3rd International Workshop on Adaptive, Compressive and Computational Imaging

November 26-28 2024, Montevideo, Uruguay

Welcome!

This book compiles the abstracts of oral presentations and posters presented during the 3rd International Workshop on Adaptive, Comprehensive and Computational Imaging (WACCI 2024), held in Montevideo, Uruguay, from November 26th to 28th. Computational imaging is an emerging interdisciplinary field that aims to design computer-aided imaging systems tailored to specific tasks, integrating elements of optics, image processing, mathematics, and computer science. The workshop aimed to strengthen the Latin American community in computational imaging, providing researchers and students with the opportunity to interact with leading international experts through plenary talks. In addition to partially funding the visit of some invited speakers, scholarships were awarded to Latin American graduate students. WACCI 2024 was a success, exceeding our expectations. Attendees highlighted the quality of the presentations and the valuable opportunity to establish new collaborations. We believe this event lays the foundation for future editions of WACCI, solidifying its position as a benchmark in the field of computational imaging in the region and internationally.

Workshop Chairs

Julia Alonso
Universidad de la República

Esteban Vera
Pontificia Universidad Católica de Valparaíso

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Scientific Topics

Compressive sensing

Unconventional imaging modalities

Imaging at extreme scales

3D Imaging

Super Resolution

Lensless imaging

Deep learning for computational imaging

Imaging through turbid media

Spectral imaging

Phase retrieval

Wavefront sensing

Adaptive optics

Inverse problems

Fourier Ptychography

Social Events

Hotel Reception

Visit and explore Uruguay's largest city from the Aloft Montevideo Hotel. Our location in Punta Carretas provides easy access to the shops at Punta Carretas Shopping Mall, the La Rambla promenade, and attractions like Estadio Centenario and Teatro Solís. The airport is just 10 km from the hotel, making travel convenient.

Colonia del Sacramento Travel

On the east bank of the Río de la Plata, 112 miles (180km) west of Montevideo, Colonia del Sacramento is a captivating blend of Spanish and Portuguese colonial history that transports visitors back to the 17th century. Founded in 1680, this UNESCO World Heritage site boasts cobblestone streets, stunning river views, and a deep historical significance.

Banquet at Uruguay Natural

First Certified Meat Restaurant by the National Meat Institute (INAC) in Uruguay, opened in 2013 Uruguayan Meat. Experiencing Uruguayan meat is not only a treat for the palate but also a gift for your health. The livestock is raised exclusively on natural pastures, ensuring a high standard of sustainability and nutrition.

Keynote Speakers

Gonzalo Arce

Charles Black Evans Professor,
JPMorgan-Chase Senior Faculty Fellow
University of Delaware

Dr. Gonzalo Arce's expertise lies in the fields of computational imaging, signal processing on graphs, and machine learning. His research is highly interdisciplinary, drawing from the theories of mathematics, optics, statistics, and artificial intelligence. Dr. Arce's primary research areas encompass computational compressive lidar, compressive sensing for spectral imaging, spectral X-Ray tomography, generative machine learning for inverse problems, and hypergraph neural networks. He applies his research to various domains, including biomedicine, Earth science, complex systems, and lithography. Dr. Arce is an active member of the Institute of Financial Services Analytics (IFSAN) and the Data Science Institute, both at the University of Delaware. He collaborates extensively with research groups worldwide, including those in Finland, China, Colombia, Bolivia, Poland, Ukraine, and Spain. Dr. Arce has twice held the Nokia-Fulbright Distinguished Chair in Information and Communications Technologies in Helsinki, Finland.

Amit Ashok

Assistant Professor of Electrical and Computer Engineering
University of Arizona

The Intelligent Imaging and Sensing Lab, under the direction of Amit Ashok, is engaged in conducting cutting-edge research to develop the next generation of optical imagers and sensors via the new paradigm of computational sensing. The computational sensing approach exploits knowledge about information-bearing signals and task-application to realize novel optical imager and sensor designs employing reconfigurable-unconventional optics and sophisticated image processing algorithms to achieve revolutionary performance. This multidisciplinary research draws from varied disciples such as physical optics, optical engineering, statistical optics, signal-image processing, machine learning, statistical inference and computer science. Students in the lab get the opportunity to gain hands-on experience with tabletop optical imaging experiments as well as develop advanced image processing algorithms for CPU-GPU based parallel architectures on the lab's computer cluster capable of six teraflops.

Keynote Speakers

David Brady

Professor of Optical Sciences
University of Arizona

Brady focuses on computational imaging. Brady led the joint Duke University and University of Arizona team that built the world's first gigapixel camera in 2012. His subsequent work has focused on reducing the size, weight, power and cost of gigapixel cameras while also improving depth of field, color fidelity, frame frame rate and other measures of image quality. Brady's current work focuses on aperture synthesis and interferometric super-resolution techniques to continue to push the physical limits of optical sensing. His lab relies heavily on artificial neural networks for camera system control, data management and image estimation. He has also pioneered compressive tomographic imaging systems for efficient hyperspectral, high frame rate, x-ray and millimeter wave imaging.

Rafael Piestun

Professor of Electrical, Computer and Energy Engineering (ECEE)
University of Colorado

Rafael Piestun's current research interests include microphotonic devices, ultrafast optics, electromagnetic theory in optics, and inverse problems. Dr. Piestun is a Member of the IEEE, IEEE Laser Electro–Optical Society, and the Optical Society of America. He served on the editorial committee of Optics and Photonics News. He was a Fulbright Scholar, and Eshkol Fellow, and received the Minerva, El-Op, and Gutwirth prizes. The research in Dr. Piestun's group deals with the control and processing of optical radiation at two significant spatial and temporal scales: the nanometer and the femtosecond. Interest in this area arises from the existence of new phenomena occurring at these scales and the fascinating applications in new devices and systems. Current challenges in sensing, imaging, communications, energy conversion, and computing provide a continuous motivation for this work.

Keynote Speakers

Enrique Tajahuerce

Professor of Optical Sciences
Universitat Jaume I

Enrique Tajahuerce is a member of the Department of Physics at Universitat Jaume I in Castellón, where he is currently an Associate Professor in the Optics Division. He earned his degree in Physical Sciences and his Ph.D. in Physics from the University of Valencia in 1988 and 1998, respectively. He currently serves as Secretary of the Institute of New Imaging Technologies at Universitat Jaume I. He leads the imaging techniques laboratory in the "Castellón Research Group on Optics, GROC-UJI". His research interests include diffractive optics, adaptive optics, optical processing, digital holography, optical encryption and security techniques, and computational imaging techniques. Currently, the GROC imaging laboratory focuses its activities on developing computational imaging techniques using structured light and detection with non-spatially-resolved sensors. He has conducted various research stays, including a notable one at the Department of Electrical and Computer Engineering at the University of Connecticut (USA) from 1999 to 2000.

Yuzuru Takashima

Professor of Optical Sciences
University of Arizona

Takashima “Advanced Lidar and Display” Lab. researches and develops optical devices such as lidar and AR display by using MEMS-based devices while incorporating various scientific and engineering disciplines: electrical engineering, optical engineering, and computer sciences.
Experienced Professor with a demonstrated history of working in the consumer and higher education industry. Strong research professional skilled in Optical Engineering including Digital Micromirror Device based Lidar, MEMS lidar, Holographic Lidar, AR/VR display engine, Micro optics fabrications, Nanotechnology, X-ray Detectors, Computer Generated Holograms, Lens System and Optical Design, Photonics Device Design, Interferometry and Holography.

Program

WACCI 2024 - PROGRAM

Tuesday November 26th

8:30-9:00AM – *Registration*

9:00-9:15AM – *Opening Words by the Workshop Chairs*

9:15-10:00AM – **David Brady**, University of Arizona, USA: "Phase and coherence in computational imaging systems" **Keynote Talk**

10:00-10:15AM – **Esteban Vera,** Pontificia Universidad Católica de Valparaíso, Chile: "Computational Imaging for Space Applications"

10:15-10:30AM – **Travis Tubbs,** AFOSR/SOARD: **"**AFOSR/ONRG/USArmy Funding Opportunities"

10:30-11:00AM – *Coffee Break*

11:00-11:30AM – **Pascal Picart**, Le Mans Université, France: "Advances in noise modeling and reduction in dual-wavelength digital holographic imaging" **Invited talk**

11:30-11:45AM – **Ali Godoy**, Universidad de Santiago de Chile, Chile: "Innovative Low-Cost detection of sickle cell disease using digital lensless holographic microscopy"

11:45-12:00PM – **Juan Llaguno**, Universidad de la República, Uruguay: "Physics-guided deep learning reconstruction applied to off-axis digital holography microscopy"

12:00-12:30PM – **Jorge García-Sucerquia**, Universidad Nacional, Colombia: "Digital lensless holographic microscopy: fundamentals, application, and forecasted future" **Invited talk**

12:30-2:00PM – *Lunch Break (on your own)*

2:00-2:30PM – **Marcus Carlsson**, Lund University, Sweden: "Single-distance nano-holotomography with coded apertures" **Invited talk**

2:30-2:45PM – **Vicente Westerhout**, Pontificia Universidad Católica de Valparaíso, Chile: "Analysis of events generation rates on recordings in space situational awareness"

2:45-3:00PM – **Josefa Silva**, Universidad de la Frontera, Chile: "Coded aperture design for temporal compressive imaging in a color-polarized video"

3:00-3:30PM – **Nelson Díaz**, Pontificia Universidad Católica de Valparaíso, Chile: "Computational Imaging for Extended-Depth-of-Field"

3:30-4:00PM – *Coffee Break*

4:00-4:15PM – **Edson Mojica**, Universidad de la Frontera, Chile: "Single Pixel Imaging with a Shifted coded aperture"

4:15-4:30PM – **Alejandro Silva,** Universidad de la República, Uruguay: "Transport of Intensity Equation in Microscopy: improvements in algorithms and biological applications"

4:30-4:45PM – **Nicolás Alegría**, Pontificia Universidad Católica de Valparaíso, Chile: "Joint design of Fourier-based wavefront sensors for extended dynamic range"

4:45-5:30PM – **Enrique Tajahuerce**, Universitat Jaume I, Spain: "Structured illumination microscopy with single-pixel detection" **Keynote Talk**

Wednesday November 27th

9:00-9:45AM – **Gonzalo Arce**, University of Delaware, USA: "Surface Topography and Vegetation Sensing and Reconstruction Systems" **Keynote talk**

9:45-10:00AM – **Alejandro Alvarado**, Pontificia Universidad Católica de Valparaíso, Chile: "Regular vs Irregular Sphere Packing for Compressive Spectral Imaging"

10:00-10:15AM – **Pablo Meza**, Universidad de la Frontera, Chile: "Information Processing Laboratory + some research"

10:15-10:30AM – **Sonia Wolff,** ONRG: **"**AFOSR/ONRG/USArmy Funding Opportunities"

10:30-11:00AM – *Coffee Break*

11:00-11:30AM – **Kristina Irsch**, Institut de la Vision, France: "Computational microscopy of the eye" **Invited talk**

11:30-11:45AM – **Miguel Arocena**, Universidad de la República, Uruguay: "Quantitative phase microscopy for studying cell responses to stress"

11:45-12:00PM – **Eduardo Peters**, Universidad de la Frontera, Chile: "Phase Retrieval by Binary Amplitude Modulation using Talbot Effect"

12:00-12:30PM – **Leonel Malacrida**, Institut Pasteur & Universidad de la República, Uruguay: "PhasorPy for phasor plots analysis of Fluorescence Lifetime Microscopy and Hyperspectral Imaging" **Invited talk**

12:30-2:00PM – *Lunch Break (on your own)*

2:00-2:45PM – **Yuzuru Takashima**, University of Arizona, USA: "Lidar, Near-to-Eye AR Display, and Imaging by Angular and Spatial Light Modulation Technique with Texas Instruments Digital Micromirror Device" **Keynote talk**

2:45-3:00PM – **Ariel Fernández**, Universidad de la República, Uruguay: "Recent advances in Mueller matrix microscopy: whole slide and single-shot imaging"

3:00-3:30PM – **Miguel Heredia Conde**, University of Wuppertal, Germany: "Recent Advances in Computational Time-of-Flight Imaging" **Invited talk**

3:30-5:00PM – Coffee Break + Poster Session*

***8:00-10:00PM – Workshop banquet at Uruguay Natural Parrilla Gourmet* (Dr. Héctor Miranda 2432)**

Thursday November 28th

9:00-9:45AM – **Rafael Piestun,** University of Colorado, USA: "Endomicroscopy with hair-thin probes" **Keynote talk**

9:45-10:00AM – **Felipe Guzmán**, Pontificia Universidad Católica de Valparaíso, Chile: "Experimental Validation of Snapshot Compressive Video in Scattering Media"

10:00-10:15AM – **Julia Alonso**, Universidad de la República, Uruguay: "Computational Imaging for Biomedical applications"

10:15-10:30AM – **José Larenas / Harry Durette,** USArmy AFC-Americas: **"**AFOSR/ONRG/USArmy Funding Opportunities"

10:30-11:00AM – *Coffee Break*

11:00-11:30AM – **Pablo Musé**, Universidad de la República, Uruguay: "Blind Motion Prediction and Deblurring from a Single Image" **Invited talk**

11:30-11:45AM – **David Morales-Norato,** Universidad Industrial de Santander, Colombia: "PSF regularizations for privacy preserving multimodal action recognition"

11:45-12:00PM – **Esley Torres,** Universidad de la República, Uruguay: "Beyong the Sparrow limit by MeanShift"

12:00-12:30PM – **Matías Di Martino**, Universidad Católica, Uruguay: "Recent advances in computer vision" **Invited talk**

12:30-2:00PM *– Lunch Break (on your own)*

2:00-2:30PM – **Julián Tachella**, CNRS, France: "Self-supervised learning for imaging inverse problems" **Invited talk**

