of *a* polarimeter's resolution limit.

Modeling of thermal response of nanoparticles inside a biological cell; Paper No.: 10743-28; Mrs. Mariya G Lisovskaya, Samara Univ., Mr. Oleg O Myakinin, Mr. Ivan A Bratchenko, Prof. Valery P Zakharov

Photodynamic therapy (PDT) is currently one of the main methods for treating various forms of cancer such as skin, breast cancer, brain tumors, including their precancerous stages as well. Moreover, PDT is a non-surgical, non-invasive method with a gentle effect on damaged organs and tissues. It produces a cytotoxic effect and does not leave scars. Furthermore, it is practically painless, and does not cause severe system and local side effects, which often allows *Dr.'s* to save the afflicted organ. In the PDT procedure, the determining factors include the optimal dose selection of a photosensitizer, the correct calculation of light source power and a laser irradiation mode. The dose of laser radiation in PDT is calculated by standard formulas taking into account size and location of the tumor, *and* the distance between the light fiber and the tissue surface. Since a laser irradiation mode is the decisive factor for an effective PDT therapy and the determination of this parameters set is non-interactive, there is no *detai*l of the spatiotemporal distribution of released heat. Therefore, there is a high probability of photodynamic damage not only to the tumor but also to healthy tissues. This paper considers modeling the distribution of thermal response inside a biological cell with embedded nanoparticles. Nanoparticles can be applied either together with photosensitizers or instead of them. Within the framework of this project, a model for a multicomponent inhomogeneous medium with an invasion of nanoparticles is presented, which simulates a biological cell and its organelles. In this pilot study, the distribution of electric and thermal fields induced by various shape*d* nanoparticles, approximately 40 nm *in* size were obtained in COMSOL Multiphysics (COMSOL Inc., USA). The obtained results may be already used for development of a biological tissue macro model with an invasion of nanoparticles.

Defocused optical system for analyzing dust defects in imaging capturing module; Paper No.: 10743-29; Mr. Yi-Ju Wu, **National Sun Yat-sen Univ.,** Prof. Li-Yin, **Prof. Li-Yin Chen (Contact Author)**

Dust *related* defects are always a critical issue *as they* degrade image quality in *various* kinds of imaging capturing modules, such as compact camera modules (CCM) and digital single-lens reflex cameras (DSLR). Dust particle may be deposited on the surface of lens or sensor in the step of assembly and even in the step of changing lens module by users. There have been lots of studies about image defects produced by dust particles on the surface of lens or sensor and the image compensation for dust defect on images, but the studies about the direct analysis of dust defects are still deficient. In this study, geometrical optics was used to analyze the image defects due to dust in the imaging capturing module. A defocused optical system with a planar light source with Lambertian emission was developed to analyze dust defect with image process and the concept of just noticeable difference (JND) of human vision. The proposed defocused optical system provides a way to help manufacturers to improve their production line efficiently.

Research progress of laser Doppler vibrometry technology and its application; Paper No.: 10743-30; Dr. Weidong Pan, **Tongji Univ., Prof. Anhu Li (Contact Author)**

Laser Doppler Vibrometry (LDV), relies on the detection of a Doppler frequency shift of the scattered light from a surface of a vibrating object, *and it* has been a promising technology. As a non-contact vibration measurement technology, LDV shows advantages in its superior measurement accuracy, wide measurement range, excellent sensibility and rapid dynamic response. In addition, LDV technology is immune to ambient noises and not sensitive to transverse vibration interference. That explains why LDV can be applied to measure various types of vibrations, especially for the certain vibrations with slight amplitude. This paper gives a review *of* the fundamental principles and the essential techniques of LDV and puts emphasis on comparing and analyzing *differences* between Scanning Laser Doppler Vibrometry (SLDV) and Continuous Scanning Laser Doppler Vibrometry (CSLDV), SLDV can only scan discrete points using point-by-point scanning method and there will be a long time measuring a large number of points. *The* scanning efficiency of CSLDV is much higher than that of SLDV, CSLDV can extend the application scope. Based on the available literature *on* LDV, some crucial issues including the optical system design for vibration measurement, the methods of noise elimination, the analysis *of* vibration errors and the required solutions are proposed and commented *on*. Particularly, the exist*ing* signal processing methods are also compared to demonstrate their advantages and disadvantages. Finally, *we describe* the research progress of engineering technology and give several kinds of products based *on* LDV technology and their applications in the fields of industry, agriculture, medicine and construction, and the future development trend of LDV is prospected.

Experimental validation of a 2D approximation method for investigating photonic components: case study refractive index sensor; Paper No.: 10743-31; Mr. Jens Høvik, Norwegian Univ. of Science and Technology, Dr. Astrid Aksness

Investigating photonic components as refractive index sensors requires reliable numerical models to avoid the costs of prototype fabrication. Performing 3D simulations of large or complex components requires powerful hardware. Alternatives to time-consuming 3D simulations are approximations such as the effective refractive index method. We propose our improved method that more closely follows 3D results, named the inverse effective index method. The accuracy of our approximation method is verified by comparing experimental results with simulations. Ring resonators with 15 μm radius are simulated and fabricated. Their performance as refractive index sensors are assessed by probing their response in DI-water and in 1M hydrochloric acid (HCl) solution. The fabricated resonators are fitted with a microfluidic channel that first immerses the resonators in water, followed by the HCl-solution. A tunable laser is used to induce resonance and the resonance frequencies are measured both for DI-water and for the 1M concentration of HCl. Variations in the results between fabrication and simulation are expected, as the refractive indices and the exact geometrical parameters are not identical between simulation and fabrication. Simulation and experimental data agree with a resonance shift of approximately 390 pm for the fabricated structure and 368 pm for the simulated component. The fabrication and characterization of the ring resonator-based refractive index sensor took approximately two days, whereas the 2D simulations took under an hour to perform. This demonstrates the usefulness of a proper simulation tool to conduct accurate performance estimations in a short amount of time.

