3-5 September 2024

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Program and abstracts

Warsaw Summer School on Advanced Optical Imaging

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Presentations

Day 1

3 September 2024

9:10 – 3 September 2024

Optical imaging - physical basics

Presented by **Maciej Wojtkowski** *(ICTER – International Centre for Translational Eye Resaerch, Insitute of Physical Chemistry PAS)*

9:55 – 3 September 2024

Optical Coherence Tomography and the promise of virtual biopsy

Presented by **Rainer A. Leitgeb** *(Medical University of Vienna)*

11:55 – 3 September 2024

Seeing anywhere in the brain through 100mm thin glass fibre

Presented by **Tomáš Čižmár** *(Leibniz Institute of Photonic Technology, Institute of Scientific Instruments of the CAS, v. v. i.)*

15:10 – 3 September 2024

Physics of imaging in fluorescence microscopy

Presented by **Jörg Enderlein** *(Georg August University)*

Day 2

4 September 2024

8:30 – 4 September 2024

Polarisation Sensitive OCT and Immuno-OCT, principles and clinical application in pulmonology and gastroenterology

Presented by **Johannes F. de Boer** *(VU Amsterdam)*

10:00 – 4 September 2024

OCT as a commercially available technology - considerations from an industry perspective

Presented by **Michael Leitner** *(Thorlabs GmbH)*

11:15 – 4 September 2024

Fluorescence in Tissue Diagnostics and Clinical Applications

Presented by **Laura Marcu** *(University of California Davis)*

13:45 – 4 September 2024

Chemometrics and Machine Learning in Raman Spectroscopy

Presented by **Shuxia Guo** *(Leibniz-IPHT, University Jena)*

15:30 – 4 September 2024

Special event: Lifting Your Academic Career: Lessons from Olympic Weightlifting

Presented by **Mateusz Szatkowski** *(Wrocław University of Science and Technology)*

16:45 – 4 September 2024

Metabolic Imaging for Sepsis Characterization of Kidney Tissue Using Two-Photon Excited Fluorescence Lifetime Microscopy

Presented by **Stella Greiner** *(Leibniz-IPHT Jena, FSU Jena)*

17:00 – 4 September 2024

A Novel Integration of 1P Confocal- and Multiphoton-FLIM in One System

Presented by **Taravat Saeb Gilani** *(Becker & Hickl GmbH)*

17:15 – 4 September 2024

1.7 MHz Fourier domain mode locked laser at 840 nm for retinal imaging

Presented by **Marie Klufts** *(University of Lübeck, Institute of Biomedical Optics)*

17:30 – 4 September 2024

Common path optical diffraction tomography for refractive index analysis of lipid droplets

Presented by **Piotr Zdankowski** *(Warsaw University of Technology)*

17:45 – 4 September 2024

Super-Resolution Microscopy Based on the Inherent Fluctuations of Dye Molecules

Presented by **Radek Lapkiewicz** *(University of Warsaw)*

Day 3

5 September 2024

8:30 – 5 September 2024

Fiber optics couplers and lanterns for OCT and confocal endomicroscopy

Presented by **Caroline Boudoux** *(Polytechnique Montréal, Castor Optics)*

9:15 – 5 September 2024

Lensless Digital Holographic Microscopy: Fundamental Principles & Applications

Presented by **Maciej Trusiak** *(Warsaw University of Technology)*

11:15 – 5 September 2024

Advances in Ptychography

Presented by **Lars Lötgering** *(ZEISS Reseach Microscopy Solutions)*

13:45 – 5 September 2024

Ultra High Resolution OCT for imaging the anterior eye segment

Presented by **Kostadinka Bizheva** *(University of Waterloo)*

14:30 – 5 September 2024

Functional retinal imaging

Presented by **Kostadinka Bizheva** *(University of Waterloo)*

15:45 – 5 September 2024

Special event: It Goes without Saying: Taking the Guesswork Out of Your PhD in Engineering

Presented by **Caroline Boudoux** *(Polytechnique Montréal, Castor Optics)*

Posters

P1: Azimuthal backflow in light carrying orbital angular momentum

B. Ghosh, A. Daniel, B. Gorzkowski, and R. Lapkiewicz

Presented by **Bernard Gorzkowski** *(University of Warsaw)*

Abstract

In wave physics there is a peculiar phenomenon called superoscillations, where a band-limited signal can contain local oscillations outside of the Fourier spectrum range. Backflow is a related phenomenon, originally formulated for quantum mechanics, but extendable to any wave system, in which a signal with a Fourier spectrum containing only positive momenta can locally oscillate with negative frequencies. We managed to demonstrate this for orbital angular momentum in optical scalar waves, in an experiment where by superposing two beams with positive angular momenta, we created a beam that locally contained a negative angular momentum density.

