APMC 13
BRISBANE 2025
13th Asia Pacific Microscopy Congress
Brisbane, Australia, February 2-7, 2025

# A Photon-Free Approach for Efficient Camera Noise Correction in Ptychography

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In coherent diffractive imaging (CDI), diffraction patterns of the sample in the far field are captured by pixelated detectors, and then phase retrieval algorithms are used to reconstruct the sample image [1-3]. However, background noise in the recorded diffraction patterns will reduce the resolution and may cause reconstruction failure [4, 5]. For quantitative analysis of the reconstructed sample, pixelwise properties of the camera must be well characterized and accounted for to avoid artifacts.

In this paper, we introduce an automated camera characterization pipeline for automatic noise correction in ptychography, a scanning CDI modality. By combining a physical camera model with a weighted flatfield image model, as shown in Fig. 1(a). Diffraction patterns are collected under various exposure times, with their mean values and variances representing the true signal level and noise level, respectively. In detector systems, signal contributions arise from both dark current and baseline components, where dark current emerges from thermal excitation without external illumination and exhibits linear dependence on exposure time with temperature sensitivity. While baseline offset persists at zero exposure, noise characteristics incorporate exposure-dependent thermal fluctuations alongside inherent readout noise from the detection system. The response range of the pixel can similarly be determined by fitting against time. By fitting these values exposure time, the noise model of the camera at any given exposure can be characterized. Additionally, adopting flatfield allows for fitting the upper boundary of the noise level, the camera-induced noise is significantly reduced and the fine details in diffraction patterns are consequenctly preserved. This photon-free approach does not require specific beam illumination and allows explicit consideration of offset, dark current, and thermal noise at each pixel during image reconstruction.

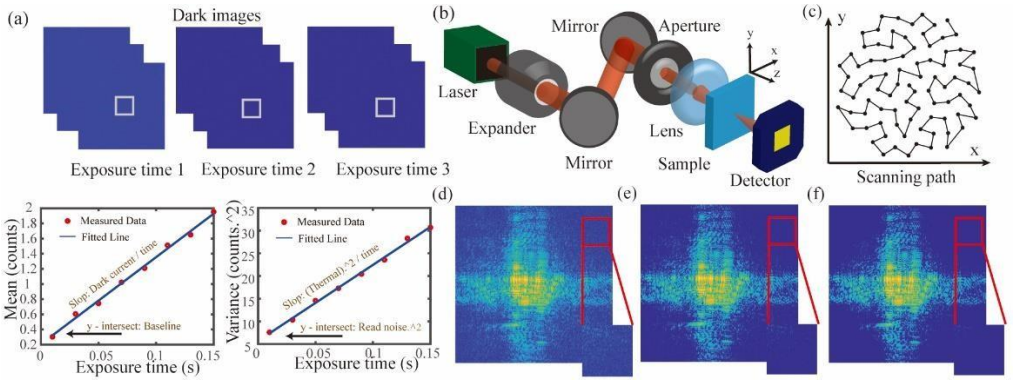



**Fig. 1.** (a) Automated camera characterization via thermally generated signal. (b) The visible light setup for ptychography image. (c) Fermat spiral sweep grid. (d)-(f) Original diffraction pattern and different methods are used to remove noise.

We conducted experiments using the setup depicted in Fig. 1(b). Quasi-monochromatic radiation was produced by a helium-neon laser (Thorlabs-HNL050LB, wavelength 632.8 nm, 5 mW). The beam undergoes expansion and apodization through a diaphragm before being focused by a lens onto the sample, creating a diffraction-limited spot with a diameter of 400 µm. A charge-coupled device (CCD) camera (pixel size: 3.86 µm, 1024 × 1024 pixels) positioned at a specific distance from the sample captures the resulting diffraction pattern. Sample movement follows a Fermat spiral scanning grid as shown in Fig. 1(c), facilitated by a linear motion stage. To ensure sufficient scanning overlap, providing an 80% overlap between adjacent scans. Especially, the distance between sample and detector is 29.6mm. This indicates that our system's Rayleigh resolution ($0.61 * \lambda/\mathrm{NA}$) limit is 6.63 microns. In Fig. 1(d)-(f), we demonstrate the diffraction patterns after denoising using different methods. Fig. 1(d) shows the original diffraction pattern, where background noise permeates throughout the entire image. While averaged dark frame subtraction reduces this noise artifact, as demonstrated in Fig. 1(e), high-frequency noise comparable to the diffraction signals still persists within the red box region. Through establishing a camera noise model and pixel response mapping, it significantly reduces noise as shown in Fig. 1(f).

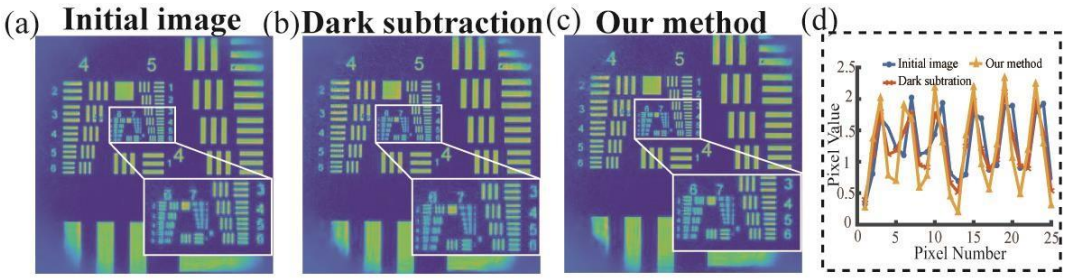



**Fig. 2.** (a) Original image. (b) After removal of camera dark frame. (c) Noise reduction using the proposed method. (d) Comparison of pixel values in a selected region.

As depicted in Fig. 2. Our denoising method achieved the system's physical resolution limit (6.63 microns) with improved feature contrast, outperforming the other approaches such as dark subtraction.

In summary, we fully characterized the camera's intrinsic physical properties using its thermal activation, without requiring any photons to reach the detector. Compared to the conventional dark frame calibration and noise removal method, our approach enabled the final imaging resolution to reach the Rayleigh resolution limit of the optical system.

**References:**

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