2:30-2:45PM – **Edgar Salazar**, Universidad Privada Boliviana, Bolivia: "A Gray-Scale Coding Approach for Compressive X-ray Compton Backscattering Imaging"

2:45-3:00PM – **Jorge Guaiquil**, Universidad de la Frontera, Chile: "Compressed spectral-depth estimation via a dual-dispersive CASSI architecture"

3:00-3:30PM – **Jorge Bacca**, Universidad Industrial de Santander, Colombia: "Unlimited Sampling: Algorithms and Imaging Applications"

3:30-4:00PM – *Coffee Break*

4:00-4:30PM – **Federico Lecumberry**, Universidad de la República, Uruguay: "Computational Super-Resolution Microscopy" **Invited talk**

4:30-5:15PM – **Amit Ashok**, University of Arizona, USA: "Quantum-inspired Imaging and Sensing" **Keynote talk**

5:15-5:30PM – *Closing Remarks by the Chairs & Poster Awards*

Friday November 29th

9:00AM-6:00PM – optional *tour to Colonia del Sacramento (details and check-in at registration)*

(*) Poster Session (Wednesday 3:30-5:00PM)

Authors	Title
Arturo Osorio Optolab and Esteban Vera	Compact Adaptive Optics System using a Deformable Lens for a 0.5m Ritchey Chretien telescope
Roman Demczylo, Diego Silva Piedra, Federico Lecumberry, Leonel Malacrida and Ariel Fernández	Mueller matrix polarimetry and hyperspectral autofluorescence imaging for histopathological diagnosis without the use of markers
Brayan Monroy, Kebin Contreras and Jorge Bacca	Modulo Imaging: Algorithms and Applications
Sebastián Valdivia and Esteban Vera	All-Sky Surveillance for Space Situational Awareness: A Real-Time Neuromorphic System
Exequiel Oliva, Benjamín Gac, Alejandro Alvarado, Camilo Weinberger, Jorge Tapia, Nelson Díaz and Esteban Vera	Hardware-in-the-Loop Framework for Diffractive Optics Design for Multispectral Classification
Emmanuel Martinez, Kebin Contreras, Henry Arguello and Jorge Bacca	End-to-End Band Selection for HSI Classification
Eduardo Sepulveda, Jinyang Liang and Pablo Meza	Compressed optical Shack-Hartmann ultrafast photography

Vicente Cisternas and Asticio Vargas	Iteration Reduction for Mueller Matrix Calculation Using Orthogonal Camera System
Daniela Fritz, Hector Vargas, Edson Mojica and Pablo Meza	Object Tracking System Based on Phase Modulation
Kebin Contreras, Emmanuel Martinez, Brayan Monroy, Tatiana Gelvez Barrera, Hans Garcia, Henry Arguello and Jorge Bacca	Spectral Assessment for Cocoa Quality
Benjamin Gonzalez, Nicolas Hernandez, Bastian Romero and Esteban Vera	Real-time control loop implementation of adaptive optics systems based on deep learning
Rodrigo Muñoz, Felipe Guzmán, Nicolas Hernández and Esteban Vera	Development of a Hologram Printer for Holographic Wavefront Sensors
Diego Hernandez, Daniel Yunge and Esteban Vera	Embedded Systems for Object Detection Using Neuromorphic Event Cameras and FPGA Video Libraries in Astronomical Observatories v2
Vladimir Cisternas, Vicente Westerhout and Esteban Vera	Development of an autofocus algorithm for event-based cameras for space awareness and astronomical applications

Keynote Speakers Abstracts

Surface Topography and Vegetation Sensing and Reconstruction Systems

Gonzalo Arce[1*]
[1] *University of Delaware, USA*
arce@udel.edu

Abstract

Sensing of the Earth's surface topography and vegetation (STV) metrology relies on lidar, radar, stereophotogrammetry, or a combination of these remote sensing techniques. STV metrology, however, suffers from low spatial and height resolution or sparse coverage if lidars and stereophotogrammetry are deployed at orbital heights. Many scientific applications, such as bare Earth, cryosphere, and hydrology, require meter or sub-meter STV observables in spatial resolution with submeter vertical resolution. This work is aimed to overcome the STV resolution gap by use of a simple observation system composed of an orbital CS lidar aided by high-resolution monocular RGB photography. The system first produces a super-resolved digital elevation model by fusing satellite compressive lidar photon returns with monocular photography using an image-to-image translation generative Brownian-Bridge-Diffusion Model (BBDM). Subsequently, the low photon count lidar measurements together with the high-resolution DEM are then used in a constrained denoising diffusion probabilistic model to reconstruct super-resolved, wall-to-wall, and photon-rich hyperheight STV data cubes.

Quantum-inspired Imaging and Sensing

Amit Ashok[1*]
[1] *Wyant College of Optical Sciences, University of Arizona, USA*
**ashoka@optics.arizona.edu*

Abstract

This talk will present novel imaging and sensing techniques based on quantum information theory, with applications such as wavefront sensing and optical super-resolution imaging.

Phase and coherence in computational imaging systems

David J. Brady[1*]

[1] *University of Arizona, USA*

**djbrady@arizona.edu*

Abstract

Diverse sampling with array cameras, mode filters, and interferometers enables phase sensitive imaging systems. Such systems may exceed conventional resolution limits via aperture synthesis and advanced signal estimation.

Endomicroscopy with hair-thin probes

Rafael Piestun[1*]

[1] *University of Colorado Boulder, USA*

**piestun@colorado.edu*

Abstract

In-vivo imaging using hair-thin multimode fibers has been recently accomplished. Multimode fibers are attractive for endoscopic applications due to their thin cross-section, high modal density, and flexibility. We introduce the techniques and discuss the latest in-vivo implementations.

Structured illumination microscopy with single-pixel detection

Enrique Tajahuerce[1*]

[1] *Universitat Jaume I, Spain*

**tajahuer@uji.es*

Abstract

I will describe computational microscopy techniques based on structured illumination and single-pixel detection. Specifically, I will focus on new methods that offer optical sectioning and super-resolution in bright-field and fluorescence microscopy.

Lidar, Near-to-Eye AR Display, and Imaging by Angular and Spatial Light Modulation Technique with Texas Instruments Digital Micromirror Device

Yuzuru Takashima*, Parker Liu, Ted Liang-tai Lee, Chuan Luo, Brandon Friedman, Gregory Nero, Yexin Pei, Tianyao Zhang, Xianyue Deng, Jeff Ching-wen Chan, Eunmo Kang, Chin-I Tang, Jeff Chen, Rajesh Shrestha, Yefu Zhang, and Emil Varghese
James C. Wyant College of Optical Sciences, 1630 E. University Blvd. Tucson AZ 85721 USA
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Abstract: *Beam and image steering by Micro Electro Mechanical System (MEMS) spatial light modulators decouples trade-offs between resolution, field of view and size of displays and optics that solves optical design challenges commonly found in lidar and Augmented Reality display engine, and potentially opens new applications in imaging.*

1. Introduction

Interestingly many optical systems encounter similar challenges. In near-to-eye Augmented Reality (AR) display devices, a trade-off exists among FOV, resolution, and number of pixels that determine a critical form factor. In lidar system, similar trade-off in FOV and resolution exists [1]. In this paper, we overview the solutions to overcome the Etendue limited performance in AR. lidar and imaging system by employing diffractive beam and image steering by Micro Electro Mechanical System (MEMS) based Spatial Light Modulators (SLMs).

2. MEMS-SLM for Angular and Spatial Light Modulation (ASLM)

As a MEMS-SLM, we employ Texas Instruments Digital Micromirror Device (TI-DMD). The TI-DMD consists of an array of micro mirrors that tilt in +/– 12 degrees that corresponds to on- and off-pixel states, respectively [2]. In between the on- and off-states, the tilt angle of mirror array continuously changes from +12 to −12 degrees [3]. The key idea of the Angular and Spatial Light Modulation (ASLM) is accessing to the transitional state of the mirror by using a ns pulsed laser. The timing of the pulsed laser to the mirror transition adds phase tilt that diffracts beam and image into one of the diffraction orders with high efficiency. Figure 1a shows a phase profile of DMD mirror array while mirrors are in transition [3, 4]. Suppose the short pulse illuminates the mirror array in motion so that the phase profile satisfies the blaze condition, the pulse which is spatially modulated is diffracted with high diffraction efficiency. The pulse synchronization process is repeated at each of mirror transitions while addressing different blaze conditions (Fig. 1b). In this way, images illuminated by short pulse laser is redirected to one of the several to ten diffraction orders.

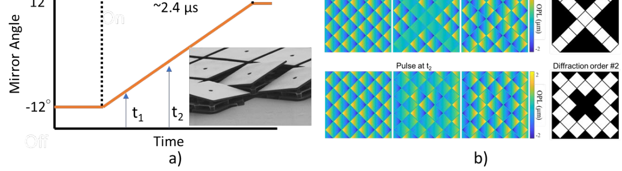

Fig. 1. Phase profile if DMD mirror array when (a) all the mirrors are actuated, (b) pattern is displayed, at timings t_1 and t_2 while mirrors are in motion [4].

3. Applications of the ASLM technique

ASLM was applied to single chip DMD lidar, holographic single chip lidar, all-MEMS scanning lidar, wide FOV steering flash lidar, and OPA (optical phased array) equivalent beam and image steering [1,3,5-7]. In display area, multi-axis projection, multi-view, giga-pixel-equivalent, single-chip occlusion, and multi-domain multiplexed display were demonstrated [4,8,9]. In imaging, streak-camera and high-speed camera were demonstrated based on ASML technique by sorting the time events into angular domain [10,11].

4. Conclusion

The angular and spatial light modulation (ASLM) solves challenges in performance trade-off commonly found in optical devices. A flexible control of light in angle, pattern, phase, amplitude, and timing, which provides potential and hopefully significant benefit for imaging and sensing applications.

Acknowledgement: A part of the research is supported by Texas Instruments, and TxACE, Semiconductor Research Corporation.

References

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[2] L. J. Hornbeck, "From cathode rays to digital micromirrors: a history of electronic projection display", TI Tech. J. ***15***, 7–46 (1998).

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[4] B. Hellman and Y. Takashima, "Angular and spatial light modulation by single digital micromirror device for multi-image output and nearly-doubled étendue," Opt. Express ***27***, 21477-21496 (2019).

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[6] E. Kang, et al. "All-MEMS Lidar Using Hybrid Optical Architecture with Digital Micromirror Devices and a 2D-MEMS Mirror", Micromachines ***13***, 1444 (2022).

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[10] D. M. Benton, "Temporal and spectral dispersion of an optical source using a micromirror array-based streak camera," Optical engineering 61, 114108-114108 (2022).

[11] X. Liu et al. "Diffraction-Gated Real-Time Ultrahigh-Speed Mapping Photography." Optica 10.9 (2023).

Invited Speakers Abstracts

Single-distance nano-holotomography with coded apertures

Marcus Carlsson[1*]
[1] *Lund University, Sweden*
**Pending Email*

Abstract

High-resolution phase-contrast 3D imaging using nano-holotomography typically requires collecting multiple tomograms at varying sample-to-detector distances, usually 3 to 4. This multi-distance approach significantly limits temporal resolution, making it impractical for operando studies. Moreover, shifting the sample complicates reconstruction, requiring precise alignment and interpolation to correct for shift-dependent magnification on the detector. I will present a novel single-distance approach that leverages coded apertures to structure beam illumination while the sample rotates. This approach relies on a joint reconstruction scheme, which integrates coded phase retrieval with 3D tomography. This scheme ensures data consistency and achieves artifact-free reconstructions from a single distance.

Recent advances in computer vision

J. Matias Di Martino[1*]

[1] *Universidad Catolica del Uruguay, Uruguay*

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Abstract

We will review the state of the art and recent advances of computer vision.

Digital Lensless Holographic Microscopy: Fundamentals, Application, and Forecasted Future

Jorge Garcia-Sucerquia[1*]
[1] *Universidad Nacional de Colombia Sede Medellín, Colombia*
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Abstract

In this contribution the fundamentals, both physical and computational, some past and current applications, and forecasted future of digital lensless holographic microscopy, are presented and discussed.

Recent Advances in Computational Time-of-Flight Imaging

Miguel Heredia Conde[1*]

[1] *University of Wuppertal, Spain*

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Abstract

This talk shows how tailored computational imaging methods can overcome fundamental limitations in ToF imaging, such as high power consumption, limited range for accurate depth estimation, and measurement distortions due to harmonics and multi-path interference.

Computational microscopy of the eye

Kristina Irsch[1*]
[1] *Vision Institute (CNRS), France*
**kristina.irsch@gmail.com*

Abstract

Abstract pending.

Computational Super-Resolution Microscopy

Federico Lecumberry[1*]

[1] *Universidad de la República, Uruguay*

**lecumberry@fing.edu.uy*

Abstract

Abstract pending.

PhasorPy for phasor plots analysis of Fluorescence Lifetime Microscopy and Hyperspectral Imaging

Leonel Malacrida[1,2*]
[1] *Universidad de la República*
[2] *Institut Pasteur de Montevideo, Uruguay*
**Leonelmalacrida@gmail.com*

Abstract

Fluorescence lifetime imaging microscopy (FLIM) and hyperspectral imaging (HSI) are powerful tools for biomedicine research and diagnostic. Nonetheless the analysis of such dataset could be challenging. The phasor approach is an intuitive and model-free method that makes simple the analysis of FLIM and HSI. PhasorPy is a Python-based open-source library developed for a comprehensive tool for all Phasor analysis.

Blind Motion Prediction and Deblurring from a Single Image

Pablo Musé[1*]
[1] *Facultad de Ingeniería, Universidad de la República, Uruguay*
**pmuse@fing.edu.uy*

Abstract

Abstract pending.