P2: Nonlinear Phase Wrapping for Linear Information Forwarding

G. R. Cheeran B. Fischer, M. Chemnitz

Presented by **Glitta Rosalia Cheeran** *(Leibniz Institute of Photonic Technologies , Friedrich-Schiller-Universität, Jena)*

Abstract

The study of nonlinear dynamics in optical fibers has gained attention due to their applications in multi-frequency laser engineering and nonlinear imaging. Recently, we have demonstrated an optical neuromorphic system in highly nonlinear fiber, that has high accuracy for benchmark classification tasks, but struggles with MNIST digit classification. We hypothesize that strong nonlinearity may hinder performance for MNIST, which might require less nonlinearity. Our objective is to study nonlinear phase wrapping, where the phase encoded in the input pulse is mapped onto the output supercontinuum's intensity. Using numerical methods, we explore this mapping at various input pulse powers to identify where linear information breaks down.

P3: OCT with Tunable Focus - Towards Quantification of Ocular Opacifications

I. Grulkowski, P. Artal

Presented by **Keerthana Soman** *(Nicolaus Copernicus University in Toruń)*

Abstract

Optical coherence tomography (OCT) is a non-invasive imaging modality enabling detection of weakly scattered light and generation of images with micrometer resolution. The design of efficient light delivery scenario is critical to optimize the performance of OCT system. In particular, dynamic control of the optical beam focus allows for OCT image enhancement, leading to the visualization of the crystalline lens anatomy as well as the vitreous details at both interfaces in an unprecedented manner. Here, we demonstrate spatially non-homogenous nature of optical properties of the crystalline lens and the vitreous. The

analysis of the signal in OCT data allowed for quantification of age-related opacities in healthy subjects and cataract patients.

P4: Mode field adapters improving the efficiency of fiber laser systems for nonlinear imaging

A. Jamrozik, M. Pielach, B. Fabjanowicz, K. Krupa, Y. Stepanenko

Presented by **Agnieszka Jamrozik** *(Institute of Physical Chemistry PAS)*

Abstract
Low-loss optical fiber fusion splicing plays a key role in constructing fiber laser systems that can be used for nonlinear imaging. In this work, we present a CO2 laser-based splicing technique that enables the fabrication of mode field adapters. Our approach is tailored for polarization-maintaining optical fibers and can reduce the splice loss by 30%. The proposed fully-fused components can significantly increase the efficiency of ultrafast high-energy fiber-based systems.

P5: Spatial Light Modulator based wavefront sensor with structured light

K. Kalinowski, A. Korzeniewska, J. Masajada, M. Łukowicz, M. Szatkowski

Presented by **Kamil Kalinowski** *(Wrocław University of Science and Technology)*

Abstract
Structured light shapes light's amplitude, phase, and polarization for unique features. This work explores using Laguerre-Gaussian (LG) modes with Spatial Light Modulators (SLMs) to improve wavefront retrieval. SLM-based sensors dynamically adjust without physical changes. We implemented a Shack-Hartmann sensor with LG modes, which are excellent beam quality markers due to their phase singularity and circular symmetry. Comparing LG and Gaussian modes, we found LG modes enhance center detection and reduce wavefront errors under static aberrations. Simulations show LG beams outperform Gaussian beams in challenging conditions.

P6: Luminance of two-photon stimuli

K. Komar, O. Kaczkoś, M. Grochalski, J. Pniewski, M. Wojtkowski

Presented by **Oliwia Kaczkoś** *(ICTER – International Centre for Translational Eye Research, University of Warsaw)*

Abstract
Two-photon vision is a visual perception of pulsed infrared lasers (800-1300 nm) due to isomerization of visual pigments caused by two-photon absorption. Future applications of this effect, both in medical diagnostics and in augmented reality (AR), require the ability to determine the luminance of the two-photon stimuli. However, the luminous efficiency function outside of the visible range is unknown. This study proposes a brightness-matching method to determine the subjective luminance of two-photon stimuli. This approach presents the relationship between the two-photon luminance and a novel physical quantity connected with perceived brightness: two-photon retinal illuminance. Our results predict the luminance of a two-photon stimulus of nearly 170 cd/m2 within safety limits.

P7: Mouse retina hemodynamics analysis using advanced optical imaging, estimating pulse wave frequency, phase and velocity.

