Real Time Quantum Imaging via Compressed Sensing

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Abstract: We demonstrate quantum imaging in real time by measuring quantum noise reduction frame by frame in a moving quantum image. We obtain and reconstruct quantum images using a compressed measurement technique, demonstrating quantum compressive imaging.
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1. Introduction

One of the most important metrics in imaging is resolution, or the level of discernible detail. In low light scenarios, it is difficult to obtain images with high resolution: low light levels result in low contrast, making discernment of details a complicated task. The maximum level of detail in all images is directly influenced by the amount of noise present in the light used to read an image, which has a fundamental classical noise floor known as the shot noise limit. Shot noise, which arises from the particle nature of light, is most problematic for weak imaging fields. However, quantum noise reduction can be exploited in order to overcome this limit [1]. Quantum noise reduction (or "squeezing") stems from quantum correlations between light beams that cannot exist classically.

Recently quantum imaging below the shot noise limit has been achieved using CCD cameras and discrete photons [2]. Such implementations require long integration times due low photon flux and the need to illuminate all pixels simultaneously. Further, cross correlations between spatial modes must be done in post processing. We have developed a method which adapts compressed sensing to the problem of differential quantum imaging. Our method relies on replacing the CCD cameras with digital mirror arrays, where each pixel is replaced by a micromirror which can direct light towards or away from a detector. By applying patterns to the array, different sampling functions can be applied to the incident light field and a compressive imaging measurement can be performed [3]. Through judicious choice of sampling functions, image acquisition can be sped up by an order of magnitude or more, enabling real time quantum imaging. Our experiment relies on multimode twin beams for quantum correlations. Thus, we perform differential compressive imaging with two mirror arrays and detectors to exploit quantum noise reduction.

2. Experimental configuration and results

Our squeezed light source is based on four wave mixing in rubidium vapor (see Fig. 1) in which a weak probe field interacts with a strong pump and is amplified. It produces many spatially correlated modes of light in twin beams, a main requirement for imaging, and it produces very highly quantum correlated light, which is the basis for increased sensitivity in the images [4]. After production of multimode light, the fields can be used for differential quantum imaging, with the CCDs replaced by compressive imagers in this case.

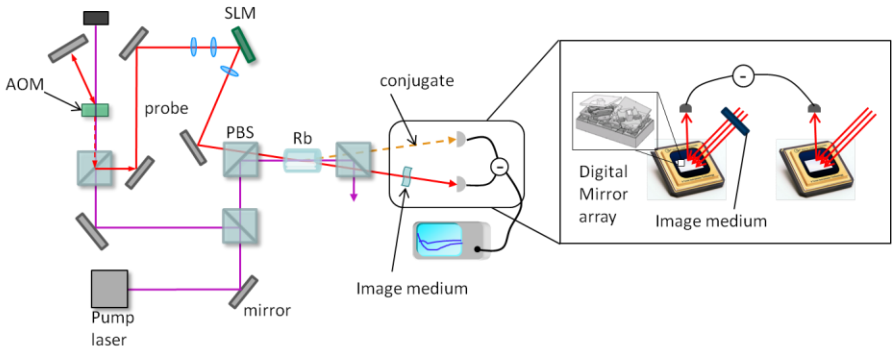

Figure 1: Four wave mixing and compressive quantum imaging experiment schematic. AOM: acousto-optic modulator; SLM: spatial light modulator; PBS: polarizing beam splitter; Rb: rubidium vapor cell. Inset: close up of detection apparatus consisting of micromirror arrays and detectors, comprising compressive imagers.

The nonlinear four wave mixing interaction is based on a double lambda system between the hyperfine ground states and the D1 excited states. The atoms absorb two photons from the pump beam (denoted by "P" in Fig. 2), which builds coherence between the two ground state levels. The presence of a probe beam ("pr" in Fig. 2)

stimulates emission of photons into the probe frequency, and due to energy conservation the atoms must emit into a third frequency, the conjugate beam (called "C" in Fig. 1). The process is coherent, and the probe and conjugate photons are emitted simultaneously, resulting in quantum correlations. Our source currently is capable of 4.1 dB of quantum noise reduction using 82% efficient detectors. We expect to increase the amount of observable squeezing to ~9 dB with >95% efficient detectors.

We will report our recent results in real time quantum imaging, including demonstration of frame by frame correlations in subsequent, time dependent quantum images produced using a spatial light modulator on the imaging cell input.

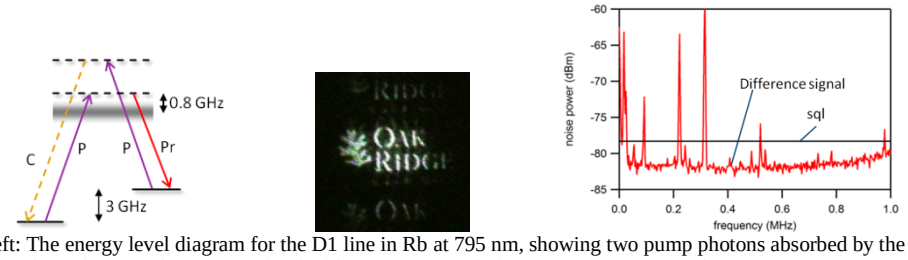

Figure 2. Left: The energy level diagram for the D1 line in Rb at 795 nm, showing two pump photons absorbed by the vapor and two subsequent "probe" and "conjugate" photons reemitted with quantum correlations. Middle: an image frame imprinted on the probe beam by the SLM. Right: a squeezing spectrum of a single frame obtained with twin multimode imaging beams showing 4.1 dB of noise reduction.

We will also report our latest results in differential compressive imaging, in which two compressive imaging detectors are used. We will compare and contrast the cases of intensity differencing after each sample (before reconstruction) versus in post processing in order to illuminate the most optimal case for differential quantum imaging.

4. References

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