Recent advances in noise modelling and processing in digital holographic metrology

Pascal Picart[1]*

[1] *Le Mans Université - LAUM CNRS, France*

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Abstract

Dual and multi-wavelength digital holography has demonstrated to be a relevant tool for desensitized testing of steep optical surfaces (aspheric mirrors and lenses) [1], large deformation of structures [2] or surface shape profiling [3]. Such an approach can also be used for surface roughness measurements when the roughness is large compared to the wavelength [4]. With the advent of digital holography [5], a wide range of applications of dual/multi-wavelength holography was demonstrated, such as endoscopic imaging [6, 7], calibration of mechanical structures [8], erosion measurements [9], in-line industrial inspection [10], melt-pool monitoring in additive laser welding manufacturing [11] or more recently accurate profiling by coherence scanning profilometry [12]. However, due to the natural roughness of the inspected surface, speckle decorrelation occurs and noise is included in the intermediate data. This noise refers as the "speckle decorrelation" noise [13] and is very particular since its properties are very different from those of classical technical noise in photonic systems. Especially, the noise is non-Gaussian, non-stationary, amplitude–dependent and may be anisotropic. In order to yield high quality data for metrology purpose, the speckle decorrelation is required to be spatially filtered [14, 15]. Recently deep learning has emerged as a powerful and rapid approach for processing phase data [16].

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Self-supervised learning for imaging inverse problems

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Abstract

Recently, many self-supervised learning methods for image reconstruction have been proposed that can learn from noisy data alone, bypassing the need for ground-truth references. In this talk, I will introduce a theoretical framework that characterizes this expressivity-robustness trade-off and propose a new approach that doesn't require knowledge about the noise level.

Contributed Talks Abstracts

Computational Imaging for Biomedical applications

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1. Abstract

This talk will explore the intersection of optics and computation in microscopy. We will explore two key areas: multifocus fluorescence imaging and quantitative phase imaging. By highlighting the current challenges and promising research directions, we aim to inspire collaborative efforts in advancing this exciting field.

2. Introduction

Optical microscopy, while crucial, often fails to capture the full complexity of biological samples. Physics-informed computational microscopy [1, 2] addresses this by integrating computational methods with established optical principles.

This talk focuses on two key techniques. Multifocus imaging [3] captures data from multiple focal planes, offering a more comprehensive view than single-plane imaging [4, 5]. Quantitative phase imaging [6] extracts quantitative phase information, revealing crucial details such as thickness and refractive index variations [7].

Transport of Intensity Equation (TIE) [8] is a prominent method in quantitative phase imaging. By analyzing intensity variations across defocus planes, TIE efficiently extracts phase information [9, 10].

Digital Holographic Microscopy (DHM) captures the entire wavefront of light, enabling direct reconstruction of both amplitude and phase [11]. While DHM offers a richer dataset, it often requires more complex setups compared to TIE.

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A Gray-Scale Coding Approach for Compressive X-ray Compton Backscattering Imaging

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Abstract

We propose and develop a gray-scale coding technique for compressive X-ray compton backscattering imaging CXBI [1]. Results show a major improvement against binary random and Model-based optimized patterns in terms of Peak Signal-to-Noise Ratio (PSNR) and structural similarity index (SSIM).

Methodology and Results

A data-driven reconstruction and optimization framework is developed for CXBI. The sampling sub-network consists of a matrix $\mathbf{H} \in R^{N \times N+M-1}$ that accounts for the coding using M snapshots for a $N \times N$ scene; the matrix $\mathbf{H}$ is shifted one column to acquire different pixel information per each snapshot. To model the sensing process as a matrix-vector multiplication, each snapshot pattern is flattened and row-wise stored into the matrix $\mathbf{A} \in R^{M \times N^2}$; after that, the measurement vector is obtained with the expression $\mathbf{y} = \mathbf{Ax}$, where $\mathbf{x} \in R^{N^2}$ is the vector-wise scene to be recovered. A first rough estimation is done by solving the problem $\min_x (||\mathbf{y} - \mathbf{Ax})||_2^2 + \lambda R((x))$, (where $R(\mathbf{x})$ is a denoising prior) using the Iterative Shrinkage Threshold Algorithm (ISTA) with $\mathbf{A}^T$ as a learnable parameter. This first estimation passes through a Deep Neural Network composed of five Residual U-blocks (RSU) and one spatial-attention module that focuses on the spatial information of the image. The network loss-function is guided with both the Mean Squared Error and Structural Similarity Index. Moreover, three different regularizers are added in accordance to code-design principles, being the first used to guarantee incoherence among snapshot patterns, the second to control the transmittance of the shots, and the final to guarantee that mask pixel values are within the set $\{0, 0.25, 0.5, 0.75, 1\}$; this last one is used to restrict gray-scale pixels to a finite number of values. We compare our proposed approach with random and Model-based Gradient-descent optimized binary codes, with a compression ratio of 12.5% and a transmittance of 10% per shot. Results show major visual and quantitative improvements as depicted in Fig. 1, with an increase of more than 7dB in PSNR and more that 0.3 in SSIM.

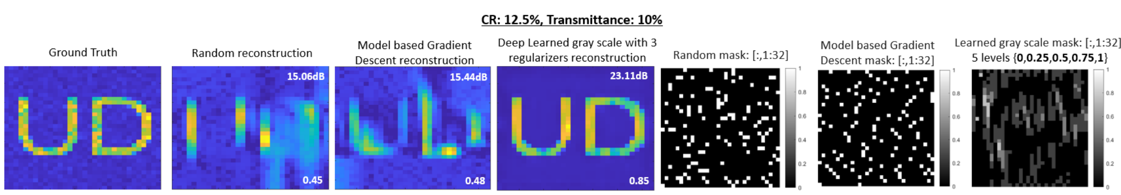

Fig. 1. From left to right: Ground-truth, reconstructed scene with random, model-based designed, and gray-scale codes; corresponding random, model-based optimized and gray-scale patterns.

Conclusions

We develop a gray-scale coding approach for CXBI that shows considerable improvements in the reconstructions. Our presentation will include a thorough study of the impact of the gray-scale level into the quality of the reconstructions, as well as testing this algorithm with other scenes (i.e anthropomorphic figures).

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Regular vs Irregular Sphere Packing for Compressive Spectral Imaging

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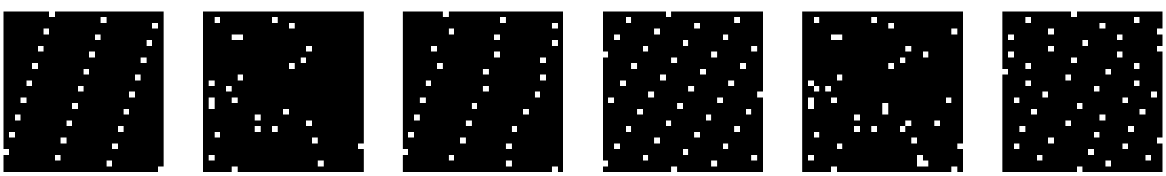
Multispectral imaging is a technique used in many areas, such as remote sensing, medicine or environmental monitoring, where the sensor collects spatio-spectral information in three dimensions: a datacube. To acquire spectral images, the state of the art provides different scanning methods, which are commonly limited by resolution or time acquisition. As an alternative, snapshot acquisition provides a single shot method to acquire a subsampled image where each pixel acquires information from 1 band, and the whole datacube is reconstructed using a demosaicking algorithm [1, 2]. Nevertheless, the transmittance decreases in subsampled acquisition limiting the reconstruction quality. An alternative is compressive spectral imaging which exploits compressive sensing to captured multiplexed measurements and the underlying datacube is recovered solving an ill-posed problem, which is relaxed by assuming sparsity [3]. In each pixel the acquisition includes information of more than one band, improving the measurement signal-to-noise at the expense of requiring compressive recsontruction methods. The generated inverse problem is better conditioned with a lower condition number (CN) of the sampling matrix, which implies a better reconstruction since the CN is correlated with the linear independence of the vectors within the sensing matrix. Random patterns often deliver low CN.

In this work, we extend the sphere packing approach [1] to maximize the density of spheres and increase the number of spheres in the container to increase the transmittance, converting the single-band pass filter into multi-band pass filter, multiplexing spectral bands [3]. However, the main problem with regular sphere packing for designing multiplexed multispectral filter arrays [1] is that the vectors in the sensing matrix are often linearly dependent, leading to a high CN. To overcome this limitation, we study that shuffling the regular patterns tend to reduce the CN, but the coded aperture (CA) still preserves the benefit of sphere packing showing a reduction in the reconstructions of nuisances such as color distortion, artifacts and the zipper effect. Different CAs are shown in Figure 1(a) and 1(d), which correspond to the first band in the sphere packing design with 56 bands with 2 and 3 multiplexed bands. Equivalent CAs in Figure 1(b) and 1(e) are random obtained from patterns. Finally, the CAs in Figure 1(c) and 1(f) correspond to the proposed randomized sphere packing.



(a) (b) (c) (d) (e) (f)

Fig. 1: CA of the 1st band: (a) 2 MUX ρ=0.56, CN=3.98x10^6, (b) Rand 2 MUX ρ=0.13, CN=2.49, (c) 2 MUX Rand ρ=0.27, CN=6.38, (d) 3 MUX ρ=0.36, CN=1.32x10^{12}, (e) Rand 3 MUX ρ=0.14, CN=3.84, (f) 3 MUX Rand ρ=0.26, CN=9.15

To conclude, we design an irregular sphere packing approach to reduce the CN in the CA. By combining optimal regular sphere packing patterns with random patterns with low CN, we are able to obtain a better conditioned inverse problem to reconstruct the whole datacube.

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Quantitative phase microscopy for studying cell responses to stress

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Abstract

Quantitative phase microscopy (QPM) allows for a detailed visualization of the cell interior in a label-free form, and at the same time extracts relevant information of cell contents in the form of refractive index maps. Therefore, QPM is a promising tool to study cell organization, its dynamics and the alterations it suffers in conditions of cell stress. However, many key cellular events, particularly in response to stress, pose challenges to their label-free identification and analysis by QPM. We have begun studying cellular responses to different sources of stress, such as microenvironmental hypoxia and chemotherapeutic drugs, with the purpose of identifying aspects of these responses particularly amenable to characterization by QPM. Our results might contribute to the effort of extending label-free analysis by QPM to multiple and simultaneous cellular responses to stress.

Computational Imaging for Extended-Depth-of-Field

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This work presents a review of computational imaging for the extended-depth-of-field (EDoF) methods of incoherent optical systems. The depth of the field refers to the range of distance over which an object resembles in-focus in a photographic image. Traditionally, in photography, the straightforward approach to performing EDoF is controlling the camera's aperture. A large aperture or small f-number yields a shallow depth-of-field. In contrast, a small aperture, *i.e.*, a large f-number, induces a deep depth-of-field. However, there are scenarios where closing the aperture is inconvenient because the number of photons is limited, and the system must be compact, for example, in the next generation of smartphones. Therefore, in optics and computational imaging (CI), an approach that designs wavefront coding for EDoF, which uses transparent elements such as diffractive optical element (DOE) or refractive lens that encode the wavefront and promotes a depth-invariant point spread function (PSF), which simplifies the blurring problem to non-blind deconvolution has emerged.

Specifically, in 1995, Dowski and Cathey proposed a classical approach of EDoF with a cubic phase modulation mask that promotes a consistent modulation transfer function (MTF) according to the change in the object distance [1]. In recent years, with the emergence of deep learning, interest in the use of the End-to-End (E2E) framework, which uses a DOE and a reconstruction algorithm to jointly optimize the optical system has increased. In detail, in 2018, the pioneering work of Vincent *et al.* was presented and applied for achromatic EDoF and snapshot superresolution imaging [2]. In 2021, Baek *et al.* introduced an E2E approach to design a DOE and recovering algorithm for depth-map and hyperspectral images; however, this approach has considerable drawbacks, for instance, the method struggles with low-light and intensity-saturated scenes, and long-tail PSFs reduce the contrast for real captured images [3]. Some recent works include a refractive lens before the DOE to reduce distortion [4,5]. In particular, in 2021, Akpinar *et al.* used the E2E strategy to design a DOE, which outperforms conventional wavefront coding [1] for $\alpha \geq 30$ and the traditional E2E approach [2]; the resulting f-number of the optical system is 7.38. Recently, in 2023, Pinilla *et al.* introduced the hardware-in-the-loop (HIL) technique, where the DOE implemented in an SLM, is configured and updated. Moreover, the refractive lens and the sensor remain fixed. The main advantage of HIL is to design the optics computationally; then, the optimization process addresses the sensor noise and calibration errors. Furthermore, the resulting optical system has an f-number of 1, which is a significantly challenging scenario. Finally, the main challenge of EDoF in computational imaging is the mismatch between the designed and the fabricated DOE. HIL might be a reasonable alternative to overcome this challenge.

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Recent advances in Mueller matrix microscopy: whole slide and single-shot imaging

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1. Abstract

Division of Focal Plane (DFP) sensing, combined with linearly independent States of Polarization (SOPs) at the input, enables the acquisition of 3×3 Mueller matrices of tissue samples. Image stitching facilitates an extended Field of View (FOV), while color polarization encoding of the source, in conjunction with DFP color polarimetry, enables single-shot Mueller matrix microscopy.

2. Introduction

Polarized light microscopy has emerged as a label-free technique for evaluating tissue alterations [1] . Mueller matrix (MM) polarimetry [2] has become a valuable tool for quantitatively assessing these microstructural changes, with applications ranging from cancer detection [3] to surgical imaging guidance [4]. Even simplified MM approaches [5] can be effective, as diagnoses often rely on relative changes in polarimetric parameters compared to healthy tissue Polarized light microscopy is an emerging label-free tool to assess changes in tissue samples . Mueller matrix (MM) polarimetry has recently established in this regard for the quantitative characterization of microstructural changes with applications that can be found for example in cancer detection or surgical imaging assistance . Even reduced forms of the matrix can be useful since diagnosis is often based not on the exact values of polarimetric parameters but on their relative change in comparison to healthy tissue [6].