W. Kulesza, M. Wielgo, P. Węgrzyn, S. Tomczewski, K. Kordecka, A. Galińska, B. Bałamut, E. Auksorius, A. Foik, R. Zawadzki, M. Wojtkowski, D. Borycki, A. Curatolo

Presented by **Wiktor Kulesza** *(Institute of Physical Chemistry PAS, ICTER – International Centre for Translational Eye Research)*

Abstract
Introducing STOC-T, an ultrafast imaging system capturing mouse retina OCT images at 112 Hz. Equipped with a calibrated fundus camera and white-light illumination, it enables precise alignment and focal plane adjustment for STOCT imaging within the retina. Our system efficiently extracts essential data, including pulsatile blood flow frequency and other hemodynamic parameters, from structural-only OCT images of retinal and choroidal vessels. The system is versatile with the highly phase-stable OCT data acquisition capacity, allowing for high precision tissue displacement tracking across large areas. This capability underscores STOC-T's potential as an effective tool for monitoring retinal hemodynamics with remarkable precision.

P8: Efficient multiphoton microscopy with high-energy picosecond laser pulses

K. Kunio, J. Bogusławski, G. Soboń

Presented by **Katarzyna Kunio** *(Wrocław University of Science and Technology)*

Abstract
Efficient multiphoton microscopy leverages high-energy picosecond laser pulses for deeper tissue imaging with reduced photodamage. We propose a setup using a 10 nJ Yb:fiber laser producing picosecond pulse trains, achieving performance comparable to femtosecond pulses while mitigating chromatic dispersion issues. Our all-fiber setup eliminates the need for a compressor, enhancing user-friendliness. Experiments demonstrated superior image brightness and contrast using picosecond pulses compared to femtosecond pulses despite similar duty cycles. This innovative approach underscores the benefits of flexible, dispersion-resistant multiphoton microscopy with compact, portable systems.

P9: Design and development of a static Fourier transform spectrometer for microplastic detection in aquatic environments

F. Łabaj, R. Stojek, M. Łowcewicz, J. Kalwas, R. Piramidowicz

Presented by **Filip Łabaj** *(Warsaw University of Technology, VIGO Photonics S.A.)*

Abstract
Micro- and nanoplastic pollution is a global issue, negatively influencing ecosystems and human health. We present the design and development of a mid-infrared spectrometer system for the detection of micro- and nanoplastics in aquatic environments, based on a linear-variable filter and an array of miniature thermal emitters. The spectral selectivity of

the system allows for real-time monitoring of the presence of micro- and nanoplastics in samples. Tests were performed using microplastic particles ranging in sizes from 1 to 100 µm and consisting of polyethylene, polystyrene and polypropylene.

P10: Metasurface Enhaced Lensless Endoscope

A. Loucif, S. Khadir, E. Andresen

Presented by **Amir Loucif** *(Université Cote d'Azur, CRHEA-CNRS)*

Abstract
Recent advancements in lensless endoscopes offer promising solutions for non-invasive, in-vivo imaging, especially within the brain. However, challenges in miniaturization and optimizing optical performance persist. Systems using multicore fibers as probes typically employ Spatial Light Modulators (SLMs) to manage beam control, compensating for phase and group delays induced in the fibers. Yet, SLMs are bulky and require additional components, limiting their efficiency and field of view. Metasurfaces provide an innovative alternative by offering precise control over amplitude, phase, and polarization. Integrating metasurfaces with multicore fibers creates a flexible, minimally invasive probe for two-photon endoscopy, reducing the endoscope's footprint and enhancing its functionality.

P11: Non-invasive imaging through a dynamic scatterer in the photon counting regime

A. Makowski, B. Gorzkowski, P. Szczypkowski, A. Daniel, S. Gigan, and R. Lapkiewicz

Presented by **Adrian Makowski** *(University of Warsaw, Sorbonne Université)*

Abstract
In fluorescence microscopy scattering poses a significant challenge, leading to progressive degradation of image quality at increasing depths. Imaging becomes more difficult with dynamic scatterers like biological tissues that change in time. We demonstrate non-invasive imaging of fluorescent objects hidden behind dynamic diffusers. Our reconstruction uses a stack of images recorded for different diffuser realizations, and works even when individual camera frames contain small photon numbers.

P12: STOC-T method with increased SNR for in vivo cellular-level imaging of the human retina

M. Mikuła-Zdankowska, D. Borycki, P. Węgrzyn, M. Wojtkowski

Presented by **Marta Mikuła-Zdankowska** *(Institute of Physical Chemistry PAS, ICTER – International Centre for Translational Eye Research)*

Abstract
Speckle reduction in Spatio-Temporal Optical Coherence Tomography is achieved through spatio-temporal averaging of light that has traversed different guided modes in the multimode optical fiber (MMF). However, MMFs are prone to modal noise, where uneven distribution of optical power across multiple modes causes speckle patterns. We propose the utilization of a phase-randomizing deformable mirror to dynamically change the illumination intensity distribution coupled with a numerical averaging technique. This approach allows for a significant increase in signal-to-noise ratio, approximately by 12 dB

compared to the previously suggested strategy using MMF. We present the latest structural data from in vivo imaging of the human retina.

