Executive Summary:

Quantum-enhanced optical learning machine

Category: Information

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The pressing demand for information processing systems with high-bandwidth, high-speed, and energy-efficient capabilities is of considerable significance in the current information era. This has driven the development of alternative computing architectures over the recent decades including analog computing, neuromorphic computing, reservoir computing, extreme learning machines, and quantum computing. Among those, recent progress in optical computing has demonstrated positive results, indicating an efficient way to perform optical neural networks with a sensing capability. In parallel, the research area of quantum metrology has shown the improvement of high sensitivity on diverse optical instruments as well-established examples of gravitational wave detections and many configurations of quantum imaging and spectrometry. One of the experiments is known as the nonlinear SU(1,1) interferometer, proposed in 1986 by Yurke *et al.,* which has garnered significant attention thanks to its presence of sub-shot-noise sensitivity, even in the presence of external loss and a possibility to extend to multimode. Despite the advancements in such classical optical computing and quantum metrology, fundamental questions about the feasibility of exploiting optical quantum effects for information processing and machine learning remain open.

Our research proposal aims to address this challenge by investigating the capability of a quantum optical platform for simultaneously sensing and performing a pattern recognition task. We propose the development of an optical apparatus - the "*quantum-enhanced optical learning machine*". It consists of a cascade of multimodal optical parametric amplifiers, interspersed with a linear optical circuit and reconfigurable optical phase arrays. One layer of the optical machine is the reconfigurable multimode nonlinear SU(1,1) interferometer. We aim to explore the intricate interference between signal and idler radiations in the cascade setting. By implementing linear optical circuits, one can adjust the relative phases between the optical pump, signal, and idler fields of spatial modes of optical parametric amplifiers; hence enabling us to control the de/amplification and quantum correlation of parametric downconversion light in the circuit. Using the quantum effect, we aim to show the feasibility study of the high sensitivity of phase imaging beyond the standard quantum limit. Moreover, the learning capability and trainability of the optical machine will be investigated to estimate the potential and limitations of the machine in terms of measurement sensitivity, expressibility, and trainability. With those successes, we aim to showcase an application of the optical machine for simultaneous sensing and performing pattern recognition tasks.

The outcomes of the research project could have a far-reaching impact on our understanding of the role of the quantum effect presented in cascaded OPAs on simultaneously sensing and information processing with a possibility to address the global demand in sensing and computing.