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Ph.D. DISSERTATION DEFENSE

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Title: Compressive Photon Measurement for Machine Learning

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ABSTRACT

Artificial intelligence (AI) requires more energy for its rapid development. Saving energy in detection and machine learning part is imminent. We study how photon-counting noises degrade a single-pixel optical classifier via compressive sensing, and how its performance can be restored by using quantum parametric mode sorting (QPMS).

Using modified National Institute of Standards and Technology (MNIST) handwritten digits as an example, we examine the effects of detector dark counts and in-band background noises and demonstrate the effectiveness of mode filtering and upconversion detection in addressing those issues. We achieve 94% classification accuracy in the presence of 500 times stronger in-band noise than the signal received. To reveal in the information contained in targets, we take advantages of deep neural networks (DNN) for image construction. We benchmark our approach in a telecom-LiDAR system against that using direct photon counting detection. Our results show that with only 25 sampling patterns (corresponding compression ratio ~0.043%, QPMS plus DNN give peak signal-to-noise ratio and structural similarity index measure on average above 22 dB and 0.9, respectively, much higher than those with direct detection (DD). The details of our targets from QPMS are more clearly compared with from DD. Notably, such high performance is sustained even in the presence of 500 times stronger in-band background noise, while DD fails. The high efficiency and robust noise rejection promise potential applications in various fields, especially in photon-starving scenarios.

Optical Neural Network (ONN) is extremely attractive as an alternative to develop AI since it could save energy. Augmenting photon detection technology with ONNs offers a promising avenue for realizing these networks at the single-photon level. We explore how ONNs utilizing quantum optics can execute tasks by leveraging the arrival of the first photon within each time window, a methodology we term "first photon machine learning." Using MNIST dataset as an illustration, we implement an ONN comprised of one-layer Hermite-Gaussian (HG) modes and QPMS. We achieved 35.63% conditional probability from our experiment setup while classical one photon detection in simulation is just around 22.65% if we must decide after detecting the first photon from an optical system.