Multi-camera Fourier Ptychographic Microscopy

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Abstract: We demonstrate aperture-synthetic diffracted field measurement using multiple mutually incoherent cameras in Fourier ptychography to provide a scaleable increase in data acquisition bandwidth. Our nine-camera system enables an order of magnitude improvement in image acquisition speed.

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Introduction

Digital pathology for rapid patient screening and *in vitro* cell culture studies needs high-throughput microscopy techniques to capture images with the best possible resolution and the widest field-of-view (FOV) [1]. Conventional microscopy is only capable of low-throughput imaging due to an inverse relationship between FOV and resolution. One way to overcome this limitation is via computational imaging techniques such as Fourier ptychography microscopy (FPM) [2], where multiple images of the sample are recorded with varying angular illumination. This angular diversity enables recording of spatial-frequencies higher than the objective's cutoff frequency.

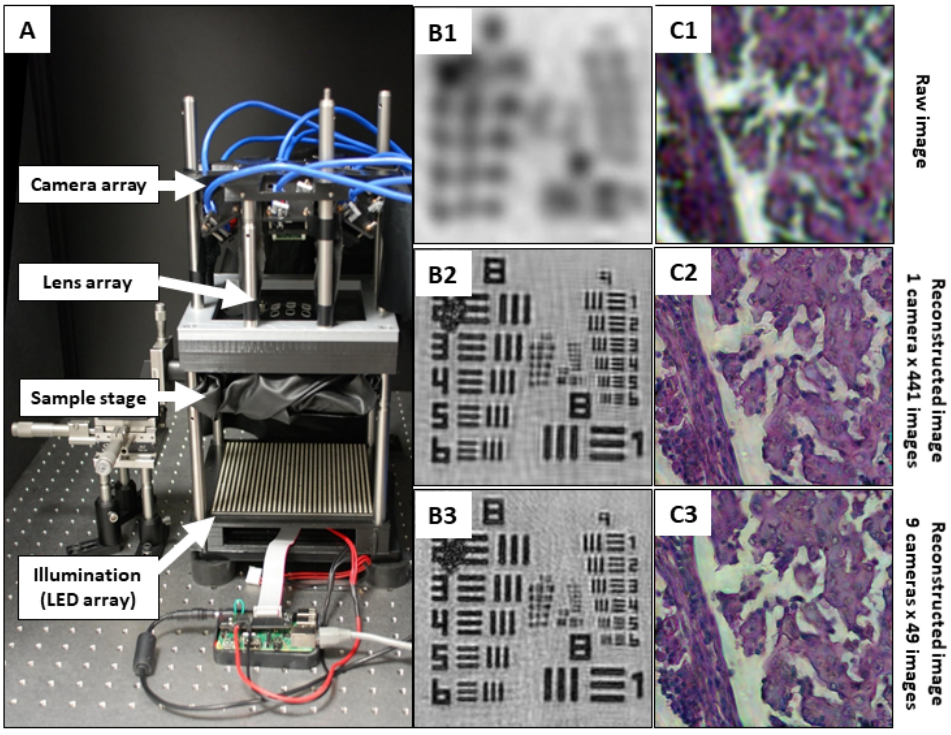

Fig. 1: (A) Experimental setup with sensors and lenses arranged in a Scheimpflug configuration. (B1) USAF resolution chart raw image. FPM reconstruction with (B2) one camera, 441 LEDs and (B3) multi-camera FPM with 9 cameras, 49 LEDs demonstrating near-equivalent resolution improvement. (C1) Raw image of lung carcinoma sample; (C2) reconstruction obtained with standard FPM and (C3) multi-camera FPM indicate comparable reconstruction quality. Image in (C3) was reconstructed using aberrations recovered on a different sample indicating stability and robustness of the experimental setup.

In FPM these low-resolution images are stitched together into a single wide-field, high-resolution amplitude and phase image using Gerchberg-Saxton-Fienup phase retrieval algorithms.

The requirement for multiple (usually hundreds of) images makes FPM unsuitable for imaging non-static samples. Attempts were made to improve image acquisition speed with LED multiplexed FPM [3] demonstrating full FPM data-set acquisition times of under a second [4]. But this requires expensive custom hardware and it did not achieve single snapshot imaging. Our approach implements multiple cameras for the image capturing process to improve the data bandwidth, reducing image capture times by a factor of N (number cameras). Viability of such a FPM technique has been demonstrated by translating a single camera to mimic a 9 camera system [5]. We present an implementation with 9 parallel cameras, which enables an order of magnitude improvement in image acquisition speed without sacrificing reconstructed image quality. It can also be integrated with current state-of-the-art FPM techniques - such as LED multiplexing - providing a bridge towards video-rate gigapixel imaging.

Experimental setup and results

We present a 3D-printed multi-camera FPM prototype with 9 individual cameras shown in Fig.1(a). The cameras and lenses are arranged in a Scheimpflug configuration [6] (commonly used for distortion correction in projectors) to reduce aberrations present in off-axis imaging systems. While FPM can recover aberrations computationally [7], it requires a good initial estimate in the presence of severe aberrations, which becomes even more important for multi-camera systems. Moreover, alignment of a 3D-printed 9 camera system is challenging and correction of these errors requires additional computational algorithm complexity. Our calibration and reconstruction procedures provide a robust platform error correction platform required for high-quality image reconstruction.

We have demonstrated that our multi-camera FPM prototype can reconstruct wide-field, high-resolution images, using 9 cameras (each one capturing 49 images), with equivalent reconstruction quality of a single camera FPM (capturing 441 images). Quantitative resolution improvements can be seen in the USAF target reconstructions (Fig.1(b)), where standard FPM (Fig.1(b2)) and multi-camera FPM (Fig.1(b3)) were able to resolve group 9 element 6 ($1.1\mu m$). While both methods have the same resolving power, multi-camera FPM is capable of 9 times faster image acquisition speeds enabled by parallel image acquisition.

For image reconstruction to be successful, multi-camera FPM requires optical aberrations to be known for each camera. Computational aberration recovery in FPM requires hundreds of images, but for high-speed applications such data redundancy is not practical. To reconstruct a lung carcinoma sample using multi-camera FPM (Fig.1(c2)) we recovered aberrations by imaging a different biological sample obtained days earlier. The reconstructed image quality was equivalent to those of standard FPM (Fig.1(c3)). This indicates that the lengthy calibration procedure is required only once and it remains stable for long periods of time despite using 3D-printed parts.

Conclusion

With our multi-camera FPM microscope we reconstructed images with ($1.1\mu m$) resolution. Routine hardware optimisation can provide an order of magnitude image acquisition speeds improvement, which scales with the number of cameras used providing a customizable imaging platform. More importantly this technique can be applied to current state-of-the-art FPM techniques to improve image acquisition speed even further. This presentation will expand upon the results shown here and share our experience of calibration and reconstruction techniques, which is of practical interest to the general FPM community. Latest experimental results towards video-rate FPM imaging will also be presented.

References

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