Multi-Frame Motion Imaging for Optical Microscopy

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Computational imaging involves the jointly optimized design of both imaging hardware and post-processing algorithms to enable fast, simple, and high-quality imaging modalities. In microscopy, computational imaging using coded illumination has recently been employed for a wide range of applications, including fast multi-contrast imaging [1, 2]. While some applications of coded illumination use steered laser beams or other coherent sources to project a pattern or angled wavefront onto the sample, more recent work has employed a programmable LED light source due to their low-cost, simple implementation, fast update speed, and good light-throughput

Inspired by flutter shutter photography [3], a recent publication considered the application of LED array illumination to motion deblurring, where the sample moves during the camera exposure. LED array illumination is globally modulated in order to structure the motion blur in such a way that it can be inverted [4]. Here, we propose a framework for high speed, high-throughput imaging using continuous motion and multiple frames, enabling significant speed increases compared to conventional stop-and-stare techniques, while also improving SNR over strobed illumination. In our method, the sample is in constant motion, being raster scanned quickly across a large field-of-view using a commercial XY stage during each exposure. These methods significantly enhance the space-bandwidth product (SBP) per unit time compared to conventional slide-scanning systems because the sample is in continuous motion, avoiding stop-and-stare behavior. By choosing design our illumination sequence during each exposure, we can optimize the scan strategy for optimum reconstruction SNR. To validate this method, we demonstrate a complete scan of a standard microscope slide in under 10 minutes with a $20\times$ objective, and compare it against strobed and stop-and-stare techniques on the same system.
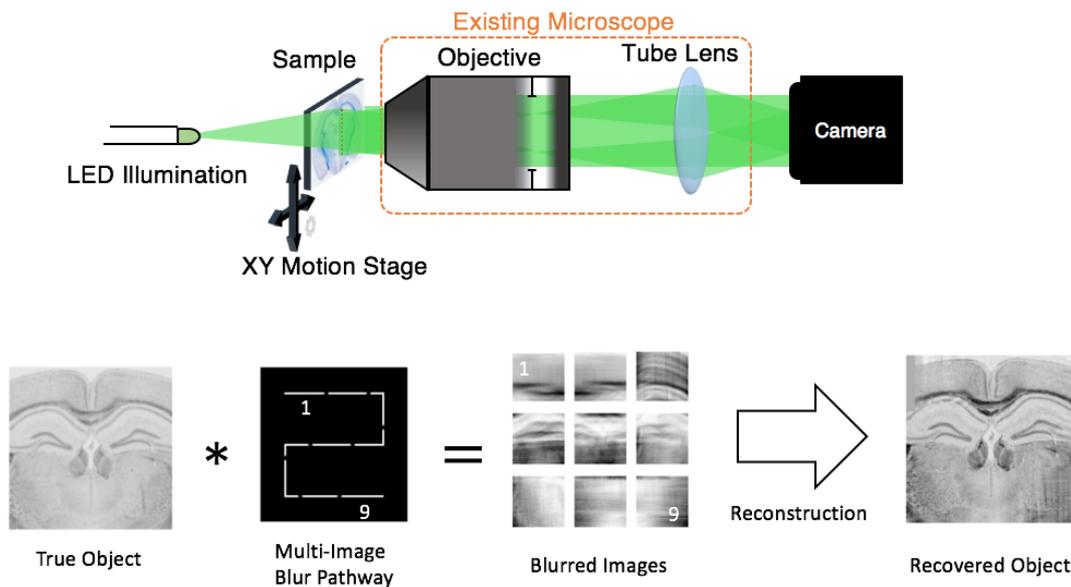

Figure 1: Multi-frame motion deblurring by computational illumination. (Top) system schematic illustrating the system illumination and imaging hardware. (Bottom) Example data collection and reconstruction (simulation)

References

[1] Zheng G, Kolner C, Yang C. Microscopy refocusing and dark-field imaging by using a simple LED array. Optics Letters. 2011;36(20):3987–3989.

[2] Liu Z, Tian L, Liu S, Waller L. Real-time brightfield, darkfield, and phase contrast imaging in a light-emitting diode array microscope. Journal of Biomedical Optics. 2014;19(10):106002.

[3] Raskar R, Agrawal A, Tumblin J. Coded exposure photography: motion deblurring using fluttered shutter. ACM Transactions on Graphics (TOG). 2006;25(3):795–804.

[4] Ma C, Liu Z, Tian L, Dai Q, Waller L. Motion deblurring with temporally coded illumination in an LED array microscope. Opt Lett. 2015;40(10):2281–2284. doi:10.1364/OL.40.002281.