AKPIK 4: Focus: Deep Learning in Electromagnetics Research

Time: Tuesday 14:00–15:30 Location: BEY/0127

Invited Talk AKPIK 4.1 Tue 14:00 BEY/0127

Beyond the Hype: Can AI Truly Transform Photonics? — •Mehdi K. Hedayati — Durham University, Department of Engineering, Durham DH1 3LE, UK

AI has become a powerful enabler in photonics, offering new routes for accelerated design and materials discovery beyond conventional trial-and-error approaches. In our group, we have demonstrated several AI-driven photonic design frameworks, with selected results experimentally verified in the laboratory. These include AI-assisted metasurface design enabling direct mapping between geometry and structural colour*allowing multiple colours from a single geometry under strain*as well as machine-learning models that capture nonlinear relationships in amorphous metamaterials, leading to proof-of-concept devices such as metasurface perfect reflectors. Yet, alongside these successes, the field is increasingly shaped by exaggeration and misplaced expectations. In reality, AI rarely delivers deployable photonic technologies; instead, it proposes candidate materials, geometries, or structures that must still be fabricated and validated experimentally. Fabrication yield, scalability, and limited characterization throughput therefore remain the dominant bottlenecks, causing progress to saturate at the experimental stage. In this talk, we will review the current state of the art of AI in photonics, examine where the field is heading in the near future, identify the key limitations we are likely to face, and discuss realistic pathways forward to better align AI-driven design with experimental reality.

Invited Talk AKPIK 4.2 Tue 14:30 BEY/0127

Machine–learning assisted design of metasurfaces — Lukas Mueller, Alexander Wolff, Janis Krieger, Steffen Klingel, Ralf Stemler, and •Marco Rahm — RPTU Kaiserslautern-Landau, Erwin-Schroedinger-Strasse, 67663 Kaiserslautern, Germany

We present several applications of machine-learning-assisted metasurface design. The first study focuses on maximizing the received signal power for two users positioned at different angles relative to a reconfigurable intelligent surface (RIS) operating at 27 GHz and 31 GHz. The RIS must function as a frequency-selective yet independently tunable beam steerer, making the optimization of the varactor bias voltages a challenging task. The optimized voltage matrices successfully steered beams at both frequencies over angles from 10° to 45°. In parallel, the work explores metasurface designs with independent control of reflection amplitude and phase using physics-informed machine learning. To significantly reduce training data requirements, a Temporal Coupled Mode (TCM) model was introduced to capture the dynamic tuning behavior using only four simulations instead of hundreds. Machine-learning models predict TCM parameters directly from the metasurface geometry, enabling fast optimization. Furthermore, transfer learning was applied to composite unit-cell design, achieving comparable accuracy with far fewer simulations than direct training.

AKPIK 4.3 Tue 15:00 BEY/0127

Optical Human Action Recognition - Less can be more? — •Maximilian Zier, Stefan Sinzinger, Kathy Lüdge, and Lina Jaurigue — Technische Universität Ilmenau, Ilmenau, Germany

Automated recognition of human actions is becoming more relevant due to applications in areas such as surveillance and autonomous driving. Modern neural networks achieve nearly perfect classification accuracies across various action datasets. However, they rely on complex feature extraction methods that lead to long training times and significant computational demands. Focusing on sustainability and efficiency, Reservoir computing systems aim to deliver similar performance combined with reduced computational effort by only training the output layer. An optically implemented reservoir offers the prospect of processing at the speed of light and nearly unlimited scalability due to inherent parallelism. In this contribution, we present results of a human action recognition task using a hybrid opto-electronic set-up based on [1]. In contrast to previous works, we forgo common preprocessing and feature extraction methods and use raw video data as input to the reservoir. Our system lags behind large neural networks in terms of classification accuracy, but has very low hardware requirements. Additionally, we reduce the length of the video sequences to one second, thereby using less input data to perform classification than previous works.

[1] Antonik, P., Marsal, N., Brunner, D. et al., Nat Mach Intell 1, 530-537 (2019)

AKPIK 4.4 Tue 15:15 BEY/0127

Loss-Minimized Incoherent Photonic Computing with Interferometer Networks — •Mingwei Yang[1,2], Konrad Tschernig[1,2], Felix Kübler[1], Okan Akyüz[1], Lennart Mannteufel[1], Enrico Stoll[1], and Janik Wolters[1,2] — [1]Technical University of Berlin, Berlin, Germany. — [2]German Aerospace Center (DLR), Berlin, Germany.

We present an algorithm for loss-minimized incoherent photonic multiplication of N-dimensional vectors with $N \times N$ matrices on standard Clements Mach-Zehnder interferometer (MZI) meshes [1]. By implementing arbitrary unitary transformations with incoherent light sources, the method avoids phase control and additional MZI blocks required by singular value decomposition in coherent schemes [2]. Optical energy per multiply and accumulate operation scales as $E = const$ in our approach, compared to $E \sim N$ in the crossbar architecture [3]. Experimentally, we implement a 4×4 photonic MVM and demonstrate an optical convolutional neural network for MNIST classification, achieving 28 correct predictions out of 31 images. Utilizing our loss-minimized architecture, we aim to reduce input intensity to the single photon regime to explore the limitations from shot noise.

[1] Clements, William R., et al. "Optimal design for universal multiport interferometers." Optica 3.12 (2016): 1460-1465.
[2] Shen, Yichen, et al. "Deep learning with coherent nanophotonic circuits." Nature photonics 11.7 (2017): 441-446.
[3] Feldmann, Johannes, et al. "Parallel convolutional processing using an integrated photonic tensor core." Nature 589.7840 (2021): 52-58.