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Adaptive Optics in the Human Eye with a Liquid Crystal Programmable Phase Modulator

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Abstract

Purpose: To evaluate a liquid crystal programmable phase modulator (PPM) (Hamamatsu X7550) as the active element of a double-pass adaptive optics system for the human eye, designed to operate as both corrector and generator of aberrations for retinal imaging and visual testing. **Methods:** The adaptive optics system was based on a previous apparatus (Fernández, Iglesias & Artal, Opt. Lett., **26**, 746, 2001). It consisted of a measurement channel allowing dual illumination (633nm HeNe or 780nm diode laser), a real time Hartmann-Shack sensor working at 25 Hz, and a double-pass retinal image recorder. Simultaneously, the subject can perform visual tasks through the system. To test the PPM as aberration generator, we induced amounts of pure Zernike modes in a single iteration and registered both the wave aberration and the associated point spread function. For testing the PPM as corrector, we first used an artificial eye, measuring the residual aberration and the retinal image after several compensation loops. Finally, two normal eyes were compensated. **Results:** The PPM proved to be a robust wavefront generator for a wide range of aberrations. For example, when inducing Zernike Z^{-1}_3 (coma), the measured coefficient was within a 5% around the intended one for values as high as 4.75 µm over a 13.8 mm pupil diameter on the plane of the PPM. The shape of the recorded images resembled very well the theoretical expectations, although a spike in the paraxial image position appeared for coma values higher than 2 µm. Also, the PPM was proved a capable corrector. The aberration RMS in an artificial eye (4 mm pupil) was reduced from 0.6 to 0.08 µm in a single iteration. Two more steps yielded 0.06 µm of RMS. For real eyes with a pupil diameter of 5.5 mm, the optical quality was also significantly improved. 77% of the RMS was removed in a single iteration in one of the subjects, increasing to 81% in the second step. Currently, a software package is being developed to perform close loop correction approaching the temporal limit of

the device (~ 5 Hz). **Conclusions:** The PPM is a capable aberration generator and corrector, and it can be an alternative to membrane mirrors in moderate-cost adaptive optics systems for vision applications. Although it has a relatively low speed response compared to deformable mirrors and presents some diffraction effects, it may be still appropriate for most visual experiments. This type of device has advantages in terms of effective stroke and mode independence allowing production and compensation of a wider range of aberrations than other correcting devices of similar cost, opening new possibilities in visual applications of adaptive optics.

Keywords: physiological optics • imaging/image analysis: non-clinical