P13: Interferometric speckle contrast optical spectroscopy

K. Nowacka, M. Dąbrowski, D. Borycki

Presented by **Klaudia Nowacka** *(ICTER – International Centre for Translational Eye Research, Institute of Physical Chemistry PAS)*

Abstract
We demonstrate the time-of-flight (TOF)-resolved interferometric speckle contrast optical spectroscopy (TOF-resolved iSCOS), which we implemented using a rapidly tunable laser and an ultrafast two-dimensional camera operating at 1.1 million frames per second. The wavelength-resolved camera frames are added to mimic the multi-exposure acquisitions, from which we achieve the time-of-flight resolved speckle contrast. This enables us to estimate the depth-dependent blood flow index to monitor the human blood flow in vivo at short source-collector separations.

P14: Colorimetric measurements obtained by spectrally corrected reading of RGB imaging system

M. Pelko, B. Skrzypiński

Presented by **Marcin Pelko** *(GL Optic Polska Sp. z o.o.)*

Abstract
Getting colorimetric quantities based on an array RGB camera requires applying transformation matrix (3×3) . Each measured source has to be considered individually as it's spectrum may contain different components. In order to obtain all coefficients of the transformation matrix it is necessary to combine spectral characteristics at minimum 4 settings of the measured object with rgb reading of the camera. Matrix obtained with such a set of data could be used for calculating chromaticity coordinates and color uniformity of measured source/display at every spot of the picture. Paper presents example of realization of RGB camera of known spectral characteristic; and built-in spectrometer. Measurement data are compared against values obtained with point measurements by spectrometer

P15: Towards environmentally stable laser for nonlinear imaging: ultrafast all-fiber Nd-doped oscillator at 928 nm

M. Pielach, A. Jamrozik, K. Krupa, Y. Stepanenko

Presented by **Mateusz Pielach** *(Institute of Physical Chemistry PAS)*

Abstract
Replacing commonly used bulky Ti:Sapphire lasers with compact fiber-based systems can reduce maintenance costs and improve the quality of nonlinear imaging. This work presents an environmentally stable all-polarization-maintaining Nd-doped fiber laser oscillator, which

delivers nJ-level ultrashort pulses at 928 nm. The system is a turn-key solution with an extended lifetime thanks to an artificial saturable absorber based on a 3×3 fiber coupler.

P16: SOA designs for MEMS-VCSEL based swept sources

D. Sajan, A. Chamorovskiy, K. Yvind

Presented by **Dixon Sajan** *(Technical University of Denmark (DTU))*

Abstract
Optical Coherence Tomography (OCT) is a non-invasive deep tissue image generation technique used in ophthalmology and other medical fields. Micro-electro-mechanical system (MEMS) vertical cavity surface emitting lasers (VCSELSs) have potential for better performance, but their high finesse limits output power. This work focuses on amplifying OCT output power using Indium Gallium Arsenide (InGaAs) - Gallium Arsenide (GaAs) double quantum well Semiconductor Optical Amplifier (SOA) provided by Superlum Diodes Ltd. The study measures amplified spontaneous emission and develops a lumerical model for analysis.

P17: Low-cost Full-Field Optical Coherence Tomography using a Raspberry-Pi

T. Sanderson, A. Bradu, R. Rajendram, A. Podoleanu

Presented by **Taylor Sanderson** *(University of Kent)*

Abstract
This work aims to address the cost component of Optical Coherence Tomography (OCT) to enable better accessibility in low-resource settings and presents a low-cost Full-Field Time Domain OCT (FF-TD-OCT) system. The instrument is designed using a Raspberry Pi single-board computer, a small, affordable, customisable computing device, and incorporates a low-cost 2D camera and various off-the-shelf components. This combination allows for a substantial reduction in costs, while delivering decent-quality images.

P18: Monitoring droplet dynamics of a levitated droplet

S. J. Shetty, J. C. Peralta, A, Nagy, P. Veis

Presented by **Sanath J. Shetty** *(Comenius University)*

Abstract
The study of liquids in the form of levitated droplets without any external contact (e.g. with the substrate) is important for precise analysis of liquids. Acoustic levitation offers a unique method to suspend liquid droplets, allowing for precise control and observation free from container walls.