Recent advancements in sensor technology have made microgrid polarizers integrated into camera chips commercially available, enabling real-time acquisition of linear Stokes parameters through Division of Focal Plane (DoFP) techniques [7, 8]. Moreover, polarization demosaicking methods can mitigate the spatial resolution loss associated with these sensors compared to division of aperture methods [9].

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Innovative Low-Cost Detection of Sickle Cell Disease Using Digital Lensless Holographic Microscopy

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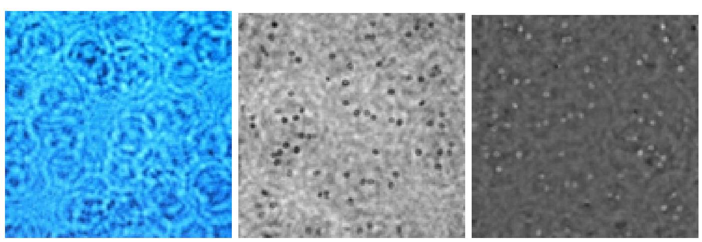
Abstract

Sickle cell anemia or sickle cell disease is one of the most frequent structural hemoglobinopathies, corresponding to the mutation in the beta chain of the hemoglobin gene, giving rise to hemoglobin S (HbS) [1]. As a result, red blood cells tend to form crystals in the deoxygenation process and return to normal upon oxygenation; this behavior weakens the cell membrane, shortening their lifespan from 120 to 14 days on average. As a result of this process, red blood cells tend to block blood vessels, leading to vasoocclusion, pain crises, organ damage and even death. In countries with a high vulnerability rate, about 500 children lose their lives daily due to lack of access to timely diagnosis and adequate treatment, which makes early access to health tests essential [2]. There are detection methods, such as immunochromatography or hemoglobin electrophoresis, which identify hemoglobin types, including HbS, but these procedures are expensive, which limits their accessibility. We propose a new and innovative medical diagnostic device for sickle cell disease, called Sickle Check, based on digital lensless holographic microscopy (DLHM). This technique uses interference patterns generated by the interaction between light and a biological sample to reconstruct the amplitude and phase of the original image using iterative algorithms based on Fresnel propagation [3]. Due to its easy implementation and low cost, DLHM is perfect for the creation of a medical diagnostic device for sickle cell disease, especially to bring to areas with limited resources. In this work, we present the implementation of a DLHM system for red blood cell image reconstruction (Figure 1) and projections of its use as a low-cost sickle cell disease diagnostic tool.



(a) (b) (c)

Fig. 1. Reconstruction of red blood cells by DLHM technique. (a) Red blood cell interference pattern used for reconstruction. (b) Amplitude reconstruction of red blood cells shown in a. (c) Phase reconstruction of red blood cells shown in a.

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Compressed spectral-depth estimation via a dual-dispersive CASSI architecture

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Several architectures have been designed to acquire high-resolution spatial and spectral information. In particular, schemes based on compressive sensing (CS) [1] stands out due to their ability to capture all spatial and spectral information from a scene in a single measurement. One of the most widely used architectures is the Dual Dispersive Coded Aperture Snapshot Spectral Imager (DD-CASSI) [2], which has proven effective in acquiring hyperspectral images. It is widely applied in areas such as remote sensing, environmental monitoring, and medical diagnostics, where both spatial distribution and spectral content are critical for analysis. Building upon this work, we extend its application to integrate Depth-from-Defocus (DfD) [3], motivated by the need to capture both spatial-spectral data and depth information in a single snapshot, enhancing scene analysis and 3D reconstruction. [3]. The dual-arm DD-CASSI architecture is shown in Fig. 1(a), where a beam splitter is used to divide the incoming light into two optical paths, each focusing on different focal planes. The sampling model for the system is represented as $\mathbf{y}=\mathbf{A}\mathbf{x}$ (Fig. 1(b)). The compressed measurements $\mathbf{y}$ received by the detector are a combination of two focal planes, $\mathbf{x}_1$ and $\mathbf{x}_2$, which are modulated with the sensing matrix $\mathbf{A}$, representing the optical elements and coded aperture required by the DD-CASSI. These measurements are the result of summing the modulated information from both focal planes before arriving at the detector. The goal is to estimate $\mathbf{x}_1$ and $\mathbf{x}_2$ from $\mathbf{y}$ using reconstruction techniques based on CS. This model relays combined information from both planes onto the detector, enabling image reconstruction through an optimization-based approach with learned spectral representations [4] and depth estimation via Scale-Invariant (SI) Depth [5]. Encoded measurements received by the detector are the sum of both codifications from the focal planes, as shown in Fig. 1(c). Fig.1(d) and 1(e) display the recovered focal planes, with a peak signal-to-noise ratio (PSNR) of 31.34 dB for the first focal plane in (d), and 32.79 dB for the second focal plane in (e), when compared to their corresponding reference in Fig. 1(b). Finally, the depth information is estimated from the reconstructed views, as shown in Fig. 1(f), where the depth is calculated using both reconstructed focal planes with a PSNR of 17.62.

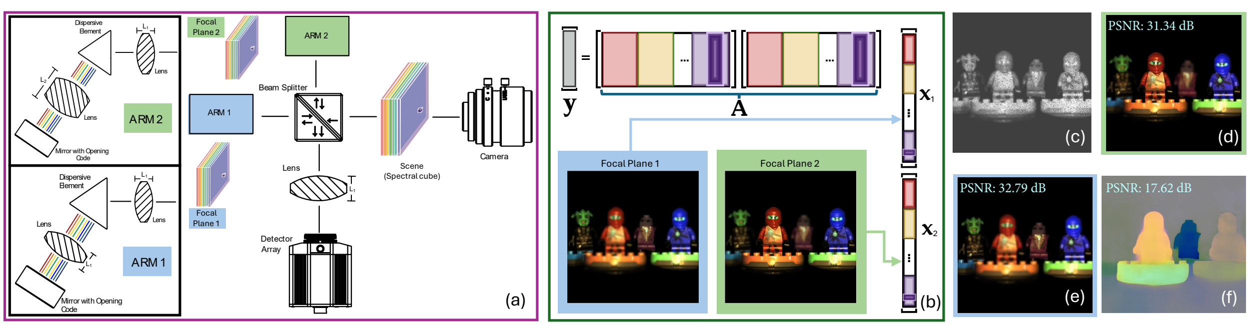

Figure 1. (a) Dual-arm DD-CASSI architecture. (b) Mathematical model. (c) Sum of encoded measurements from both focal planes received by the detector. (d) Recovered focal plane 1. (e) Recovered focal plane 2. (f) Depth estimation from the reconstructed focal planes.

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Experimental Validation of Snapshot Compressive Video in Scattering Media

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Imaging through scattering media presents significant challenges in fields such as biomedical and non-line-of-sight imaging, where light scattering obscures the visualization of internal structures or hidden scenes. Existing methods often require complex hardware, invasive techniques, stationary objects or iterative methods [1], limiting practical application, particularly in dynamic environments. To address this, snapshot compressive video (SCV) systems offer an efficient solution by capturing high-dimensional video data using 2D sensors through compressed sensing and deep learning reconstruction. SCV systems reduce data acquisition needs while retaining image quality [2]. In this work, we propose an adaptation of SCV combined with a deep neural network [3] to reconstruct dynamic scenes through unknown scattering media, achieving an 8X compression ratio with good reconstruction quality.

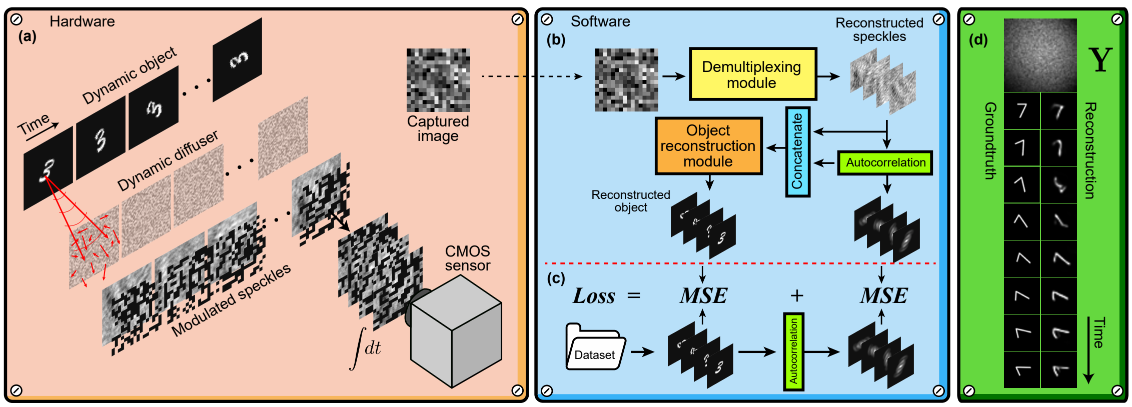

Fig. 1. The proposed compressive video scheme: (a) acquisition through scattering medium with a coded aperture, (b) The reconstruction model from speckles, (c) a loss function for optimization, and (d) experimental results comparing the reconstructed measurements with the projected frames.

As shown in Fig. 1, this work is based on the SCV acquisition system, where the measurements are defined as: $\mathbf{Y} = \sum_{t=1}^{T} \mathbf{C}_t \odot \mathbf{I}_t$. Here, $\mathbf{C}_t$ represents the t^{th} coded aperture (CA) across T frames, $\odot$ denotes the Hadamard operator, and $\mathbf{I}_t$ corresponds to the speckles, which are propagated as: $\mathbf{I}_t = \mathbf{S}_t * \mathbf{O}_t$. In this expression, $\mathbf{S}_t$ is the diffuser's PSF, and $\mathbf{O}_t$ is the object obscured by the scattering medium, and $*$ represents the convolution operation. As shown in (b), the reconstruction model consists of two modules: the first recovers $\mathbf{I}$, then performs autocorrelation, and finally reconstructs the object from the speckle and its autocorrelation, based on the loss function depicted in (c). After training, experimental results shown in (d) shows a succeful reconstruction of numerical objects with $T = 8$ from an unknown scattering medium with a single shot.

Future research could extend this method by incorporating color information and exploring its application across diverse fields, such as biomedical imaging and optical communications, where imaging through scattering media poses significant challenges.

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Joint design of Fourier-based wavefront sensors for extended dynamic range

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The classical pyramid wavefront sensor (PWFS) is a good choice for measuring wavefront aberrations in demanding adaptive optics driven astronomy [1]. This device has a pyramid object that acts as a spatial-shifting operator and generates four well-known pupils from which one can perform the aberration estimation [2]. However, the pyramid geometry imposes an inheren trade-off between the limited dynamic range and the superb sensitivity offered, which can only be changed by using active opticl modulation, a process which increases linearity at the expense of sensitivity. This motivates us to study the structure of the device. In this work, we make a generalization of the Fourier wavefront sensor [3] to consider the pyramid as a particular case. In addition, we change the Fourier geometry by considering a variable number of sides. Each of them is studied in terms of its propagation properties and how the trainable elements can improve the dynamic response. We propose an end-to-end (E2E) scheme that allows us to consider an optical Fourier preconditioner [4] and a nonlinear estimator [5], both trainable elements. We show how the preconditioner changes the properties whereas the estimator is suitable adapted for the evolving physical sensor, yielding a final response that is better than the classical counterpart. In the process, we make a training procedure which considers a dataset of Kolmogorov atmosphere ranging in a specific r_0 given beforehand. This imposes the first constraints to the system. The training considers different parameters to each element, in terms of learning rate, iterations per epochs, etc. After the training process, we make several test routines that show the response of the trained system under different inputs. In particular, we analyze the estimation error in open- and closed-loop, linearity through varied amplitude of the input, among others. We conclude that the Fourier geometry can be thought of as a simple initial condition for the optical preconditioner, which then evolves to finally achieves a similar optimal performance when combined with the neural network reconstructor.

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Physics-guided deep learning reconstruction applied to off-axis digital holography microscopy

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Abstract

Holography was invented by Gabor in 1948 and consists of recording the interference pattern, called a hologram, generated by light coming from an object and a reference beam. When the hologram is recorded by a camera sensor, we call this Digital Holography (DH). The reconstruction of the digital captured hologram is made computationally using light wave theory and signal processing (diffraction calculations to obtain the complex amplitude of object light, aberration correction of the optical system and phase unwrapping, among others). Nevertheless, these calculations have some common problems that need to be addressed: the calculations for hologram reconstruction and diffraction have high computational complexity and optics aberration that need to be corrected. Also, when the configuration used to record the holograms is in-line, several holograms must be captured at different axial distances in order to perform the reconstruction, making is not recommended for dynamic phenomena, such as cellular migration. On the contrary, if one uses off-axis holography the reconstruction can be made with only one hologram, at the cost of lower resolution.

In recent years, Deep Learning (DL) has seen impressive results in the field of image processing, microscopy, and many others. DL has been applied to DH in several different ways, such as: depth estimation [1] and direct reconstruction using DL (both supervised [2, 3] and unsupervised [4] learning). Also, lately some datasets have been made available that help to train DL-algorithms [5].

Lately the field of physics-guided neural networks is gaining momentum and has been applied in a multitude of areas, including DH [6, 7]. This approach has the advantage of increasing the interpretability of the results obtained and taking advantage of the physical modeling that we know must be fulfilled in the system. This is why my intention is to develop a DH reconstruction method using neural networks guided by physics.

