Application Note

Feasibility of using a scientific CMOS camera for two-state imaging of imbalanced ultracold Fermi gases

T. Lompe, Quantum Matter Group, Institute of Laser Physics, University of Hamburg, Germany (October 2019)

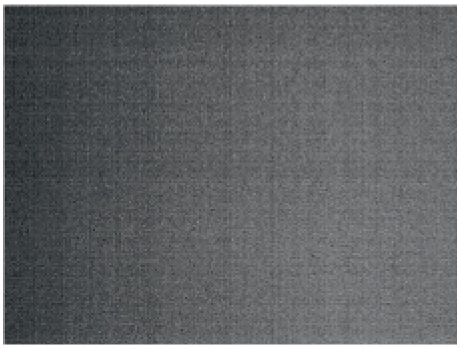
Introduction

High-resolution imaging of spin-imbalanced ultracold Fermi gases of 6Li poses a unique set of challenges: Since Lithium is a very light atom, only very few photons can be scattered before the photon recoil will start to distort the density distribution of the atoms. Hence the number of photons incident on each camera pixel is limited to values on the order of ten to a hundred photons at the most and consequently a camera with high quantum efficiency and low readout noise is required. As an additional experimental requirement, two images of the atomic distributions of the atoms in the two different spin states need to be taken in quick succession with a time delay of far below 100 µs. This timing requirement excludes using Frame Transfer CCDs and the quantum efficiency and readout noise requirements make Interline CCDs unattractive.

The Andor Zyla-5.5-USB3 scientific CMOS (sCMOS) camera offers a very low readout noise <2 e- in Global Shutter mode and allows for taking two images with a time delay in the microsecond range, which makes it appear to be ideally suited for this application.

Post-processing Andor Zyla images to remove fixed-pattern noise in PIV-mode

The Zyla-5.5 offers the PIV-mode, which allows to take two successive images with an interframe time of less than 2 µs. To achieve this, the camera is used in Global Shutter mode and the illumination of the exposure is controlled externally. However, in the Global Shutter mode the techniques that applied to eliminate fixed pattern noise in Rolling Shutter mode cannot be applied. Fig. 1a shows a typical dark image from the Zyla-5.5 in Global Shutter mode, which exhibits significant fixed pattern noise, Fig. 1b shows an absorption image of a low-density homogenous ultracold Fermi gas of 6Li atoms.



1a

1b

Fig. 1a and 1b. Caption: (a) Dark image taken with a Zyla-5.5 in Global Shutter mode. The fixed pattern noise is clearly visible. (b) Absorption image of a dilute 2D Fermi gas of 6Li atoms at 671 nm. Due to the low number of photons on the sensor the noise in the images is dominated by the fixed pattern noise of the chip.

The imaging was performed at the optimal imaging intensity of I/I_sat ~ 1 with a frequency-chirped imaging pulse to alleviate the effect of the Doppler shift due to acceleration of the atoms due to the recoil of the imaging photons as described in [1]. The fixed pattern noise of the camera is clearly visible in the image.
Since the fixed pattern noise varies randomly between images, we cannot remove it by taking and subtracting a reference image. We therefore extract and subtract the fixed pattern noise from each individual image. To achieve this, we make use of the fact that the noise varies from row to row and column to column, while the spatial variations of the imaging light generally have lower spatial frequencies. Our approach is therefore to use a low-pass filter to create a smoothed version of the image and then determine the gain and offset modification for each individual line and column that are required to make the original image as similar as possible to the smoothed image. However, this problem consists of several thousand coupled equations and is not solvable in the experimentally required timeframe.

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We therefore separate the problem into sequentially optimizing the rows and then the columns, which significantly reduces the computational cost and allows us to reduce the processing time to about ten seconds. Fig. 2 shows the resulting processed image, where the fixed pattern noise has been strongly reduced.

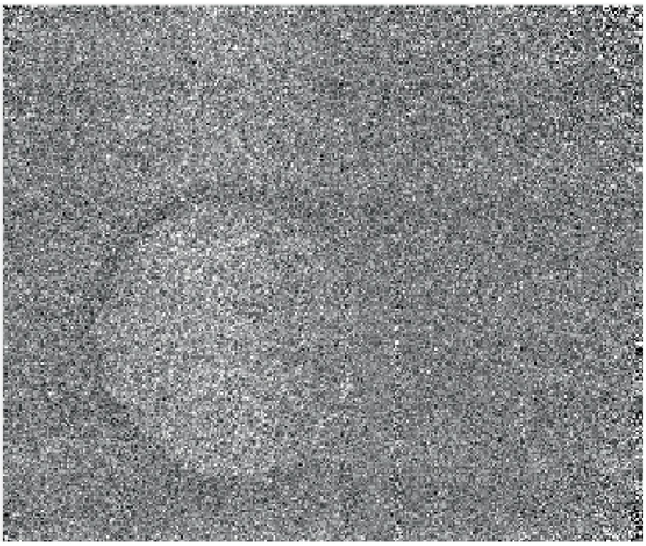

Fig. 2: Absorption Image after the image processing. The fixed pattern noise has been reduced significantly.

In conclusion, the issues related to using the Zyla-5.5 in the Global Shutter mode in low-light applications can be mitigated to some extent by post-processing the images. However, this comes at the cost of relatively long processing times for each image and can introduce distortions into the image which might lead to spurious signals especially in measurements of pixel-to-pixel correlations. We are therefore still reluctant to use it for our experiments and are currently evaluating other solutions.

References

[1] Klaus Hueck, Niclas Luick, Lennart Sobirey, Jonas Siegl, Thomas Lompe, Henning Moritz, Logan W. Clark, and Cheng Chin, "Calibrating high intensity absorption imaging of ultracold atoms," Opt. Express 25, 8670-8679 (2017)

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