Study of scientific Complementary Metal–Oxide–Semiconductor (sCMOS) camera and few photons imaging

Author : Techit Sitthiwong , Advisors : Assistant Professor Dr. Waranont Anukool , Dr. Parinya Udommai

[1]Department of Physics, Chiang Mai University, Chiang Mai Thailand
[2] Quantum-Atom Optics Laboratory, Chiang Mai University , Chiang Mai Thailand

FACULTY OF SCIENCE
CHIANG MAI UNIVERSITY

Abstract

Imaging phenomena involving a few photons imaging require cameras with high sensitivity and low noise. Example for this task is imaging of photons emitted from the single atom traps in quantum atom research. This is crucial in control and manipulation of atoms in the atom quantum computer and simulator system. The Scientific Complementary Metal–Oxide–Semiconductor (sCMOS) camera is technology in scientific images, offering a wide dynamic range and high frame rate. In this study, the Sona 4.2B-6 sCMOS camera model is used to investigate low-photons imaging. The 780 nm diode laser is utilized along with series of polarizing variable attenuators to reduce the laser intensity to achieve low photon counts. The Andor Solis software is used to capture photons signal images obtained with the Sona 4.2B-6 sCMOS camera model and analyze with Fast Fourier Transform (FFT) technique to eliminate noise from image. In conclusion, the parameters of the experiment that affects the generation of a few photons is the input of laser power before the attenuator system. The optimal input power for generating a low photon signal was determined to be determined to be 30±0.5 μW and attenuator factor of $((4.1235 \pm 0.3684) \times 10^{-10})$,producing around 20 photons at the camera with exposure time of 20 milliseconds. In the image processing, a FFT technique can be used for noise reduction, whereas the processed image can also loss some detail due to filtering process with filters.

Introduction

Imaging phenomena involving only a few photons is a significant challenge in quantum physics research. One example is imaging photons emitted from single trapped atoms. Detecting and capturing these photons requires a highly sensitive camera with a wide dynamic range and low noise, both of which are essential for quantum atomic research. In this study, we simulated the detection of low-photon signals using a laser diode as the light source, with its power attenuated to generate a weak photon signal. The detection was performed using an sCMOS camera and explored techniques to reduce noise from the images.

