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Editorial

Special Issue on "Optics for AI and AI for Optics"

Jinlong Wei [1,*], Lilin Yi [2], Elias Giacoumidis [3], Qixiang Cheng [4] and Alan Pak Tao Lau [5]

1 Optical and Quantum Communication Laboratory, German Research Center, Huawei Technologies Düsseldorf GmbH, 80992 Munich, Germany
2 Department of Electronic Engineering, Shanghai Jiao Tong University, Shanghai 200240, China; lilinyi@sjtu.edu.cn
3 VPIphotonics GmbH, 10587 Berlin, Germany; ilias.giakoumidis@vpiphotonics.com
4 Electrical Engineering Division, Department of Engineering, University of Cambridge, Cambridge CB3 0FA, UK; qc223@cam.ac.uk
5 Photonics Research Center, Department of Electrical Engineering, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong SAR, China; eeaptlau@polyu.edu.hk
* Correspondence: jinlongwei2@huawei.com; Tel.: +49-89-1588344227

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We live in an era of information explosion and digital revolution that has resulted in rapid technological developments in different aspects of life. Artificial intelligence (AI) is playing an increasingly important role in this digital transformation. AI applications require edge cloud computing with low latency connections, where the significant challenge is that it needs a lot of computer processing power. Recently, the implementation of AI based on optics hardware [1–5] has become a popular topic due to its fundamentally lower power consumption and faster computation.

On the other hand, as the underlying basis of modern tele- and data-communications, optical networking becomes more and more complex, driven by more data and more connections. Generating, transmitting, and recovering such high-volume data requires advanced signal processing and networking technologies with high performance and cost-and-power efficiency. AI is especially useful for optimization and performance prediction for systems that exhibit complex behaviors [6–20]. In this aspect, traditional signal processing algorithms may not be as efficient as AI algorithms. AI methods have recently entered the field of optics, ranging from quantum mechanics to nanophotonic, optical communication, and optical networks.

The Special Issue is launched to bring optics and AI together to address the challenges that each face, which are difficult to address alone. There are 12 selected contributions for the special session, representing the fascinating progress in the combined area of optics and AI, ranging from photonic neural network (NN) architecture [5] to AI-enabled advances in optical communications including both physical layer transceiver signal processing [10–17] and network layer performance monitoring [18,19], as well as the potential role of AI in quantum communications [20].

Photonic neural network architecture: Bin Shi and co-workers proposed a novel photonic accelerator architecture based on a broadcast-and-weight approach for a deep NN through a photonic integrated cross-connect [5]. A three-layer NN for image classification was tested and it shows that each photonic neural layer can achieve an accuracy higher than 85%. It offers insights for the design of scalable photonic NNs to a higher dimension for solving higher complexity problems.

The applications of AI, especially machine learning in the field of optical communications, are more popular as reflected in the book. At the physical transceiver layer, the most discussed topic is the use of machine learning for various linear and nonlinear effects mitigation in optical communication systems ranging from short-reach to long-haul applications.

AI for short-reach optical communications: For short visible light communications, Chen Chen et al. introduced a probabilistic Bayesian learning algorithm to compensate the light-emitting diode

(LED) nonlinearity [10]. Maximilian Schaedler and his colleagues investigated a deep NN-based nonlinear equalizer in a single lambda 600Gbps coherent short-reach link and show its superior performance compared with the conventional Volterra nonlinear equalizer [11]. Stenio M. Ranzini and co-workers focused on machine learning-aided tunable chromatic dispersion compensation using a hybrid optical and digital structure in a high-speed short-reach optical link [12]. Specifically, Haide Wang and collaborators presented an interesting work, where the NN itself was not used, but its widely used optimization approaches including the batch gradient descent (BGD) method, adaptive gradients (AdaGrad), root mean squared propagation (RMSProp), and adaptive moment estimation (Adam) algorithms were examined and compared in a traditional gradient decent equalizer to significantly speed up and stabilize the filter tap coefficient convergence [13].

AI for medium- and long-reach optical communications: For up to 100 km single mode fiber (SMF)-based applications like data center interconnects, Rebekka Weixer et al., proposed a support vector machine-based detection of signals and its combination with the Volterra nonlinear detection, which shows the best trade-off between performance and complexity [14]. For a long-reach optical access network, Ivan Aldaya and co-workers presented a novel denominated histogram-based clustering algorithm to identify the borders of the high-density areas of the constellation and to classify the nonlinearly distorted noisy constellations [15]. For long-haul applications, one of the major issues is the fiber nonlinearity. Elias Giacoumidis et al. proposed a density-based spatial clustering of applications with noise (DBSCAN) algorithm to address this challenge, which shows a significant performance improvement compared with conventional K-means clustering [16]. In another work, Mutsam A. Jarajreh indicated that compared to the Volterra nonlinear equalizer, an NN was shown to be able to relax the requirement on other system parameters such as the signal quantization bits and clipping ratio, which is valuable for practical implementation [17].

AI for optical performance monitoring: At the network level, Xiaomin Liu and teammates presented a review which discussed the advanced optical performance monitoring enabled by AI-based modeling and prediction approaches to maximize the quality of transmission and resource utilization efficiency of elastic optical networks [18]. Then, concrete use cases are followed. Moreover, Qianwu Zhang and co-workers dedicate their work to the modulation format identification and optical signal-to-noise ratio monitoring of an optical link based on the K-nearest neighbor algorithm, which shows a similar performance, but requires less computing power compared with using the artificial NN [19].

AI for quantum communications: Finally, the book also includes an interesting work from Panagiotis Giounanlis et al. on photon entanglement [20], where how AI plays a constructive role remains a question for the interested readers to think about.