P19: Comparative analysis of multispectral imaging of T and B cells in murine spleen utilizing LDIR, FTIR, and OPTIR spectroscopy techniques

A. Shydliukh, S. Deinhardt-Emmer, J. Popp, C. Krafft

Presented by **Artem Shydliukh** *(Leibniz Institute of Photonic Technologies)*

Abstract

Multispectral imaging techniques based on infrared (IR) spectroscopy have become pivotal in biomedical research, offering insights into the spatial distribution and chemical composition of cells within biological tissues. A previous FTIR imaging study already identified vessels, red pulp, white pulp, and B and T lymphocytes in spleen tissue sections[1]. In 2019, new generations of IR instruments were introduced that were coupled to quantum cascade lasers (QCL) namely Laser Direct Infrared (LDIR, Agilent) and Optical Photothermal Infrared (OPTIR, Photothermal Inc.) spectroscopy. A comparative application of these three IR approaches for spectroscopy and imaging to murine spleen tissue sections with and without infection by influenza virus A will be presented.

P20: In-vivo analysis of the optical discontinuity zones at different accommodation demands

K. Soman, A. Gupta, D. Rumiński, B. J. Kaluzny, K. Karnowski, P. Artal, I. Grulkowski

Presented by **Keerthana Soman** *(Nicolaus Copernicus University in Toruń)*

Abstract

The crystalline lens is an optically non-homogeneous structure. Optical signal discontinuity(OSD) zones refer to the regions of the crystalline lens with different light scattering properties. The study focuses on morphological characteristics of ocular structures under different accommodation states using high-resolution in-vivo Optical Coherence Tomography (OCT) imaging. Thicknesses of the ocular structures, including the OSD zones, are assessed at accommodation demands ranging from 0 D to 6 D.

P21: 3D Super-resolution Optical Fluctuation Imaging with Temporal Focusing two-photon excitation

P. Szczypkowski, M. Pawłowska, R. Łapkiewicz

Presented by **Paweł Szczypkowski** *(University of Warsaw)*

Abstract

Super-resolution Optical Fluctuation Imaging (SOFI) is a method that enhances the resolution in 3D by utilizing the blinking of fluorophores. In thick samples, however, SOFI is prone to artifacts. To solve this problem, we use Temporal Focusing (TF) - a technique that can excite a thin disc in volumetric samples and is fairly simple to implement. While SOFI doesn't need any modification of the hardware, when we combine these two methods, we achieve easy 3D super-resolution in thick, dense samples.

P22: Expanding the toolbox of in cellulo transient absorption spectroscopy

A. Valavalkar, B. Dietzek-Ivanšić, M. Mueller, O. Thorn-Seshold

Presented by **Abha Valavalkar** *(Leibniz Institute of Photonic Technologies)*

Abstract
In this work, “dark” but “loud” photoacoustic agents[4] were measured in cellulo, thus obtaining temporal information environment specific information for non-emissive molecules. The outlook is to use optical imaging to probe the spatial information about the localisation of these molecules, which will complement the kinetic data. Optical imaging becomes especially relevant, for these “dark” molecules, which are intended to have eventual applications in optical coherence tomography.

P23: Investigating Phase and Amplitude Noise in MEMS VCSEL-Based OCT Systems

A. A. H. Zaidi, T. Ansbæk, K. Yvind

Presented by **Syed Ameer Hamza Zaidi** *(Denmark Technical University)*

Abstract
This research focuses on identifying and mitigating noise in Optical Coherence Tomography (OCT) A-scans when using Micro-Electro-Mechanical Systems (MEMS) Vertical-Cavity Surface-Emitting Lasers (VCSELs).

P24: Material parameters study of 1060nm SG-DBR InGaAs/GaAs-based laser for optical coherence tomography

SFA Naqvi, K. Morozov, A. Gubenko, A. Podoleanu

Presented by **Syed Farhan Ali Naqvi** *(Innolume GmbH, NetLaS- Next Generation of Tunable Lasers)*

Abstract
High-resolution swept source OCT imaging in real-time requires a fast wavelength tunable laser. InP-based widely tunable akinetic SG-DBR laser is used for telecommunication due to high reliability and compact size. Developing 1060nm multi-section SG-DBR laser with high sweep linearity and internal k-clock can be beneficial for ophthalmic OCT.

Development of such a laser, requires in-detail material study, essential for proper device designing. To study the gain of the material, special two-section chips with InGaAs/GaAs quantum well were fabricated to use the segmented contact method. Results show more than 60nm-wide gain spectrum for 1.2mm chip starting from 20mA, which fits laser operation requirements. Results of this study will be used in fabrication of widely tunable SG-DBR laser.