Experiment

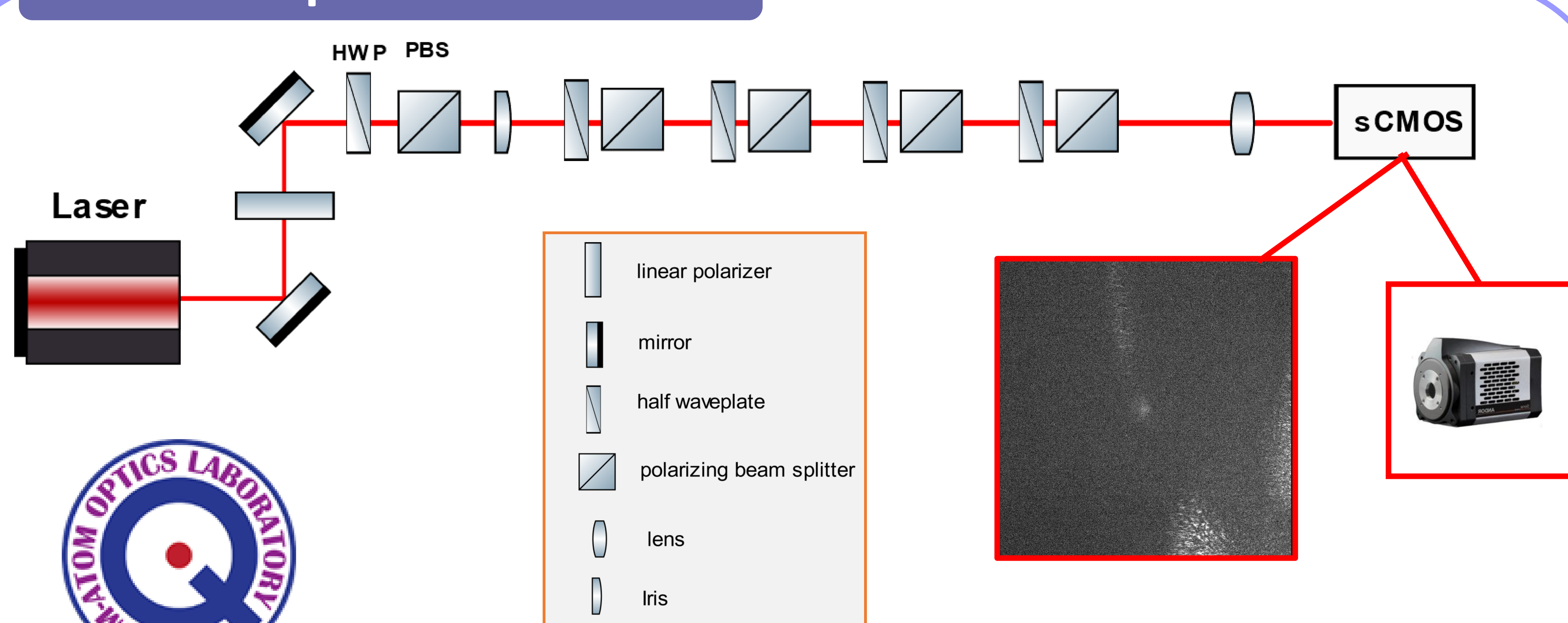

Fig 1: Experiment setup

- This study simulated low-photon signal detection using a series of HWP-PBS pairs to attenuate the laser power. Key parameters included the laser input power and the attenuator factor
- The detection of photons signal, a Sona 4.2B-6 sCMOS camera was utilized. The acquisition and photon signal imaging were conducted using Andor Solis.
- For image processing, the Fast Fourier Transform (FFT) technique and filters were used to reduce noise from image acquisition.