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References

1. Geoffrey, W.B. A role for optics in AI hardware. *Nature* **2019**, *569*, 199–200.
2. Shen, Y.; Harris, N.C.; Skirlo, S.; Prabhu, M.; Baehr-Jones, T.; Hochberg, M.; Sun, X.; Zhao, S.; Larochelle, H.; Englund, D.; et al. Deep learning with coherent nanophotonic circuits. *Nat. Photonics* **2017**, *11*, 441–446. [CrossRef]
3. Sacha, G.M.; Varona, P. Artificial intelligence in nanotechnology. *Nanotechnology* **2013**, *24*, 452002. [CrossRef] [PubMed]
4. Cheng, Q.; Kwon, K.; Glick, M.; Bahadori, M.; Carloni, L.P.; Bergman, K. Silicon Photonics Codesign for Deep Learning. *Proc. IEEE* **2020**, *108*, 1–11. [CrossRef]
5. Shi, B.; Calabretta, N.; Jordan, R.S. Numerical Simulation of an InP Photonic Integrated Cross-Connect for Deep Neural Networks on Chip. *Appl. Sci.* **2020**, *10*, 474. [CrossRef]

6. Mata, J.; Miguel, I.; Barroso, R.J.D.; Merayo, N.; Singh, S.; Jukan, A.; Chamania, M. Artificial intelligence (AI) methods in optical networks: A comprehensive survey. *Opt. Switch. Netw.* **2018**, *28*, 43–57. [CrossRef]
7. Khan, F.N.; Fan, Q.; Lu, C.; Lau, A.P.T. An optical communication's perspective on machine learning and its applications. *IEEE J. Lightwave Technol.* **2019**, *37*, 493–516. [CrossRef]
8. Giacoumidis, E.; Lin, Y.; Wei, J.; Aldaya, I.; Tsokanos, A.; Barry, L.P. Harnessing machine learning for fiber-induced nonlinearity mitigation in long-haul coherent optical OFDM. *Future Internet* **2019**, *11*, 2. [CrossRef]
9. Pu, G.; Yi, L.; Zhang, L.; Hu, W. Intelligent programmable mode-locked fiber laser with a human-like algorithm. *Optica* **2019**, *6*, 362–369. [CrossRef]
10. Chen, C.; Deng, X.; Yang, Y.; Du, P.; Yang, H.; Zhao, L. LED Nonlinearity Estimation and Compensation in VLC Systems Using Probabilistic Bayesian Learning. *Appl. Sci.* **2019**, *9*, 2711. [CrossRef]
11. Schaedler, M.; Bluemm, C.; Kuschnerov, M.; Pittalà, F.; Calabrò, S.; Pachnicke, S. Deep Neural Network Equalization for Optical Short Reach Communication. *Appl. Sci.* **2019**, *9*, 4675. [CrossRef]
12. Ranzini, S.M.; Ros, F.D.; Bülow, H.; Zibar, D. Tunable Optoelectronic Chromatic Dispersion Compensation Based on Machine Learning for Short-Reach Transmission. *Appl. Sci.* **2019**, *9*, 4332. [CrossRef]
13. Wang, H.; Zhou, J.; Wang, Z.; Wei, J.; Liu, W.; Yu, C.; Li, Z. Optimization Algorithms of Neural Networks for Traditional Time-Domain Equalizer in Optical Communications. *Appl. Sci.* **2019**, *9*, 3907. [CrossRef]
14. Weixer, R.; Koch, J.; Plany, P.; Ohlendorf, S.; Pachnicke, S. Mitigation of Nonlinear Impairments by Using Support Vector Machine and Nonlinear Volterra Equalizer. *Appl. Sci.* **2019**, *9*, 3800. [CrossRef]
15. Aldaya, I.; Giacoumidis, E.; Oliveira, G.; Wei, J.; Pita, J.L.; Marconi, J.D.; Fagotto, E.A.M.; Barry, L.; Abbade, M.L.F. Histogram Based Clustering for Nonlinear Compensation in Long Reach Coherent Passive Optical Networks. *Appl. Sci.* **2020**, *10*, 152. [CrossRef]
16. Giacoumidis, E.; Lin, Y.; Jarajreh, M.; O'Duill, S.; McGuinness, K.; Whelan, P.F.; Barry, L.P. A Blind Nonlinearity Compensator Using DBSCAN Clustering for Coherent Optical Transmission Systems. *Appl. Sci.* **2019**, *9*, 4398. [CrossRef]
17. Jarajreh, M.A. Reduced-Complexity Artificial Neural Network Equalization for Ultra-High-Spectral-Efficient Optical Fast-OFDM Signals. *Appl. Sci.* **2019**, *9*, 4038. [CrossRef]
18. Liu, X.; Lun, H.; Fu, M.; Fan, Y.; Yi, L.; Hu, W.; Zhuge, Q. AI-Based Modeling and Monitoring Techniques for Future Intelligent Elastic Optical Networks. *Appl. Sci.* **2020**, *10*, 363. [CrossRef]
19. Zhang, Q.; Zhou, H.; Jiang, Y.; Cao, B.; Li, Y.; Song, Y.; Chen, J.; Zhang, J.; Wang, M. A Simple Joint Modulation Format Identification and OSNR Monitoring Scheme for IMDD OOFDM Transceivers Using K-Nearest Neighbor Algorithm. *Appl. Sci.* **2019**, *9*, 3892. [CrossRef]
20. Giounanlis, P.; Blokhina, E.; Leipold, D.; Staszewski, R.B. Photon Enhanced Interaction and Entanglement in Semiconductor Position-Based Qubits. *Appl. Sci.* **2019**, *9*, 4534. [CrossRef]