P25: Spectral Domain Visible Optical Coherence Tomography using Balanced Detection

L. Abbott, A. Podoleanu, A. Bradu

Presented by **Lucy Abbott** *(University of Kent)*

Abstract
An OCT instrument operating in the spectral domain driven by visible light is presented. The instrument utilises balanced detection to reduce optical noise and improve the quality of OCT images; the aim is to eventually image the retina, however preliminary results and images of other samples are presented.

P26: Pixel Super Resolution in Lensless Digital In-Line Holographic Microscopy

K. Niedziela, M. Rogalski, P. Arcab, J. Winnik, M. Trusiak

Presented by **Karolina Niedziela** *(Warsaw University of Technology)*

Abstract
Lensless digital in-line holographic microscopy (LDHM) is an emerging imaging field characterized by the simplicity and cost-effectiveness since no lens are used. However, the resolution achieved by LDHM is worse than in classical microscopy due to the limited pixel size and low magnification. Pixel Super Resolution (PSR) is a technique designed to address these limitations by numerically decreasing the effective pixel size, thereby enhancing the resolution capabilities of LDHM systems. PSR aims to recover high-resolution information from a series of low-resolution images, effectively pushing the resolution towards the diffraction limit. In this contribution, we present an implementation of the PSR technique within a LDHM framework, demonstrating its potential to improve resolution.

P27: Lensless polarizing holographic microscopy

P. Arcab, M. Roglaski, M. Lopera, M. Stefaniuk, C. Trujillo, M. Trusiak

Presented by **Piotr Arcab** *(Warsaw University of Technology)*

Abstract
Lensless in-line digital holographic microscopy (LDHM) is a technique that enables the examination of amplitude and phase objects across a large field of view (FOV). However, additional information about the sample, such as polarization properties, is not captured in standard holography. Certain tissues, like brain, contain polarization-active areas that may hold significant biological importance. To address this limitation, we propose a polarized lensless microscopy system that incorporates two additional components (a polarizer and an analyzer) maintaining the simplicity of the hardware.

P28: Digital in-line holographic microscopy in low photon budget conditions

M. Rogalski, P. Arcab, E. Wdowiak, J. A. Picazo-Bueno, V. Micó, M. Józwik, M. Trusiak

Presented by **Mikołaj Rogalski** *(Warsaw University of Technology)*

Abstract
Digital in-line holographic microscopy (DIHM) is a cost-effective and robust method that offers high-contrast imaging with large fields of view. DIHM is suitable for imaging live bio-samples, ideally using reduced illumination intensity to prevent phototoxicity and photodamage. However, these illumination conditions result in low signal-to-noise ratio (SNR) data, which impairs classical DIHM reconstruction algorithms. In this contribution, we present a DIHM reconstruction algorithm that is robust against low SNR data.

P29: Tunable four-wave mixing based light source for nonlinear imaging applications

C. Corso, B. Fabjanowicz, M. Pielach, A. Jamrozik, Y. Stepanenko, K. Krupa

Presented by **Cássia Corso** *(Institute of Physical Chemistry PAS)*

Abstract
We present a widely tunable all-fiber optical parametric oscillator (FOPO) system driven by the nonlinear effect of Degenerate Four-Wave Mixing (D-FWM). We introduce a novel all-fiber method for wavelength tuning over more than 40 nm in normal dispersion regime, based on self-phase modulation (SPM) induced spectral broadening. The FOPO source emerges as a pivotal technology for advancing biomedical diagnosis particularly enabling in vitro chemosensitivity measurements.

P30: Dark adaptation for one- and two-photon visual stimuli

M. Smolis, E. Moreno, M. Grochalski, K. Komar

Presented by **Magdalena Smolis** *(Jagiellonian University)*

Abstract
In this study we present dark adaptation measurements after bleaching of 60% of rhodopsin probed with one- (520 nm, VIS) and two-photon (1040 nm, IR) visual stimuli at 6 deg temporal retinal location. Both curves have typical biphasic form ascribed to readapation of cones and rods. The rods exponents for both processes seem to be similar, while readaptation of cones probed with IR stimulus is significantly different: cone elevation levels are equal to 1.21 and 0.68 for VIS and IR stimuli, respectively. The observed differences are in agreement with previous data and may result from the smaller difference in the sensitivity of rods and cones for the two-photon stimulus than for one-photon stimulus of similar colour.

