STEVENS INSTITUTE OF TECHNOLOGY 1870

Ph.D. DISSERTATION DEFENSE

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Degree: Doctor of Philosophy
School/Department: Charles V. Schaefer, Jr. School of Engineering and Science / Physics
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Title: Hybrid Neural Networks with Nonlinear Optics and Spatial Modes

Chairperson: Dr. Yuping Huang, Department of Physics, School of Engineering &Sciences

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ABSTRACT

The field of spatial optics holds significant promise in the development of next-generation processing units. Its fast propagation speed, low energy consumption, and parallel processing capabilities make it a compelling alternative to electronics. To explore the capabilities more in this area before the technological revolution from electronics to optics, it is important to study the combination between spatial optics and the existing algorithms. Among these algorithms, machine learning, such as neural networks, is of utmost importance due to its exceptional learning capacity and widespread utilization across various tasks. This dissertation focuses on creating Optical Neural Networks (ONNs) for classification and prediction tasks by integrating spatial optics and neural networks. To achieve the desired mode-selective feature extraction and non-linearity for ONNs, the frequency up-conversion techniques of Sum Frequency Generation (SFG) and Second Harmonic Generation (SHG) are implemented. These techniques enable more intricate and richer operations than their linear counterparts.

One of the proposed works in this dissertation is a hybrid image classifier that utilizes both optical mode-selective image conversion (MSIC) and neural networks. MSIC can extract features from each target image by sequentially modifying the spatial structures of pump beams within a nonlinear crystal. The parallel processing capabilities of MSIC and its ability to downsize features further contribute to the system's overall efficiency. An optimized system is also proposed to shift the frequency up-conversion from the Fourier domain to the temporal-Fourier domain, resulting in improved classification accuracy by capturing finer details in extracted features.

The dissertation also showcases a spatial reservoir computer as a means of exploring parallel processing capabilities. Parallel processing is critical in enhancing calculation speed and mitigating the effects of environmental noise in practical machines. However, achieving this property is challenging for most current electronic and temporal-optical systems. This study uses an SHG-involved spatial reservoir computer, which treats a spatial light modulator as an input portal of the reservoir computer and decodes the output through a camera. The spatial reservoir computer is implemented with two parallel mapping methods and can predict multi-step time-series sequences with lower or comparable errors than a one-step prediction, requiring significantly fewer steps.