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Single Pixel Imaging with a Shifted coded aperture

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Single-pixel imaging (SPI) uses a coded aperture (CA) pattern that varies over time to capture spatially modulated versions of a scene [1]. In order to use a fixed CA, the system in Fig.1(a) applies a circular shift to the CA (S-CA) for each measurement, which can be modeled by arranging the rows of a matrix as shifted versions of the S-CA [2]. However, maintaining a constant number of binary elements in the S-CA leads to higher correlations between matrix rows, deteriorating system conditioning and reducing reconstruction quality [3, 4]. To address this, our work presents a designing methodology to reduce the maximal correlation between shifts, thereby maintaining optimal matrix conditioning. The proposed method modifies the CA pattern from a random to a designed distribution, as illustrated in Fig. 1(b). This is achieved by solving an $\ell_2 - \ell_0$ minimization problem, where the ℓ_2 constraint minimizes correlation, and the ℓ_0 constraint preserves a constant number of binary ones in the S-CA vector. Simulations show that the optimized S-CA pattern improves reconstruction quality by up to 3 dB in peak signal-to-noise ratio (PSNR) compared to random patterns within a compressive sensing framework Fig. 1(c). Experimental results visually in Fig. 1(d), validates the improvement of designed approach over random patterns, making it ideal for SPI systems that achieve high frame rates with S-CA patterns and fewer measurements [2].

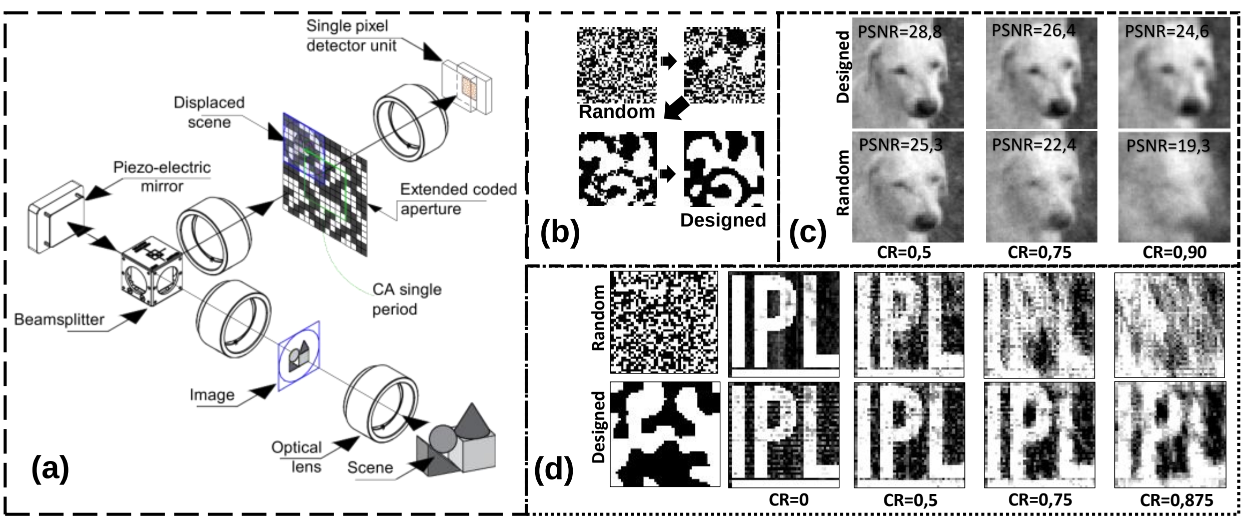

Fig. 1: Single pixel with a S-CA pattern. (a) Proposed architecture, (b) Ilustrative pattern improvement, (c) reconstructed images for random and designed patterns varying the compression ratio (CR) and (d) experimental results for random and designed patterns varying CR.

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PSF regularizations for privacy preserving multimodal action recognition

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In this paper, we propose to optimize the height map of a diffractive optical element (DOE) for privacy preservation in action recognition [1,2]. Our approach introduces two regularization terms over the point spread function (PSF), h_Φ: $\mathscr{R}_{\text{cond}}(\Phi) = |\lambda_{\min}|$, and $\mathscr{R}_{\text{MTF}}(\Phi) = \|\mathscr{F}^{2D}\{h_\Phi\}\|_2^2$, where $\lambda_{\min}$ is the minimum eigenvalue of the system's convolution matrix, and the second term represents the norm of the modulation transfer function (MTF). By minimizing $\mathscr{R}_{\text{cond}}(\Phi)$, we minimize $\lambda_{\min}$, thereby increasing the convolution matrix condition number, and in turn, enhancing privacy in the measurement by making the system more ill-conditioned. Minimizing $\mathscr{R}_{\text{MTF}}(\Phi)$ reduces the overall energy of the MTF, thus obfuscating sensitive details. The end-to-end (E2E) strategy, depicted in Fig. 1(a), comprises a learnable DOE to obfuscate the scene, and a multimodal action recognition scheme with a neural network ($\mathscr{V}_\Theta$) that extracts the visual features, and a language model ($\mathscr{T}_\Xi$) that extracts action class features.

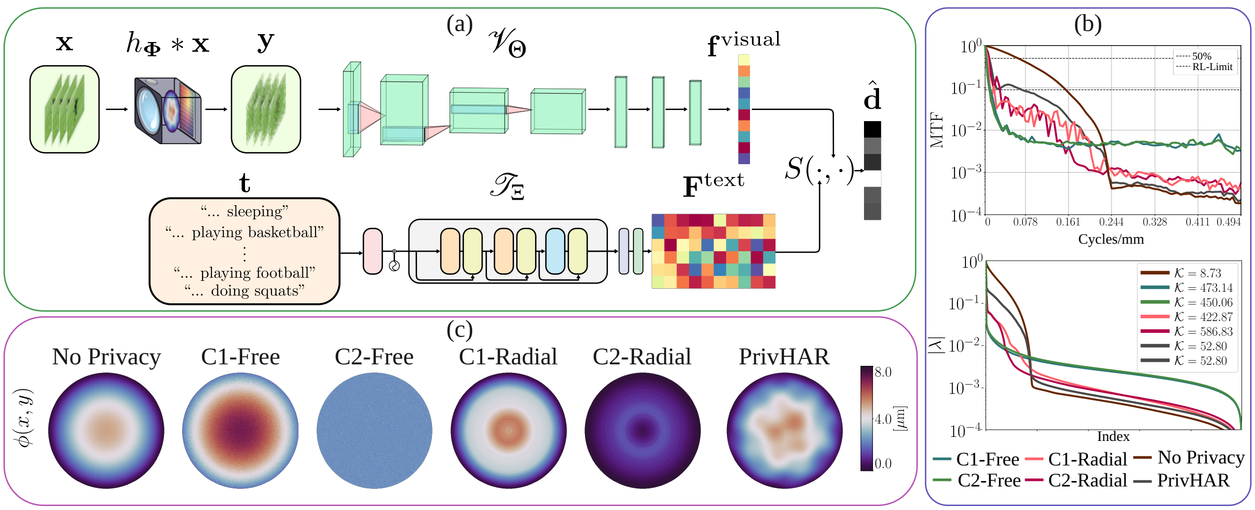

Fig. 1. (a) E2E scheme for privacy preserving multimodal action recognition, (b) MTF and eigenvalue distribution results, (c) Height map of the learned DOEs for different configurations.

To jointly train the action recognition model and to learn the optimal PSF for privacy preservation, we solve the following optimization problem:

$$\arg\min_{\Theta,\Phi} \mathop{\mathbb{E}}_{\mathbf{x},\mathbf{d}\sim\mathscr{D}} \alpha_{\text{t}}[\mathscr{L}_{task}(\mathbf{d}, S(\mathbf{F}^{\text{text}}, \mathscr{V}_\Theta(h_\Phi * \mathbf{x})))] + \alpha_{\text{p}}[\mathscr{R}_{\text{cond}}(\Phi) + \mathscr{R}_{\text{MTF}}(\Phi)] + \mathscr{R}_{\text{SC}}(h_\Phi), \tag{1}$$

where $\mathscr{L}_{task}$ is the loss function for multimodal action recognition relating the visual ($\mathbf{f}^{\text{visual}}$) and text ($\mathbf{F}^{\text{text}}$) features with the similarity function S; $\mathscr{R}_{\text{SC}}(h_\Phi)$ is a regularization term promoting compact support in the PSF, to ensure practical implementation; and α_{t} and α_{p} are weights that balance the trade-off between task performance and privacy preservation. The parameters Θ and Φ represent the neural network and optical system parameters, respectively, which are optimized using stochastic gradient descent algorithms over the dataset $\mathscr{D} = \{\mathbf{x}_k, \mathbf{d}_k\}_{k=1}^N$, where $\mathbf{x}$ denotes the input scenes and $\mathbf{d}$ the corresponding action labels.

Extensive simulations with multiple DOE configurations, summarized in Fig. 1(b)-(c), show that the proposed regularization terms increase visual privacy, measured by higher condition numbers and more attenuated MTFs. At the same time, it obtains similar performance in the action recognition tasks compared with state-of-the-art optical system design for visual privacy preserving action recognition (PrivHAR) [3].

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Phase Retrieval by Binary Amplitude Modulation using Talbot effect

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Several complex phase retrieval (PR) methods have been developed using multiple intensity measurements and an iterative algorithm based on propagation equations [1]. These methods can be used for amplitude, phase, or combined amplitude-phase objects in transmission and reflection setups. Innovative approaches have also been introduced to improve acquisition speed, reduce system dimensions, and eliminate potential mechanical errors [3]. While phase or amplitude modulation is possible in these techniques [2], digital micro-mirror devices (DMDs) allow binary masks to be projected at frequencies up to 22 kHz. This has resulted in experimentally implemented methods that take advantage of the benefits of a DMD by using it for dynamic applications [4] or to produce a controlled speckle field [5]. The DMD allows amplitude modulation, resulting in an increase in the intensity variations necessary for the correct convergence of the algorithm. However, there is a wide degree of freedom in the design of the masks, which allows the study of their effect on PR methodologies and optimization [6–8]. In many PR techniques using a DMD, it is necessary to use a 4f system to project the masks onto the object to be measured and to separate the diffraction orders inherent to the DMD. The Talbot effect, also known as the self-imaging phenomenon, occurs when a coherent light beam illuminates a periodic grating. When the grating is illuminated with coherent parallel light, multiple replicas appear periodically at various distances, known as the Talbot distances. This effect has been used for wavefront sensing and digital holography—including phase-shifting—among other applications [9, 10]. In this work, we propose a PR method using a DMD for binary amplitude modulation using the Talbot effect. Our proposal— employing coherent illumination on the DMD—uses the binary mask replicas produced by the Talbot effect to modulate the complex object to be measured without needing a 4f system, making it a lensless setup. Taking advantage of the freedom in mask design to produce intensity variations for PR, we explore the effect of pseudo-randomness and periodicity in our new binary masks set for optimal algorithm convergence.

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Transport of Intensity Equation in Microscopy: improvements in algorithms and biological applications

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Quantitative Phase Imaging (QPI) is a crucial technique, especially when combined with microscopy, which plays a vital role in biological research [1]. The phase information captured from a sample allows for the extraction of morphologically significant metrics, enabling not only a qualitative study, but also a quantitative analysis of cell viability and cellular dynamics as a whole. The phase information of light is critical in many applications, where it helps to quantify both the composition and structural characteristics of a sample [2, 3]. Specifically, optical thickness, dry mass density, and refractive index [4] can be measured from the optical phase, offering deeper insights into cell behavior.

Among the QPI methods, the Transport of Intensity Equation (TIE) [5–7] leads to a simpler configuration compared to interferometric approaches and is relatively stable against mechanical disruptions [8]. The TIE has gained significance because it allows for the retrieval of the phase from differently focused intensity measurements along the optical axis.

In this work, we combine the use of a custom-built microscope with GPU-accelerated algorithms to obtain information about the cellular structure [9] of different cell lines based on phase information. From the phase variance data, correlated with the disorder strength [10], it is possible to perform label-free segmentation, which not only allows for the segmentation of cells in bright-field images but also enables the segmentation of cell nuclei.

Based on the segmentation of the cell using phase information, it is possible to study the evolution of cellular dynamics in different regions. Additionally, after segmentation, both the cellular volume and area can be evaluated. These changes in morphology could suggest a marker for potential cellular damage [11].

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Coded aperture design for temporal compressive imaging in a color-polarized video

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Polarization is a property of light seen across all wavelengths and is widely used in astronomy. Cameras that are capable of acquiring multiple dimensions, process a greater amount of information than traditional cameras, compromising the spatial, spectral or polarization resolution. In the state of the art, it is possible to find color video cameras architectures with simple and inexpensive modifications, from which multiple color frames are recovered using a compressive sensing (CS) approach [1]. In this sense, different coded aperture (CA) such as random and complementary random, and design codes considering the spatial distribution of the acquire data have been proposed [2]. In this work an off-the-sheld camera is modified to compressively acquire and reconstruct high resolution video, dealing with the resolution trade-off. The acquired spectral bands, using a Bayer pattern, and polarization data is observed in Fig. 1(a), rendering a singular frame of the video on the detector; this is then applied to each subsequent frame of the video (Fig.1(b)). A time-varying CA designed according to its spatial, color and polarization distribution is incorporated into the optical path, modulating the incoming light of the temporal event during the integration time of the camera, producing a single frame of the recorded compressive video Fig.1(c). The dynamic spectral polarized scene is recovered by solving a minimization problem (ADMM) using the collection of compressive frames acquired by the system (Fig.1(d)). A set of vectors was made for this purpose, considering the acquisition of at least one pixel of each color and polarization of the pattern, and the best distribution of these was calculated in relation to their neighborhood until the CA is completed. Additionally, each CA is complementary to each other, this reduces the blurring of the reconstruction (Fig.1(e)). Results were obtained through compressing 8 frames during the integration time of the camera. Designed CAs allows for image quality improvement and recovery of color and polarization temporal video, which can be observed in Fig.1(f),(g) and (h), corresponding to the results of random, complementary random and designed CA respectively of the 90^o polarization using PSNR (peak signal to noise ratio). Finally, in Fig.1(i) a comparison of the videos is shown where differences in the reconstruction quality can be seen.

