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Resolution and MTF Improvement in a Fourier Ptychography Microscope using Low-Cost Optics

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Introduction: Malaria is a blood-borne parasitic disease with an estimated 247 million new cases and 619,000 deaths worldwide in 2021. While this represents a staggering problem at the global-health level, it is tragic among children under the age of five in sub-Saharan Africa where it is the number one cause of death. Even when treatments are available, they are less effective if not administered within a few days of symptoms, often non-specific and flu-like, and used only for positive cases due to limited availability and the risk of developing malarial resistance. Rapid diagnosis, often in remote regions, is a serious challenge. Malaria is diagnosed from images of parasites in stained red blood cells, requiring laboratory-grade microscopes and trained pathologists or technologists reviewing blood-smear slides. Unfortunately, the cost of transferring suspected cases to testing centres is prohibitive, even if the infrastructure exists, and it is similarly not feasible to distribute microscopes to remote settings in need.

Fourier ptychography is a new computational-optics technology with potential to produce high-quality images with resolution better than the diffraction-limit of light in high NA (low cost) optics having 1-μm resolution and more than 0.25-mm field-of-view, something that has been possible only with high-quality laboratory equipment. Our objective is to develop Fourier ptychography for practical implementation and use existing cell phone infrastructure to transmit images to regional facilities for diagnosis.

Methods: The ptychography system uses a Raspberry Pi computer and custom 225-LED matrix light source. FPM images are reconstructed using in-house Python software. The MTF was determined using a 1951 USAF resolution test pattern. A least-squares analysis was used to determine image modulation at each fundamental frequency plus the first two harmonic terms of a square wave. These were normalized to larger uniform regions of the pattern and combined to generate a pre-sampling MTF which extends beyond the sampling cut-off frequency imposed by pixel spacing.

Results: In the object plane of raw images, pixel size was 0.75 μm and the pupil function diffraction limit was 280 cycles/mm, increasing to 1200 cycles/mm in the FPM images. The 5% MTF frequency was 350 and 650 cycles/mm in raw and FPM images, respectively. A low-frequency drop of approximately 0.3 was observed in both raw and FPM images.

Conclusions: The limiting pre-sampling MTF frequency of the Fourier ptychography microscope was measured as 650 cycles/mm, approximately twice the expected diffraction limit. This corresponds to a resolution better than 1 μm and close to the sampling cut-off frequency of 670 cycles/mm imposed by pixel spacing.

Keyword-1

optics

Keyword-2

Fourier ptychography

Keyword-3

microscopy

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