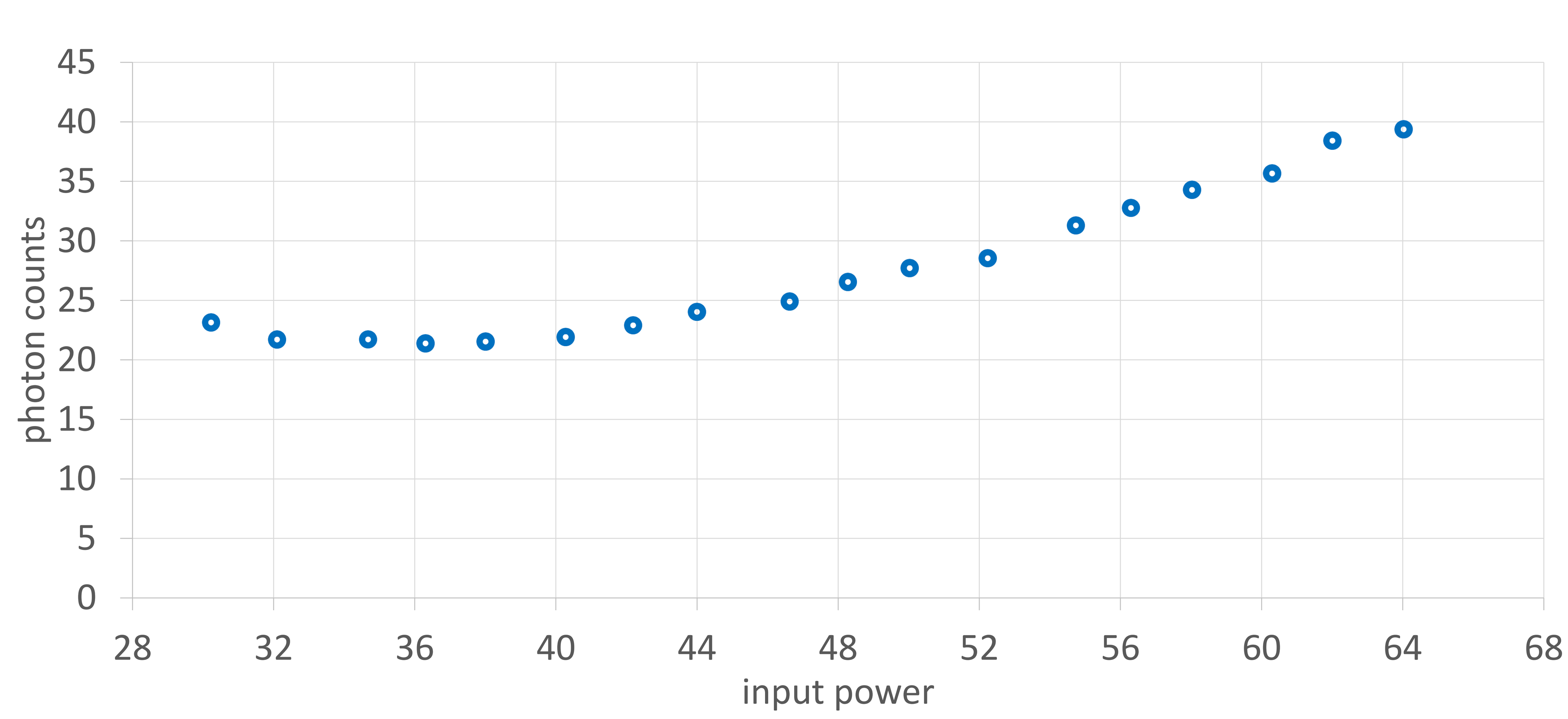

Fig 2: Relationship between input power and photon counts per pixel

- From the graph, the optimal input power for generating a low-photon signal was determined to be 30±0.5 μW. The attenuator factor was $((4.1235 \pm 0.3684) \times 10^{-10})$, producing approximately 20 photons per an exposure time of 20 milliseconds.

Result & Discussion

Image processing using FFT and applied filters at an input power of 30 μw

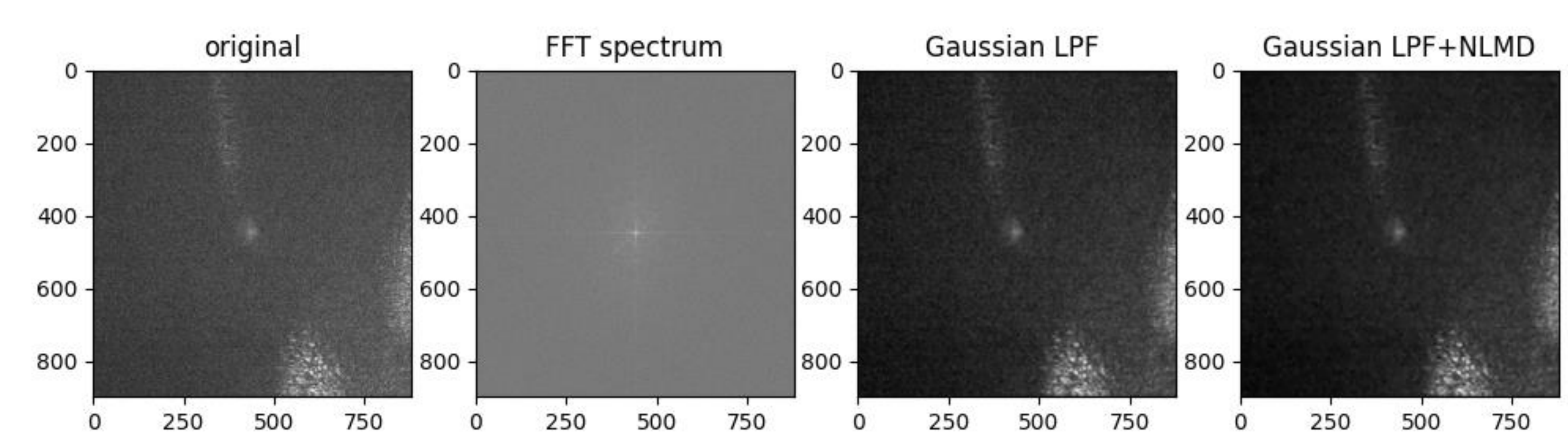

Fig 3: Results of FFT technique with Gaussian low-pass filter and non-local means denoising for noise reduction

- Applying FFT transforms spatial data into the frequency domain, where low frequencies define structure and high frequencies capture details. A Gaussian low-pass filter (GLPF) removes high frequencies to reduce noise, while non-local means denoising (NLMD) further minimizes noise while maintaining details