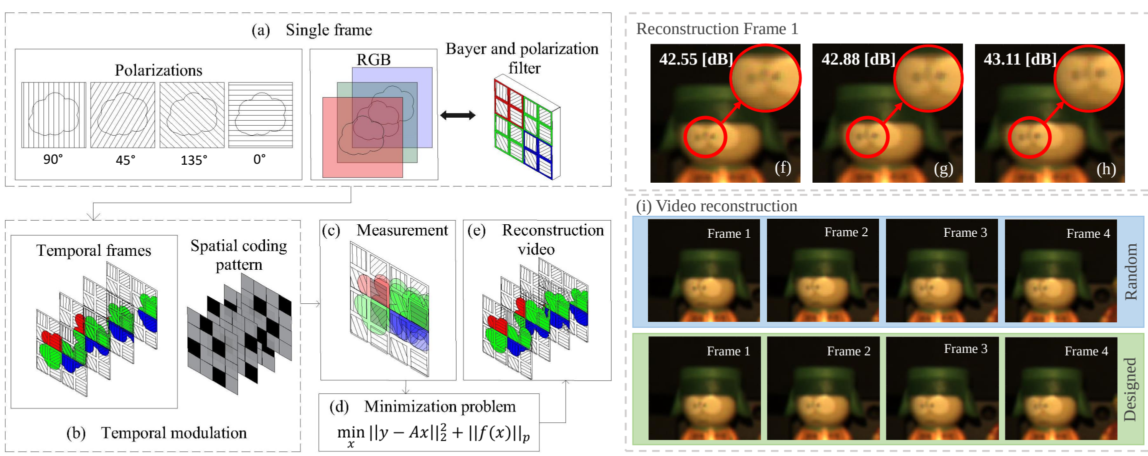

Fig. 1. Time polarized video compression's simulated system model.

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Beyong the Sparrow's limit by MeanShift

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Extended Abstract

The resolution of an optical system refers to its ability to differentiate between closely spaced objects, rendering them as distinct entities rather than a single blurred object. Several criteria have been proposed over time to characterize the limit of resolution depending on the optical system used. Among these, the Rayleigh [1] and Sparrow [2] resolution limits are the most widely employed. While the Rayleigh criterion is commonly used in optical microscopy, the Sparrow resolution limit is often applied in astronomy. The Sparrow limit serves as an upper boundary for distinguishing two-point sources with equal intensity, and any method capable of surpassing this limit can potentially exceed other resolution thresholds as well.

The mathematical theory underlying the Sparrow resolution limit can be described through the intensity profile of a single point source, which produces an Airy pattern. This pattern is modeled using a Bessel function of the first kind of order one. To simplify calculations, the Gaussian distribution is frequently used as an approximation for this Airy pattern. According to the Sparrow criterion, the intensity between the two-point sources becomes flat at the midpoint, meaning there is no valley or dip between the sources. In other words, it can not decide if there are one or two objects.

MeanShift (*MS*) [3, 4] is a statistical tool that offers a powerful method for analyzing data with many applications across different scientific fields. Its strength lies in its ability to identify local density modes by always pointing in the direction of the gradient. In the context of Super-resolution microscopy, *MS* is highly relevant because it is use on methods to improve resolution imaging. This approach allows the identification of separate sources even when they are too close, surpassing the limits defined by diffraction patterns.

We demonstrate that the condition for the Sparrow resolution limit, where the first and second derivatives are zero, is satisfied when the separation between the sources is equal to 2σ, where σ is the standard deviation of the Gaussian distributions. And the main result of this work, we show that the MeanShift method can exceed the Sparrow resolution limit when point sources are described by Gaussian distributions, both in discrete and continuous data scenarios. This breakthrough has direct consequences for extending the range and applicability of MSSR (MeanShift SuperResolution) algorithm [5].

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Analysis of events generation rates on recordings in space situational awareness

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Abstract

There is an increasing interest in using satellites for multiple purposes, hence the increment in numbers of objects orbiting Earth through the years. For this reason, systems has been designed and tailored to detect and continuously track these objects to avoid collisions between them. However, to our knowledge, none of these systems had balance correctly the trade-offs to have a great FOV, low storage and processing load and real-time operation, this is mainly because standard CMOS cameras operate with big pixels arrays that captures data in frames periodically, not minding much that a lot of the data captured in this way is actually redundant in the night sky, like stars and most of the background. This is worse while considering that the majority of this systems need to be placed in areas away from light pollution of big cities and with optimal either conditions, making very necessary a low bandwidth to transfer or storage the data.

To optimize the last requirements, event-based cameras has been chosen as a experimental replacement due to its asynchronous pixels and differential log illumination capture, allowing to storage a minimum of data while focusing in the information in the scenes, i.e. objects passing through the sensor in linear trajectories. Also, these sensors are able to measured changes with a bigger time resolution while not trading off any of its initial spatial resolution as standard frame based cameras does. Previous works have shown good results capturing satellites in low-earth orbits (LEO) and in the Geostationary orbit (GEO), and some stars and planets [1]. However, event-based sensors are heavily affected by noise, but it source may change depending on the lighting conditions of the scene, photon and electron shot noise in low illumination settings and leakage noise in bright conditions [3] . Traditional processing to diminish the effect of noise in event-based recordings take the form of background activity filters (BAF) [2] that help lowering the noise event rate by including only recurring activation of events in a spatio-temporal window, but this solution is prone to exclude informative events and don't accounts for the most faint objects.

In this work, an analysis of the optimal work conditions of event-based cameras for space situational awareness is propose. Considering distinct illumination conditions that may vary by lunar phase, daylight recordings or captures near cities is possible to improve the user controllable biasing of the event-based camera and verify the limits of capture of these sensors. Furthermore, traditional event-based processing is tested to find the limiting in which satellites can be record with such algorithms. Finally, the conditions favor the capture of objects in the night sky and what processing problems arise making space situational awareness with event-based sensors is discuss.

Acknowledgements

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Contributed Poster Abstracts

Iteration Reduction for Mueller Matrix Calculation Using Orthogonal Camera System

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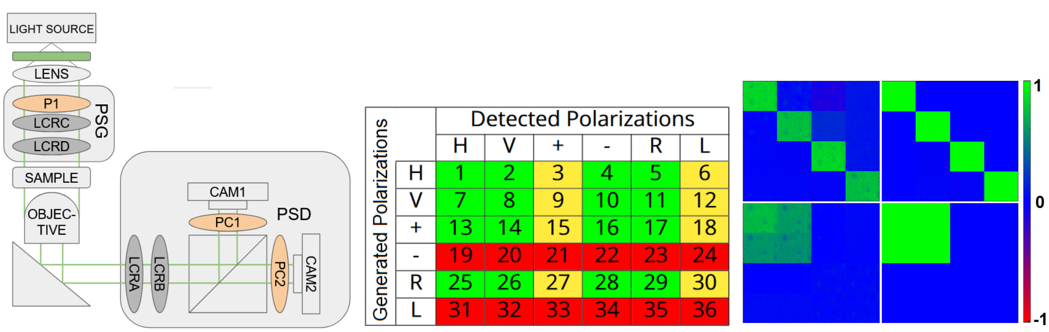
Mueller Matrix (MM) polarimetry has been of great use in biological and medical topics [1] but this technique shows problems when applied to dynamic objects. We are addressing this problem by developing an advanced imaging polarimeter that employs a system of orthogonal cameras (Fig. 1a). The use of Liquid Crystal Retarders (LCR) in both the Polarized States Generator (PSG), [2] and the Polarized States Detector (PSD), enables a fully automatic polarimeter capable of generating and detecting all the states of polarization (SoP) required for MM calculation, without mechanical movement, enhancing robustness and resistance to misalignments.

The orthogonal camera system allows for the simultaneous detection of two SoPs, whose Stokes vectors are orthogonal. To minimize potential errors from the two-camera setup, the system was equalized and the MM calculation was based on a modified 16-image method [3], where Camera 1 detects 12 SoPs (horizontal, diagonal, and right-handed circular), and Camera 2 detects 4 orthogonal SoPs (vertical). This approach reduces the number of iterations from 16 to 12 while maximizing the utilization of both cameras whenever possible. Figure 1b shows three types of polarization images: obtained and used (green), obtained but non-used (yellow), and non-generated (red).

We presented the process, calculation diagram, calibration, and results for an automatic imaging polarimeter capable of reducing the image acquisition iterations needed for MM calculation. Figure 1c shows results for free space and a linear polarizer, with the upper and lower rows corresponding to each case, while the left and right columns depict experimental and theoretical MM results, with the color bar representing the possible MM values. This configuration has the potential to achieve the same results as a single-camera polarimeter while requiring fewer acquisition iterations.



	H	V	+	-	R	L
H	1	2	3	4	5	6
V	7	8	9	10	11	12
+	13	14	15	16	17	18
-	19	20	21	22	23	24
R	25	26	27	28	29	30
L	31	32	33	34	35	36

(a) (b) (c)

Fig. 1: (a) Proposed polarimetric system (b) SoPs used for MM calculations (c) Calibration results.

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Development of an autofocus algorithm for event-based cameras for space awareness and astronomical applications

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Abstract

Automatic focusing is essential for many applications, and has been widely developed in consumer frame-based cameras. However, event-cameras operate very differently from traditional cameras, which capture a fixed number of frames per second. Instead, event cameras generate information asynchronously by detecting small changes in brightness [1], becoming extremely challenging to develop methods that can enable automatic focusing in these systems.

Given the increasing amount of space debris in orbit, it is crucial to have a surveillance system where cameras can quickly focus on the sky without human intervention, which tends to be slow, inaccurate, and prone to errors. To the best of our knowledge, this is the first reported work on a neuromorphic methodology with automatic focusing applied space and astronomy. While algorithms exist for finding the focal point in a scene [2] or in optical microscopy [3], no reports have been found in this area. In this work, we propose a new autofocus search algorithm for space observation, capable of focusing in seconds with the goal of detecting any satellite crossing the field of view.

To achieve this, we equipped the EBCs with an autofocuser, installed on a telescope with an mount. Our strategy involved recording a single star, keeping it within the field of view to observe the behavior as we moved the focuser axially. We observed that the generated pattern resembled a bimodal data distribution, where the optimal focus is located in the valley of the function. In other words, the more out of focus the star becomes, the more events are generated, while fewer events are produced at the optimal focal point. When the star and field are focused, satellites are immediately detected. The challenge with this method is the potential for detect false positives. As the star becomes increasingly unfocused, the dispersion of events is such that they are not sufficiently clustered, confusing the algorithm, which expects fewer events at the focal point. To address this, we implemented a second method that involves coloring positive and negative events, revealing a distinct pattern. As the focuser approaches optimal focus, the brightness decreases, generating more negative events; conversely, once it passes the focal point, the brightness begins to increase, producing positive events. These preliminary results demonstrate a robust and precise algorithm for focusing on the night sky and detecting any objects, such as space debris or the large number of satellites passing overhead. In the future, this algorithm is expected to be optimized and implemented on a neuromorphic chip, enabling greater efficiency in both processing time and data analysis.

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Spectral Assessment for Cocoa Quality

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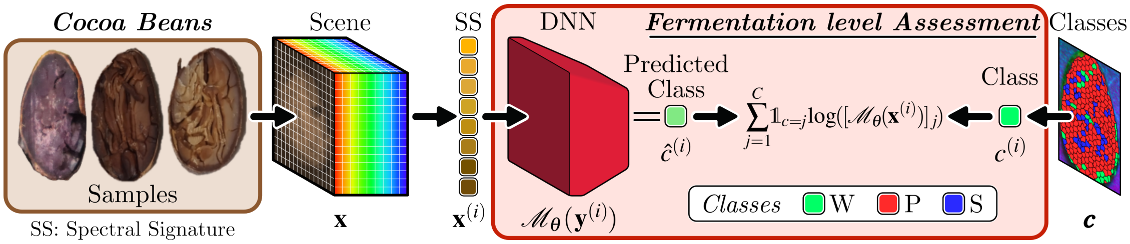

Abstract

This work presents a method combining near-infrared (NIR) spectroscopy with machine learning to assess the quality of Colombian cocoa beans, offering a fast and non-invasive alternative to traditional, subjective, and destructive methods. Cocoa quality is primarily determined by the fermentation level. Therefore, this work adapt different models to enhance the spectral data analysis, promoting sustainable and reliable practices in the Colombian cocoa industry.

Near-infrared for cocoa bean quality estimation

The NTC-1252-2021 standard in Colombia assesses cocoa quality by evaluating the fermentation of 100 beans, which are cut and visually classified by an expert as well-fermented (W), partially fermented (P), or slightly-fermented (S). Traditional methods destroys the beans to make a chemical based assessment. In contrast, NIR spectroscopy captures spectral data that can be used to estimate fermentation levels through machine and deep learning methods in a non-destructive way to estimate fermentation levels through machine and deep learning methods [1].

Learning-Based

Given a dataset $\{\mathbf{x}^{(i)}, c^{(i)}\}_{i=1}^{S}$ with S spectral samples $\mathbf{x}^{(i)}$ and corresponding labels $c^{(i)} \in \{1,2,3\}$ representing the fermentation levels (W, P, S), we aim to optimize a deep neural network (DNN) $\mathscr{M}_\theta(\cdot) \in \mathbb{R}$ with parameters θ. The overview of the proposed method is shown in the figure, whose optimization is

$$\theta^* \in \underset{\theta}{\arg\min} - \sum_{i=1}^{S} \sum_{j=1}^{C} \mathbb{1}_{c=j} \log([\mathscr{M}_\theta(\mathbf{x}^{(i)})]_j), \tag{1}$$

where $\mathbb{1}_v$ is an identity function that is equal to 1 if v is true and 0 otherwise, and $[\mathscr{M}_\theta(\cdot)]_j$ is the j^{th} element of the network output, corresponding to the predicted probability for class j.

Results

For evaluation, we used the dataset provided in [1] and five different methods, where Spectralformer [3] outperformed all methods, achieving an OA metrics of 97.53%, an AA of 98.39%, and a Kappa score of 93.28%. It performed 5.9% better in OA than SVM, which highlights Spectralformer's superior ability to capture long-range dependencies in spectral data.

