PUPIL SEGMENTATION WITH MULTI-ACTUATOR ADAPTIVE LENS

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The application of adaptive optics to microscopy is important for the correction of the aberrations due to the mismatch of refractive index of the sample and the imperfections present in the optics used. Adaptive optics in microscopy does not require elevated operating frequencies however, inserting a wavefront sensor and an adaptive element (e.g. a deformable mirror) within the microscope optics, is not straightforward and brings to complicated optical setup. Past works have used wavefront sensorless techniques based on the process of image sharpening.[1] Our work instead, focused on designing a new and simple alternative solution that can be easily implemented in the microscope setup with a very compact device. Pupil segmentation is a recent wavefront sensing technique, based on the division of the pupil in smaller sub-apertures. In these sub-pupils, the wavefront is locally comparable to a flat tilted wavefront, with a different slope in each aperture. These tilt variations are evaluated directly from the imaging sensor (i.e. a CCD camera) from the displacement of the PSF spots of the sup-pupils from a reference spot. It is in this way possible to calculate the average gradient and, from an appropriate matrix calculation, reconstruct the wavefront. The first approach to this technique made use of spatial light modulator (SLM) to select portions of the beam [2], having the problem that also a field stop is required in the system in addition to the liquid crystals modulator, loosing on simplicity of the setup. To avoid that, we designed and developed an appropriate mechanical sub-aperture selector, that can be implemented on a single device with a multi-actuator adaptive lens. The lens can correct the aberrated wavefront, once its gradients are evaluated, in a closed loop operative mode.[3] The system (light source, selector with its stepper motor, lens, adaptive lens and camera) are automated and controlled by a self-made software and, before the experimental set-up was set, simulations were performed on some defined simulated aberrations. The device was applied using both a point source and an extended image. Furthermore, the wavefront reconstruction obtained by pupil segmentation was compared to the evaluation made by a classical Shack-Hartmann sensor in the same conditions, observing that the input values of the Zernike coefficients were reproduced with good agreement in both situations. Finally, the adaptive lens was successfully used to correct the wavefront from the inputs obtained using the pupil segmentation set-up with iterative evaluation of the corrected wavefront, obtaining diffraction-limited results.

[1] *Booth, M. J. (2007). "Adaptive optics in microscopy." Philosophical Transactions of the Royal Society of London A: Mathematical, Physical and Engineering Sciences* ***365****(1861): 2829-2843.*

[2] *Ji, N., et al. (2009). "Adaptive optics via pupil segmentation for high-resolution imaging in biological tissues." Nature methods* ***7****(2): 141.*

[3] *Bonora, S., et al. (2015). "Wavefront correction and high-resolution in vivo OCT imaging with an objective integrated multi-actuator adaptive lens." Optics express* ***23****(17): 21931-21941.*