A novel multicolor structured illumination microscope and quantitative control of polychromatic coherent light with a digital micromirror device

Peter T. Brown[1,*], Rory Kruithoff[1], Gregory J. Seedorf[2], and Douglas P. Shepherd[1]

[1]Department of Physics and Center for Biological Physics, Arizona State University, Tempe, AZ 85287, USA
[2]Department of Pediatrics and Pediatric Heart Lung Center, University of Colorado Anschutz Medical Campus, Aurora, CO 80045, USA
[*]Email: ptbrown1729@asu.edu

Structured illumination microscopy (SIM) is a broadly applicable super-resolution microscopy technique which does not impose photophysics requirements on fluorescent samples. Multicolor SIM implementations typically rely on liquid crystal on silicon (LCoS) spatial light modulators (SLM's) for precise patterning of the excitation light, but digital micromirror devices (DMD's) are a promising alternative, owing to their lower cost, increased imaging rate, and simplified experimental timings. Given these advantages, why do existing DMD SIM implementations either rely on incoherent projection, resulting in an order of magnitude lower signal-to-noise, or utilize coherent light at only a single wavelength? The primary obstacle to realizing a multicolor coherent DMD SIM microscope is the lack of an efficient approach for dealing with the blazed grating effect. To address this challenge, we developed quantitative tools applicable to a single DMD acting as a polychromatic diffractive optic. These include a closed form solution of the blaze and diffraction conditions, a forward model of DMD diffraction, and a forward model of coherent pattern projection. We applied these to identify experimentally feasible configurations using a single DMD as a polychromatic diffractive optic for combinations of three and four common fluorophore wavelengths. Based on these advances, we constructed a DMD SIM microscope for coherent light which we used to validate these models, develop a high-resolution optical transfer function measurement technique, and demonstrate SIM resolution enhancement for calibration samples, fixed cells, and live cells. This low-cost setup opens the door to applying DMD's in polychromatic applications which were previously restricted to LCoS SLM's.