Method	OA	AA	Kappa
SVM	92.09 ± 0.51	94.93 ± 0.55	92.58 ± 0.78
MLP	92.00 ± 1.02	92.56 ± 0.77	87.99 ± 1.84
CNN	$\underline{96.47 \pm 0.15}$	$\underline{97.48 \pm 0.18}$	$\underline{92.68 \pm 0.24}$
SpectralNET [2]	94.05 ± 2.13	94.95 ± 1.60	90.95 ± 3.24
Spectralformer [3]	$\mathbf{97.53 \pm 0.77}$	$\mathbf{98.39 \pm 0.81}$	$\mathbf{93.28 \pm 1.18}$

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Mueller matrix polarimetry and hyperspectral autofluorescence imaging for histopathological diagnosis without the use of markers

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Abstract

Pathological anatomy is crucial for the diagnosis, prognosis, and treatment of diseases. However, it mainly relies on the visual inspection of tissues stained with histological dyes and the expertise of a specialist. In this regard, there is a growing need to integrate new multimodal microscopy techniques to obtain a quantitative assessment of tissue alterations. Polarized light [1] microscopy, particularly based on the calculation of Mueller matrices [2], is an emerging tool for determining microstructural features of tissues without the need for markers, and it has gained attention for its significant advantages in distinguishing tissue changes non-invasively. Additionally, fluorescence microscopy and spectroscopy allow for the exploration of endogenous molecular markers in tissue, such as autofluorescence [3], providing further insights into disease biology. This work will focus on the development of a microscopy technique that combines Mueller matrix polarimetry and hyperspectral autofluorescence microscopy using novel methods in each modality involved: illumination engineering combined with multi-view elements to obtain Mueller matrices, and filters with sine/cosine modulation in transmittance to extract spectral information without needing to capture the entire spectrum [4]. Moreover, an XY motorized stage enables the analysis of these measurements across the entire tissue sample, which can be seamlessly combined using a stitching algorithm [5]. The integration of these advanced imaging techniques offers new perspectives in pathological anatomy for a quantitative evaluation based on both structural and molecular characterization of diseases, further enhancing the understanding of underlying pathological processes.

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Object Tracking System Based on Phase Modulation

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Optical tracking follows the trajectory of an object in a dynamic scene by processing information such as shape, size or intensities [1]. This work introduces a pre-designed phase-only modulation (phase mask) of a diffractive optical element (DOE), enabling the accurate tracking of the desired object (target) on the detector. The architecture shown in Figure 1(a) expands a laser beam to generate a collimated version of the scene, passing through the half-wave plate (HWP) and a lineal polarizer (POL. 1), in order to be modulated at the pupil plane of a Liquid Crystal of Silicon (LCoS) [2]. A second polarizer (POL. 2) modulates the signal to remove any undesired response produced by the LCoS. The DOE is created by combining the target's phase with a selected portion of the scene, as shown in Figure 1(b), this phase is designed using the Gerchberg-Saxton algorithm [3] and is combined with a Fresnel lens, with the result shown in Figure 1(c). Simulation results in Figure 1(d) represent the expected outcome based on the correlation between the designed filter and the system's scene response [4]. Preliminary experimental results are shown in Figure 1(e), where the light peaks show a close match to simulations, suggesting successful detection. Future work could focus on refining the phase design to enhance the quality and accuracy of the results.

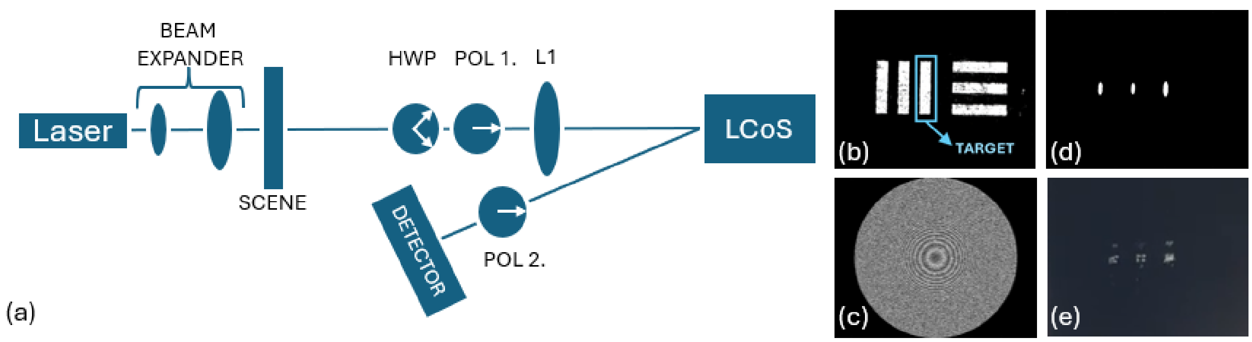

Fig. 1. a) Architecture b) Scene with target to detect c) DOE d) Simulated result e) Result.

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Founding

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Real-time control loop implementation of adaptive optics systems based on deep learning

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Adaptive Optics (AO) is an indispensable technique for improving image quality in large ground-based telescopes, particularly in the upcoming generation of Extremely Large Telescopes (ELTs). AO systems work by compensating for the distortions introduced by the atmosphere on the incoming wavefront of light. These distortions, often described by Zernike polynomials, cause significant image degradation if left uncorrected. Thus, the precise measurement and correction of the incoming wavefronts are critical to achieving high-resolution astronomical observations or also to establish high-speed, free-space optical communication links. Traditionally, AO systems rely on sensors such as the Shack-Hartmann or Pyramid sensors to detect these aberrations and characterize the incoming wavefront, which is then corrected using a deformable mirror (DM) to produce a nearly flat wavefront. These sensors typically operate at frequencies around 1 kHz, enabling real-time corrections. In this work, we propose a novel approach to AO control using wavefront sensors powered by Deep Learning estimation techniques, which have shown promise in providing with more accurate and efficient wavefront correction compared to conventional methods [1]. Our deep learning-based sensor is integrated into a real-time AO loop, where the entire wavefront estimation process is carried out on a Graphics Processing Unit (GPU). By converting the neural network (NN) model into a format optimized for GPU execution, we leverage the processing capabilities of the GPU to enhance the speed and accuracy of wavefront correction [2] [3] [4]. Additionally, we implement a shared memory architecture (inspired by the Durham Adaptive Optics realtime engine, DAO) that facilitates seamless communication between the various devices in the AO loop, including the camera sensor, deformable mirror, and neural network. This shared memory allows the system to access and update information or send commands in real-time, ensuring efficient operation at nearly Khz speeds [6] [5] [7].

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Embedded Systems for Object Detection Using Neuromorphic Event Cameras and FPGA Video Libraries in Astronomical Observatories

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Abstract

The field of computational imaging is experiencing significant advancements through the integration of innovative sensing technologies and high-performance embedded systems. This research introduces a novel approach to satellite detection in astronomical observatories by leveraging neuromorphic event-based cameras, which operate on an asynchronous data acquisition model. Unlike traditional frame-based imaging systems, neuromorphic cameras capture changes in the scene at the event level, providing a continuous and highly dynamic stream of data that is particularly well-suited for detecting fast-moving objects such as satellites.

To process this event-driven data in real-time, we employ the Intel Altera DE1-SoC platform, which combines Field Programmable Gate Arrays (FPGAs) and Hard Processor Systems (HPS). The Intel Altera FPGA [4] is utilized for its robust parallel processing capabilities, enabling efficient handling of the high-throughput data generated by the neuromorphic sensors. The integration of MATLAB's FPGA video processing libraries [1] with the Altera DE1-SoC hardware facilitates the rapid development and implementation of sophisticated video processing algorithms directly on the FPGA. This integration not only accelerates the design process but also enhances the overall system performance by optimizing data flow and minimizing latency.

The HPS component, embedded within the DE1-SoC, adds further processing flexibility, allowing for the implementation of adaptive algorithms that can dynamically respond to varying observational conditions in real-time. This dual approach—merging the deterministic power of Intel Altera FPGAs with the adaptability of HPS—results in a system that is both robust and responsive, capable of maintaining high detection accuracy even in challenging environments characterized by low light and high noise levels.

Extensive simulations and field tests have been conducted to validate the proposed system, demonstrating its effectiveness in operational observatories. The results indicate a significant improvement in detection speed and accuracy compared to conventional imaging systems, underscoring the potential of this technology to enhance the capabilities of astronomical observations. This research not only contributes to the field of satellite detection but also opens up new avenues for the application of neuromorphic imaging in other domains, such as space surveillance and remote sensing.

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End-to-End Band Selection for HSI Classification

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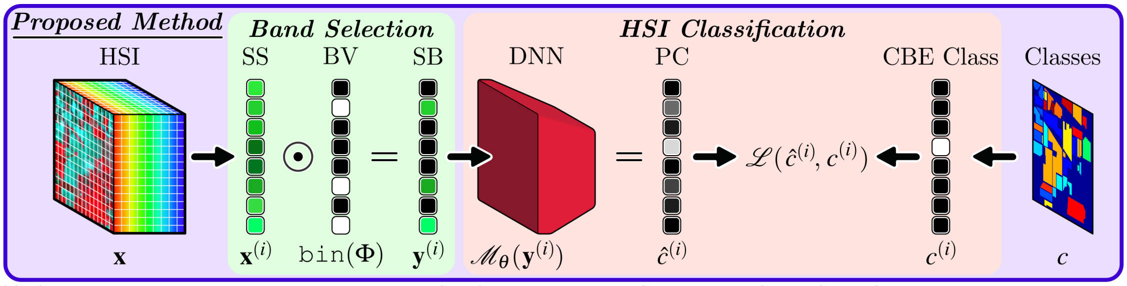

SS: Spectral signature; BV: Binarization Vector; SB: Selected Bands; PC: Predicted Class; CBE: Categorical Binary Encoding

Abstract

Hyperspectral image (HSI) classification is highly relevant for real-world applications, such as remote sensing and agriculture, but redundant spectral bands reduce performance. Therefore, band selection (BS) emerges to select the most representative spectral bands. However, most current BS techniques focus on feature extraction, where entire spectral bands are necessary to choose the desired ones, limiting the development of low-cost optical devices with the selected bands.

Band Selection

Considering a spectral signature $\mathbf{x} \in \mathbf{R}^l$ with l bands, BS can be performed as $\mathbf{y} = \Phi \odot \mathbf{x}$, where $\Phi \in \{0,1\}^l$ is a binarization vector that selects specific bands from $\mathbf{x}$ and $\odot$ is the hadamard product operator [1]. If the desired number of bands is B, the binarization vector must be constrained as $||\Phi||_1 = B$. Finally, the resulting vector $\mathbf{y} \in \mathbb{R}^l$ retains only the values from the selected bands while the rest are set to zero.

Proposed Method

Given a dataset $\{\mathbf{x}^{(i)}, c^{(i)}\}_{i=1}^{S}$ with S samples of spectral signatures from an HSI with its respective labels, where each $c^{(i)} \in \{1,\ldots,C\}$ and C is the total number of labels and a deep neural network (DNN) $\mathscr{M}_\theta(\cdot)$ with parameters θ, we can perform a joint optimization of the binarization vector and the DNN in an end-to-end (E2E) fashion by solving

$$\{\Phi^*, \theta^*\} \in \underset{\Phi,\theta}{\arg\min} \sum_{i=1}^{S} \mathscr{L}(\mathscr{M}_\theta(\mathtt{bin}(\Phi) \odot \mathbf{x}^{(i)}), c^{(i)}) + \mathscr{R}(\mathtt{bin}(\Phi)), \tag{1}$$

where $\mathscr{L}(\cdot,\cdot)$ is the cross-entropy loss function. Since Φ is optimizable, it is constraint through $\mathtt{bin}(\Phi) = \{1 \text{ if } \Phi_l \geq 0, 0 \text{ if } \Phi_l < 0\}$ and regularization term $\mathscr{R}(\mathtt{bin}(\Phi)) = \rho|B - ||\mathtt{bin}(\Phi)||_1|^p$ controls the selection of the desired number of bands, where ρ is a regularization parameter and p is a weighting factor.

Results

The proposed method outperforms state-of-the-art [1] on the Indian Pines dataset for $B = 10$ by over 2% in OA, AA, and Kappa metrics for 10 selected bands using the E2E approach. With retraining (RT) of the DNN $\mathscr{M}_\theta(\cdot)$ on the selected bands, it still surpasses [1] by 8%, though slightly below E2E performance as expected. Results are in the table to the right.

Method	Ablation		OA		AA		Kappa	
	bin	p	E2E	RT	E2E	RT	E2E	RT
[1]	✗	2	54.10	65.39	66.36	53.20	61.48	60.33
Proposed	✓	2	75.12	72.56	64.40	65.19	71.57	68.70
	✓	1	74.74	73.96	65.09	66.12	71.14	70.28
	✓	0.5	**76.07**	74.18	**67.45**	66.23	**72.62**	70.58

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Modulo Imaging: Algorithms and Applications

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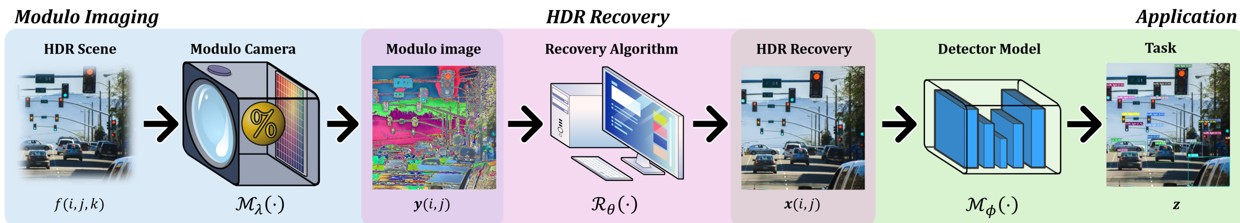

Abstract

High Dynamic Range (HDR) imaging is essential for capturing the complete spectrum of light tones in scenes, which is important for computer vision applications such as HDR video and autonomous driving. Standard imaging cameras struggle with light quantization, limiting HDR abilities. Modulo imaging, based on Unlimited Sampling (US) theory, addresses this by resetting signals upon saturation and estimating resets through neighboring intensities. However, US algorithms for two-dimensional HDR images remain limited.