P31: Color matching of two-photon stimuli projected by scanning laser

M. Grochalski, M. Smolis, E. Moreno, K. Komar

Presented by **Mateusz Grochalski** *(Nicolaus Copernicus University in Toruń)*

Abstract
The goal of this study was to plot the perceived colors of VIS (520 nm) and IR (1040 nm) stimuli on standardized color space CIE1931. The IR stimulus was perceived as green due to two-photon vision. Light source used for color matching had a gamut that covered broad

portion of the CIE1931 space and matching was performed by four healthy participants. The perceived hue was measured at various power levels. The results showed a dependence of the perceived hue on power for IR stimulus. Such dependence was not observed for VIS stimulus. The results were compared with recent ones, but obtained for a display with smaller gamut. A full understanding of two-photon color perception will broaden knowledge of two-photon vision and could be useful in development of two-photon retinal display

P32: Quantitative evaluation of tissue clearing and expansion using brightfield microscopy

W. Szymska, M. Rogalski, P. Arcab, P. Zdańkowski, M. Józwik, M. Trusiak

Presented by **Wiktoria Szymska** *(Warsaw University of Technology, Silesian University of Technology)*

Abstract
The observation of tissues under a microscope is crucial for various biomedical applications, but their natural opacity requires effective clearing to make them suitable for study. This study aims to identify the optimal procedures for tissue clearing to enhance microscopic observation. Data were collected for different tissues, varying thicknesses, and different clearing fluids. The data were analyzed to determine the average tissue absorption and expansion. The study identified effective clearing methods for various tissue types. Optimized clearing techniques, combined with systematic data analysis, improve the visualization of tissue structures, offering valuable insights for biomedical research.

P33: In Vivo Insights: Vitreous Dynamic Study Using SS-OCT System

E. P. Devaraj, D. Ruminski, B. Kaluzny, J. Sebag, I. Grulkowski

Presented by **Evangeline Priyadharshini Devaraj** *(Nicolaus Copernicus University in Toruń)*

Abstract
The vitreous body is the eye's most significant component, essential for development, cell barrier function, oxygen metabolism, and eye disease pathogenesis. It comprises 80% of the eye's volume, mainly water, collagen, and hyaluronan. Ageing and myopia cause changes like fibrous liquefaction. Due to its high water content (~98%) and transparency, visualizing the vitreous is difficult. This study used a prototype SS-OCT and advanced imaging to analyze vitreous structure and opacities during saccadic movements. We found that floater velocity increases with age, indicating more significant vitreous liquefaction over time and supporting the hypothesis that the vitreous becomes more liquefied as people age.

P34: Analysis and optimization of large area two-photon polymerization phase fabrication

E. Wdowiak, M. Józwik, P. Zdańkowski, M. Trusiak

Presented by **Emilia Wdowiak** *(Warsaw University of Technology)*

Abstract

Large-area two-photon polymerization (TPP) holds promise for diverse applications in quantitative phase imaging methodologies but raises concerns regarding fabrication precision across the entire printing area. Utilizing TPP system from Nanoscribe GmbH, we explore these issues within theoretically precise area, declared by system's specification. Significant phase errors are observed, confirmed by Linnik interferometry. We investigate these errors using Zernike polynomial fitting for effective aberration analysis. Our methodology allows error correction, significantly reducing phase variations and improving large-area TPP quality.

P35: Autofocusing for numerical reconstruction in off-axis lensless digital holographic microscopy.

J.Dudek, M.Rogalski, J.Winnik, P.Arcab, M.Trusiak

Presented by **Julia Dudek** *(Warsaw University of Technology)*

Abstract
Lensless digital in-line holographic microscopy (LDIHM) is a cost-effective computational microscopy technique that allows large field-of-view quantitative phase imaging. In a standard configuration, it employs on-axis illumination, however, it can also benefit from angled illumination. This addition enhances the imaging process, improves reconstructions, and reduces twin image noise through multiple measurements. A significant challenge is numerical focusing. Angled illumination complicates focusing more than on-axis, as it requires precise angle determination, not just propagation distances. We present a robust autofocusing method based on the sharpness criterion that optimizes propagation distance and illumination angle, allowing high-precision holographic data reconstruction.

P36: Measuring Pulsatile Motion in Ocular Structures with Swept-Source OCT

V.K. Kathirvelu, K. Soman, D. Ruminski, I. Grulkowski

Presented by **Vasantha Kumar Kathirvelu** *(Nicolaus Copernicus University in Toruń)*

Abstract
Swept-Source Optical Coherence Tomography (SS-OCT) is a leading-edge imaging technology known for its exceptional depth-resolved and high-resolution capabilities. It effectively captures dynamic changes in ocular tissues caused by pulsatile forces throughout the cardiac cycle. SS-OCT's key strengths are its micron-scale resolution and real-time, non-invasive imaging, allowing for precise tissue movement and deformation assessment. This advanced method provides crucial insights into ocular biomechanics, enhancing diagnostic accuracy and research potential.

