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Fast physical-optics modelling of microscopy system with structured illumination

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Recent advancements in microscopy techniques such as super-resolution imaging, multi-photon excitation, correlative microscopy, adaptive optics, image processing etc. opens up new possibilities towards imaging single live cells in deep tissue with high resolution. Structured illumination microscopy (SIM) is one of the fluorescence imaging techniques that can tackle this challenge. However, in the case of thick samples the SIM technique suffers from out-of-focus fluorescence background signal, which significantly reduces the signal-to-noise ratio (SNR). To overcome this obstacle, it has been suggested to use two-photon excitation in combination with spotlight structured illumination. For the analysis and optimization of this kind of high-NA microscopy system, a fully vectorial physical optics modelling is required that includes polarization, diffraction, aberration and interference effects.

In this work, we perform a fast-physical optics modelling in the context of field tracing. The Local Plane Interface Approximation (LPIA) algorithm, a free space propagation algorithm and the Fourier Modal Method (FMM) are all combined. We analyse the homogeneity of the spot-like illumination interference pattern at the focal plane, which should be accounted for in image processing. We find that various effects influence the homogeneity of the pattern, such as the aberration of the real lens system, diffraction of the plane wave by an aperture, the Gaussian illumination profile and inclination of the blazed grating, which causes the asymmetry of the intensity distribution at the -1 and +1 diffraction orders. We also optimize the structured illumination system to minimize the inhomogeneity. Finally, the parameters of the optimized system can be obtained to apply to the experimental system.