X and Y cross-sections of the processed image at an input power of 30 μw

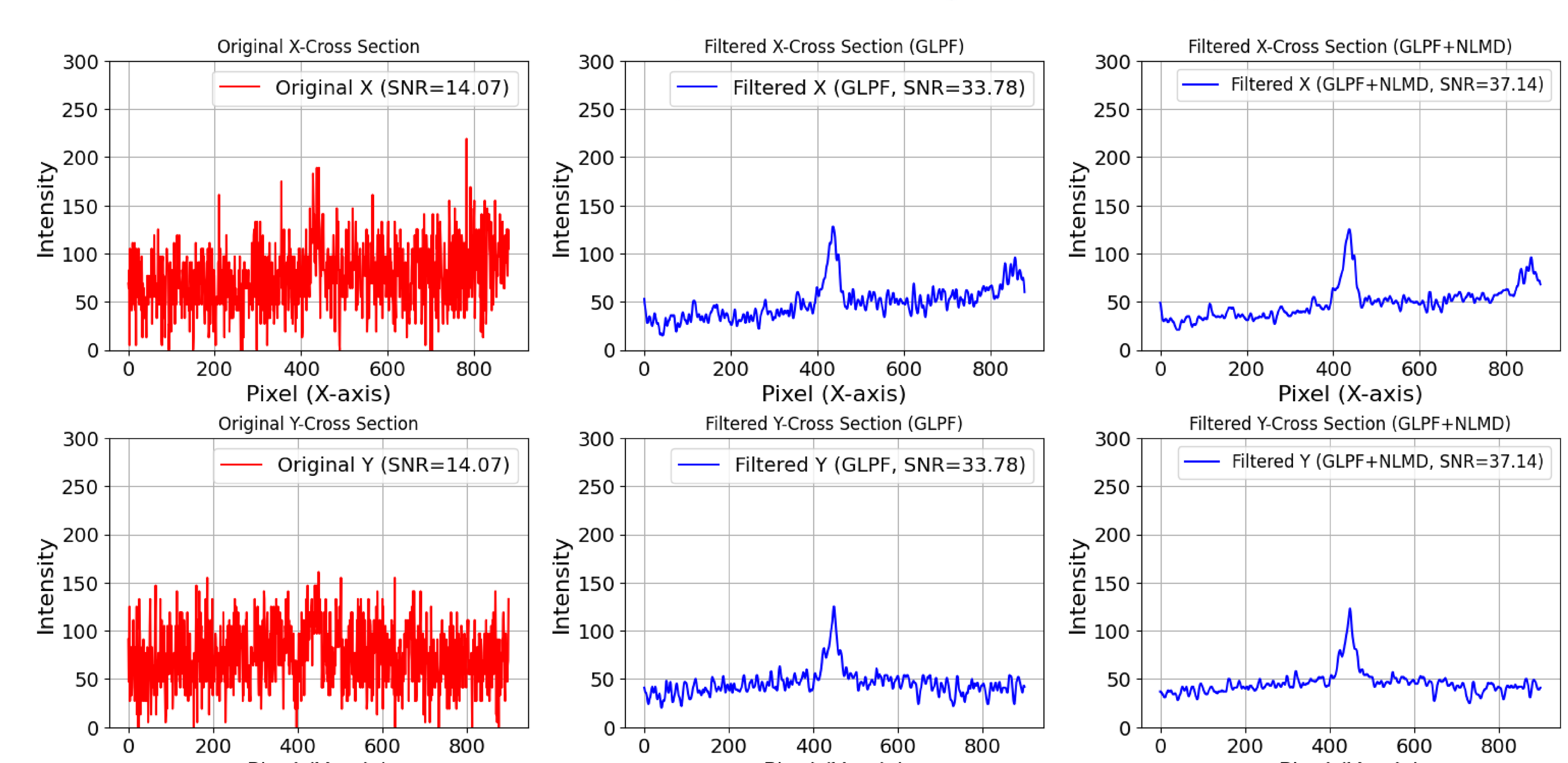

Fig 4: Comparison SNR of the cross-section results using the FFT technique with Gaussian low-pass filter and non-local means denoising

- The results from comparing the use of GLPF and GLPF+NLMD show that the Signal-to-Noise Ratio (SNR) of the original image is 14.07. Using GLPF improves noise reduction as the SNR increases to 33.78, while applying GLPF+NLMD further increases the SNR to 37.14, resulting in more effective in noise reduction than using GLPF individually.

Conclusion

- The key parameters of the experiment that affect the generation of a few photons are the input laser power before the attenuator system and the attenuator factor $((4.1235 \pm 0.3684) \times 10^{-10})$.
- In image processing, the FFT technique can reduce noise. However, the processed image can also lose some details due to the filtering process.
- From the comparison of SNR in the cross-section images, the use of the GLPF+NLMD filter achieves better noise reduction, as the SNR increases from 14.07 to 37.14.

Reference

[1] Picken, C. J., Legaie, R., & Pritchard, J. D. (2017). *Single atom imaging with an sCMOS camera*. University of Strathclyde.
[2] Andor Technology Ltd. (2024). *Sona and Marana Hardware Guide B-6 Models (Version 1.4, October 8, 2024).*