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Ph.D. DISSERTATION DEFENSE

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Title: Quantum Parametric Detection for Hyperdimensional Sensing

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

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ABSTRACT

Active optical sensors capable of faithful operation under challenging conditions, such as strong background radiation or complex scattering environments, are highly desirable for remote sensing applications spanning diverse domains. Examples such as long-range terrestrial mapping, orbital seismology, or non-invasive biomedical imaging, additionally include extreme photon starvation of the probing signal, creating conditions that can be prohibitively challenging for conventional sensors based on linear optics. In this work, we address these challenges by demonstrating a novel sensing system, based on nonlinear optics, that is capable of simultaneous three-dimensional imaging and vibrometric profiling, with single-photon sensitivity and exceptional tolerance to various sources of noise. This nonlinear optical system utilizes Quantum-Parametric-Mode-Sorting (QPMS), a nascent technique for selective detection of individual signal photons over spectro-temporally overlapping photons that would produce interfering noise for other systems based on linear optics.

This work demonstrates a QPMS-based imager that can reliably reconstruct the surface morphology of targets behind highly scattering obscurants with millimeter depth resolution, due to nonlinear optical time-gating of picoseconds pulses. Utilizing mode-selective upconversion in a lithium niobate waveguide, we demonstrate noise-tolerant imaging where few signal photons are embedded in 34-fold spectro-temporally overlapping background photons, which amounts to over 100,000 times more background photons per probe pulse.

After introducing the QPMS-based imager, the dimensionality of its sensing capabilities is extended to include vibrometric measurement that resolves the time-varying intensity fluctuations caused by surface vibrations. We show that depth-resolved vibrometric profiling of can be performed by calculating the vibration spectra as a function of the optical gating. Using the vibrometric signature as a contrasting mechanism, we demonstrate a 20 dB improvement in detecting a vibrating target behind a strongly scattering obscurant.

This research lays the foundations for a novel detection modality that may be adapted for a variety of applications.