Optical design of fundus camera for smartphone; Paper No.: 10743-32; Mr. Weilin Chen, **Beijing Institute of Technology**, Prof. Jun Chang, Ms. Benlan Shen, Ms. Xin Liu, Mr. Dajiang, **Prof. Jun Chang (Contact author)**

Fundus camera is widely used in diagnosis of retinal disease, and smartphone is also widely used in daily life. Combining smartphone with fundus camera can reduce the complexity of the equipment and improve the portability. The participation of smartphones provides the possibility of mobile medical. This paper analyzes the characteristics of fundus camera for smartphone, uses the bi-ocular lens structure to construct the imaging optical path, and considers the influence of human eye aberration and refractive error. The Liou human eye model is introduced, the external focus compensation and compensatory lens are used to correct the refractive error, the correction range is -15D ~ +15 D. The MTF of the imaging system is greater than 0.2 at 100 lp / mm, the maximum distortion is less than 3% over the field of view. Lighting system using ring light source to eliminate corneal stray light, and to achieve uniform lighting of the fundus.

Analysis of optical schemes of HMD systems for the possibility of their *use* in binocular or biocular displays in the aircraft industry; Paper No.: 10743-33; Mr. Dmitrii D. Stefanidi (Contact Author), Dr. Aleksei. S. Garshin, Dr. Galina E, Romanova, ITMO Univ.

Modern development of aircraft engineering and consequently of the piloting process itself leads to an increase *in* the volume of information that the pilot has to control. This makes *it* necessary to improve the comfort of displaying flight information for the pilot. One of the main methods is the *use* of a Helmet-Mounted Display (HMD) in which the image is formed specifically in such *a* way that the pilot's eyes are not required to re-accommodate when reading output information. This allows *for an* increase *in* the concentration of the pilot on the outboard situation, reduc*ing* the *pilot eye fatigue* and improv*ing* the overall comfort of the flight. Today many HMD systems are implemented in monocular design but for more comfort and informative work system should be binocular (or biocular), however not all optical schemes allow this to be done. *This* work presents the analysis of modern solutions of Head-Mounted optical systems design and an assessment of the feasibility of using certain systems in the form of binocular or biocular helmet displays.

Passive target tracking method based on vision information feedback; Paper No.: 10743-34; Prof. Anhu Li, Tongji Univ., Mr. Xingsheng Liu

Risley prism beam scanner*s* *have* already been employed in many active beam alignment or target tracking applications, because such scanner*s* *are* advantageous in structural compactness, angular dynamic range and response performance. However, there *is* much more effort required in order to apply the scanner for passively tracking a dynamic target without any prior information. In this paper, we propose a passive target tracking method that relies on the feedback of target position information from a variable boresight imaging system. Firstly, the theoretical model of the variable boresight imaging system, which consists of a camera and a Risley prism scanner, is established to help demonstrate how the camera boresight is steered by rotating *the* Risley prisms. To be resistant to the manufacturing, assembly and misalignment errors of the system in practice, the target tracking operation is designed to be a closed-loop procedure. Particularly, two essential parts of the closed loop are described in detail, including the determination of target position and the optimization of boresight adjustment strategy. The former part is focused on processing the images captured by the camera and extracting the target position relative to the image center, while the latter part is highlighted to decouple the pitch angle and the azimuth angle of the steered camera boresight. In addition, the experiment*al* setup is introduced with both hardware and software to help evaluate the accuracy and efficiency of the proposed target tracking method. Further analysis is finally presented on the basis of experiment*al* results, which is of great significance and necessity to improve the target tracking performance in some industrial and military applications.

Laser proximity sensor effects in missile application; Paper No.: 10743-35; Mr. Doğan Uğur Sakarya, Roketsan A.S.

Tactical missiles have *a* seeker capability to detect and track targets. Because of the seekers' field of view, detonation range of the missiles has a limit. Mostly this limit is far away from the desired distance which *ties to* a seeker's blind spot. To increase missile's effectiveness against target, *a* laser proximity sensor is used. Where the seeker's blind spot distance is arrived *at,* the proximity sensor will be used until its minimum distance *reaches its own* limits. In this study, missile parameters are assumed and minimum detonation distance for seeker will be found. Effectiveness of warhead at this distance will be calculated. Later, parameters of proximity sensor are determined. Optical design and modeling of the proximity sensor will be conducted and minimum distance of it will be determined. Warhead effectiveness of this minimum distance will be given. Finally, *the* results *from the different systems* will be compared.

Spectral and spectral sampling analysis of the spectral imaging system based on the light-field architecture; Paper No.: 10743-37; Ms. Lijuan Su, Beihang Univ., Mr. Yujian Liu, Prof. Yan Yuan

The light filed modulated imaging spectrometer (LFMIS) can obtain a multispectral data cube in a single shot. The spatial sampling is affected by the design of spectral filters, because the diffraction limit increases as the sizes of the filters decrease. The spatial and spectral sampling characters of the system are determined by the system parameters, specially the parameters of the filters. This research presents the models of the system and the linear-variable optical filters (LVFs). The spatial sampling character is analyzed theoretically and confirmed by simulation results. Simulation experiments are performed to analyze the *characteristics* of LVFs that effect the spectral sampling character *of the system.* The results provide the parameter requirements of LVFs when designing an LFMIS system based on LVFs.