Modulo Imaging

Assuming a vector form of the signal $x \in \mathbb{R}^n$, the modulo imaging model can be defined as $y = \text{mod}(x, \lambda) = \mathscr{M}_\lambda(x)$ where $\text{mod}(t, \lambda)$ is the modulo operator, y is modulo measurements, and $\lambda = 255$ is the saturation value [1]. We can **decompose the HDR image** as $x = y + k\lambda$, where $k \in \mathbb{N}^n$ is an integer value for the times the modulo operator is applied. For the signal $||\Delta^n x||_\infty < \lambda/2$ we have $\mathscr{M}_\lambda(\Delta^N y) = \Delta^N x$.

Recovery Method

This work presents a reformulation of the USF framework as an auto-regressive ℓ_2 phase unwrapping problem [2]. Specifically, based on the fact that $\Delta^N k = \Delta\Delta^{N-1}k = \Delta s^{(1)}$, we can reformulate the unwrapping problem as a subset of iterative optimization problems, where

$$s^{(n+1)} = \underset{\Delta^{N-1-n}k \in \mathbb{Z}}{\arg\min} \quad ||\Delta(\Delta^{N-1-n}k) - s^{(n)}||_2^2 + R(y + \lambda k) \quad \text{for } n = 0, \cdots, N-1, \tag{1}$$

with $s^{(0)} = \mathscr{M}_\lambda(\Delta^N y) - \Delta^N y$ and $s^{(N)} \approx k$. Interestingly, each sub-problem can also be solved for each component using the DCT transform as the conventional phase unwrapping recovery [3].

To apply US recovery to 2D modulo measurements, we adapt the 1D signal recovery method by vectorizing the image and solving the unwrapping problem. We propose neighborhood vectorization $x = \mathbf{P}\texttt{vec}(\mathbf{X})$, and use $\mathbf{P}$ as a permutation matrix to align contiguous pixels in the 1D signal with those in 2D images. Our approach improves HDR reconstruction from modulo images, significantly enhancing object detection in autonomous driving scenes. This improvement is quantified as an increase in the Intersection over Union (IoU) to 71.06% without the need for retraining, compared to 59.60% achieved by conventional digital cameras in saturation scenarios.

Acknowledgments: *This work was supported by VIE-UIS, under project 3924.*

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Development of a Hologram Printer for Holographic Wavefront Sensors

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The image quality of objects observed through ground-based telescopes is significantly affected by atmospheric turbulence, leading to distorted and inaccurate visual information [1]. This distortion results from fluctuations in the Earth's atmosphere, causing unpredictable bending of light waves from celestial objects. The current primary solution to this issue is Adaptive Optics (AO), an advanced optical system designed to correct wavefront phase aberrations in real-time. However, the implementation of AO systems can be prohibitively expensive, primarily due to the significant cost of the wavefront sensor (WFS). Holography, which enables the recording and reconstruction of the full wavefront information of light, has been widely explored in various optical fields and presents an alternative approach for wavefront sensing. To address this challenge, we propose the design and implementation of a Holographic Wavefront Sensor (HWFS), focusing primarily on developing a cost-effective fringe printer (FP) for hologram recording [2–4]. While holography has been extensively studied for various optical applications, its potential for wavefront sensing remains an area of active research.This work centers on constructing a robust hologram printer capable of producing high-fidelity interference patterns for the creation of a HWFS. The holographic approach offers a high degree of control in generating a hologram of intangible entities, such as wavefronts, and promises to be less costly than traditional wavefront sensing methods, while maintaining flexibility. Preliminary results from the created holograms demonstrate the control and versatility of this strategy for hologram recording. The proposed method utilizes a Spatial Light Modulator (SLM) to replicate previously calculated interference patterns through Computer Generated Holography (CGH) techniques [5], highlighting its potential for future advancements in wavefront sensing technology.

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Hardware-in-the-Loop Framework for Diffractive Optics Design for Multispectral Classification

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Multispectral imaging (MSI) is essential for acquiring distinctive information for scene classification with applications in fields such as remote sensing, biomedical imaging, and environmental monitoring. However, traditional MSI systems are typically limited in acquisition time since they heavily rely on scanning. To address these challenges, diffractive optical elements (DOE) offer a compelling optical coding solution to design snapshot compressive imaging systems, allowing for lightweight, compact designs that manipulate light more efficiently over a broader depth-of-field. In this regard, the Hardware-in-the-Loop (HIL) methodology has been shown to be critical for optimizing the DOE, enabling continuous refinement based on feedback from the real system response without the need for simulations neither repetitive manufacturing cycles. This approach significantly reduces the development time while improving performance through iterative testing.

In this work, we propose a novel approach to multispectral imaging classification that combines optical hardware and advanced algorithms [1], including neural networks, to enhance both depth-of-field and spectral fidelity, and also improving the spectral classification accuracy. The crucial method of the system is based on a HIL approach, which is an in-situ design technique that integrates physical hardware components (DOE) into a controlled testing framework. This method allows for continuous testing and optimization by iteratively adjusting hardware parameters on the basis of feedback from simulated or real-world data. By enabling rapid iteration and refinement, the HIL approach eliminates the need for fully manufactured hardware prototypes at every stage, significantly accelerating the optimization process. In our system, the HIL approach is used to optimize the DOE pattern design, improving both the spectral classification and the overall performance of the system. Through iterative refinement of the DOE, the phase modulation is dynamically adjusted via a spatial light modulator (SLM) [2, 3], enhancing the quality of the captured RGB images. These images are then processed via the multistage spectral-wise transformer (MST++), a neural network that exploits spectral correlation and self-similarity, enabling the hallucination of up to 31 spectral bands from RGB data. Note, this reconstruction is an hallucination of the hyperspectral spectrum based on learned patterns. We are currently implementing the HIL framework while also modifying the neural network reconstruction scheme to optimize the system for direct multispectral classification, as insensitive as possible to depth-of-field variations in the scene.

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3. Samuel Pinilla, Seyyed Reza Miri Rostami, Karen Egiazarian, ”Hybrid diffractive optics design via hardware-in-the-loop methodology for achromatic extended-depth-of-field imaging”, Optics Express, 2022

Compact Adaptive Optics System using a Deformable Lens for a 0.5m Ritchey Chretien telescope.

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Abstract

Adaptive optics (AO) is classically used to correct the blurring in astronomical images caused by light passing through the atmosphere. Its classic implementation implies the usage of a Wavefront Sensor (WFS) to infer the phases present in the aberrated wavefront arriving in the telescope, a computational system and a Deformable Mirror (DM) to introduce the needed corrections to flatten the wavefront. The DM operates a series of actuators under a reflective membrane/flexible mirror by the control system using the information of the WFS, typically the Shack Hartman or the pyramidal WFS, among others. The configuration of an AO like the one previously described, has challenging characteristics for its implementation in small telescopes, like its weight and volume. Because of that, it's interesting to develop an AO configuration more compact than the traditional one. In recent years a new generation of this technology has begun to develop which allows us to miniaturize AO systems, like the deformable lenses that work altering the tension over a translucid membrane, similar to the DM, and new techniques of deep learning based WFS that infers the aberrations from the Point Spread Function. In this work, we present an Optical Design based on this new technology previously named, to obtain a reduced size and weight AO system, allowing its installation in a 0.5 m telescope. In particular, we propose the replacement of the DM using a Deformable Lent manufactured for Dynamic Optics, in the optical path inside the telescope, gaining space in the back focus allowing a more compact AO system, and enabling its usage in a small telescope, like the 0.5 m Ritchey Chretien built by Plane Wave.

References

Compressed optical Shack-Hartmann ultrafast photography

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Phase variations due to atmospheric fluctuation limit the resolution of terrestrial telescopes images/videos. The use of imaging technology like the Shack-Hartmann wavefront sensor (SH-WFS) allows the retrieval of real-time wavefront information [1]. Integrating compressed ultrafast photography (CUP) offers the advantage of acquiring both phase and temporal coordinates of a dynamic scene in a single snapshot, enabling the observation of transient events [2] like atmospheric turbulence. In this work we propose a compressed optical Shack-Hartmann ultrafast photography (COSHUP) system, which measures the time course of the SH-WFS spot diagram in one measurement and compensates for phase changes in real time. An schematic of the system is shown in Fig. 1(a), where the incoming phase is distorted by atmospheric turbulence and imaged through a microlenses array. The resulting spot diagram is projected onto a digital micromirror device, where a binary pseudo-random coded aperture (CA) is applied. The encoded frames are then relayed to a camera after passing through a shearing device (e.g., galvanometer), which linearly shifts the frames along the camera's plane based on their time of arrival.

The simulations form the basis of this work, showcasing the ability to emulate the atmospherically distorted phase, the Shack-Hartmann spot diagram and the respective reconstruction for different frames of a scene (Fig 1 (b) and (c)). The time-sheared and unsheared views from the dual-view CUP's algorithm [3] are presented in Fig. 1(d) and (e).

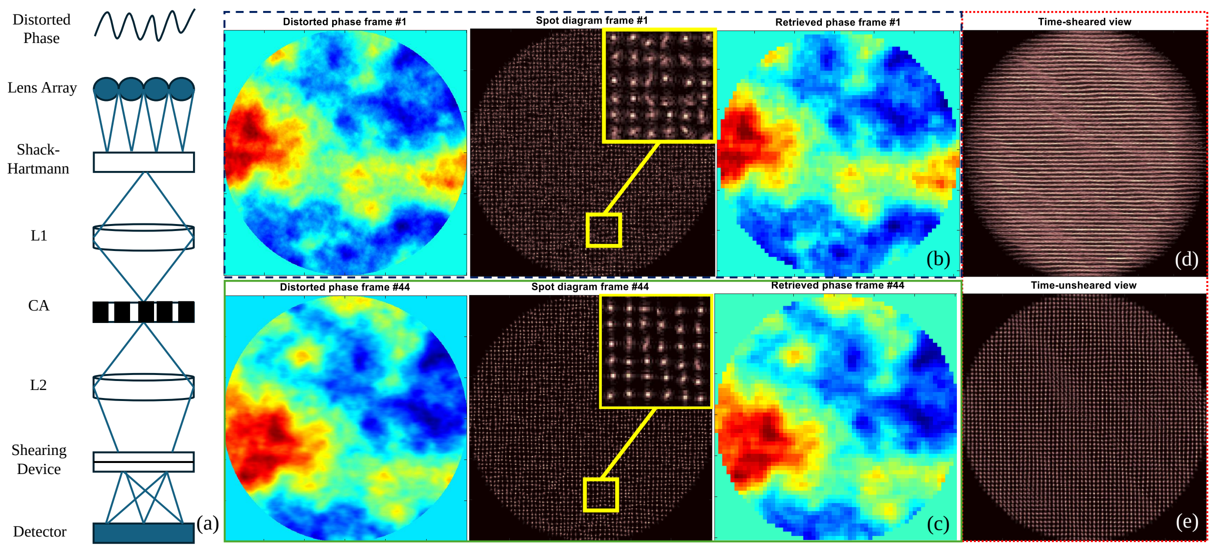

Fig. 1. (a) Proposed compressed optical Shack-Hartmann ultrafast photography system. (b) Frame #1 reconstruction process. (c) Frame #44 reconstruction process. (d) Spot diagram's time-sheared view. (e) Spot diagram's time-unsheared view.

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All-Sky Surveillance for Space Situational Awareness: A Real-Time Neuromorphic System

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Abstract

The growing problem of space debris orbiting the Earth has highlighted the urgent need for effective identification and tracking systems from ground-based stations. As the number of satellites and debris in Earth's orbit increases, space situational awareness becomes crucial to avoid potential collisions, enhance our understanding of orbital traffic, and protect the orbital environment.

Traditional optical systems often struggle in low-light conditions and dynamic environments, especially when real-time data is required, due to the need for long exposure times. This work introduces a highly efficient approach to satellite and space debris detection by integrating multiple Event-Based Cameras (EBCs) with Spiking Neural Networks (SNNs). EBCs are neuromorphic sensors capable of detecting minute changes in light contrast with a temporal resolution close to 1 us, making them ideal for identifying small variations caused by satellites in the night sky [1, 2]. These cameras also significantly reduce memory usage and energy consumption compared to conventional cameras. Meanwhile, SNNs offer advantages such as faster learning speeds, lower energy consumption, and superior adaptability to neuromorphic sensors compared to traditional neural networks [3].

The proposed system employs twelve EBCs, each mounted on telescopes and oriented in fixed directions. The cameras are connected to a multi-core processing unit, where a noise filter is applied to each camera simultaneously [4]. An attention algorithm [5] detects if there is activity in any of the cameras, and indicates the data to be sent to the SNN for further analysis. This approach allows irrelevant data to be discarded, reducing the traffic to the SNN and focusing on significant events, thereby improving classification accuracy. The SNN was trained on a custom dataset of multiple recordings of objects passing through the night sky, classifying them into three primary categories: background, satellite, or other (such as planes, birds, bugs, other celestial phenomena, etc.). Once the SNN detects a satellite, the data can be compared with publicly available datasets to determine whether it is a registered satellite or space debris [6]. Preliminary results demonstrate the system's ability to detect and classify in-orbit objects with 90% accuracy and delays of less than 0.1 seconds, covering a wide area of the sky. The system also provides a low-energy, high-efficiency solution for all-sky surveillance, with the potential for scalability through the deployment of additional systems, enabling widespread monitoring from multiple locations.

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