P37: From Development to Detection: Dendritic Nanostructures in SERS for Advanced Biomolecular Analysis

A. Dwivedi, V. Sivakov, J. Popp, D. Cialla-May

Presented by **Aradhana Dwivedi** *(Leibniz Institute of Photonic Technologies)*

Abstract
Surface-enhanced Raman spectroscopy (SERS) is a powerful technique that has shown great promise in the field of biomolecular detection for various applications in medical diagnostics and research. By using silver sulfate as a precursor instead of silver nitrate, we developed dendritic nanostructures with sensitive SERS detection capabilities. Silver sulfate acts as a growth agent and a mild capping agent, simplifying the fabrication process and enhancing substrate stability. We integrated these dendritic nanostructures with electrochemistry to create a platform for the potential-dependent SERS analysis of biological molecules. As an example, we have utilized dendritic structures to detect and analyze DNA tagged with an alkyne molecule.

P38: Optimization-free, phase utilizing alignment method for multiple spectrometer-based OCT

P. Kasprzycki, M. Szkulmowski, M. Wojtkowski, K. Karnowski

Presented by **Piotr Kasprzycki** *(ICTER – International Centre for Translational Eye Research)*

Abstract
We introduce a phase information-based, free-of-optimization multiple spectrometers' spectral alignment method. Our technique relies on the observation that the slope of the unwrapped phase of the interferometric signal changes linearly with the same gradient for all identical spectrometers. Our method shows the clear benefit of shorter computational time compared to previously proposed methods based on optimization algorithms. The approach presented here can be used with commercially available spectrometers in which access to optical elements is limited and physical alignment is impossible.

P39: Investigation of novel methods for hyperspectral data analysis in multiphoton microscopy

M. Barna, J. Bogusławski, G. Palczewska, K. Palczewski, G. Soboń

Presented by **Maciej Barna** *(Wrocław University of Science and Technology)*

Abstract
This work explores phasor-based analysis of hyperspectral data in multiphoton microscopy to address efficiency issues caused by large data volumes. By replacing full spectral data with their phasor form for machine learning algorithms, data volume is significantly reduced. Results show that phasor-based methods offer comparable accuracy to full spectral data, improving efficiency, reducing resource needs, and enabling faster processing with cost-effective equipment.

P40: Quantitative estimation of total retinal arterial blood flow using real-time Doppler holography at 24,000 frames per second

Y. Fischer, Z. Auray, O. Martinache, M. Dubosc, N. Topeza, C. Magnier, M. Boy-Arnould, M. Atlan

Presented by **Michael Atlan** *(CNRS, ESPCI)*

Abstract
We present a study on the quantitative estimation of total retinal arterial blood flow using real-time Doppler holography at 24,000 frames per second. This novel technique utilizes high-speed digital holographic imaging for non-invasive angiography, enabling the assessment of retinal blood flow with potential applications in ophthalmology. The study demonstrated Doppler holography's capability to detect blood flow variations, although results indicated a potential underestimation of retinal blood volume rates compared to other advanced methods. The research suggests that increasing frame rates may resolve observed discrepancies, paving the way for enhanced retinal health monitoring in clinical settings.

P41: Fourier transform spectroscopy using broadband coherent light sources

A. Kotulska, J. Mnich, A. Chlebowski, J. Sotor, Ł. Sterczewski

Presented by **Agata Kotulska** *(Wrocław University of Science and Technology)*

Abstract
Typical Fourier-transform infrared spectrometers rely on thermal sources, providing excellent spectral coverage from near- to mid-infrared (MIR) but struggling to deliver adequate power in the terahertz (THz) region. Their incoherent nature leads to low interference contrast. Here, we develop a spectrometer based on nonlinear frequency conversion of ultrashort laser pulses (23 fs) in nonlinear optical crystals, producing coherent coverage from MIR to THz suitable for non-destructive sample analysis.

P42: Advanced Light Microscopy Node Poland

Presented by **Jedrzej Szymanski** *(Nencki Institute PAS)*

Abstract
Laboratory of Imaging Tissue Structure and Function operates as an imaging-microscopy core-facility at the Nencki Institute of Experimental Biology PAS (Warsaw, PL). We provide training, support and consultations to internal and external users in a wide range of light and electron microscopy imaging methods.. The facility is also a part of EuroBioimaging Advanced Light Microscopy Polish Node which is a part of larger European Research Infrastructure Consortium 'Euro-BioImaging'. Euro-BioImaging offers open access to biological and biomedical imaging technologies, training and data services across 41 Nodes, comprised of 237 facilities, in 18 countries and the EMBL. The "ALMF Node Poland" is coordinated by the Nencki Institute of the Polish Academy of Sciences (PAS). Check amf.nencki.edu.pl