Use of white light illumination for the adaptive optics visual simulator implementing Liquid Crystal on Silicon (LCOS) technology

***Enrique J. Fernández*[1,2]*, Pedro M. Prieto*[1,2]*, P. Artal*[1,2]**

[1]Laboratorio de Óptica, Instituto Universitario de Investigación en Óptica y Nanofísica, Universidad de Murcia, Edificio IU-IOyN (Nº 34), Campus de Espinardo, E-30071 Murcia (Spain)

[2]Voptica S.L., Centro Europeo de Empresas e Innovación (CEEIM), Campus de Espinardo Murcia, (Spain)

Enriquej@um.es,Pegrito@um.es,Pablo@um.es

Purpose

In this work we have investigated the use and performance of a particular adaptive optics system (AO): the monocular visual simulator. The instrument uses a high resolution Liquid Crystal on Silicon (LCOS) correcting device, under white light illumination. The purpose of this investigation is twofold: understanding how phase wrapping and dispersion might affect the performance of white light aberration correction and generation; and establishing ranges of use of the technology for visual oriented application.

Methods

The monocular visual simulator (Voptica S.L., Spain) incorporates AO technology for the precise generation and manipulation of wavefronts. Subjects can undergo visual testing, through standard acuity tests, contrast sensitivity tests, or more sophisticated procedures, while aberrations are being measured and subsequently manipulated. Aberrations are controlled exclusively by optical means, with no moving or mechanical elements, nor any digital processing of displayed images. Therefore, simulation of any given optical element or situation is accomplished by exactly reproducing the same wavefront than the actual situation would generate. Such advantageous technology is primary based on the use of a high resolution Hartmann-Shack wavefront sensor, and a sophisticated correcting device. The latter is a LCOS programmable phase modulator (Holoeye Photonics AG, Germany) showing full HD resolution. Those types of correctors are controlled by phase wrapping, allowing huge ranges of amplitude in the aberration generation, solely limited by the density of available pixels compounding the phase map. Using phase wrapping immediately imposes the selection of a working wavelength. This fact has promoted the general use of monochromatic light for liquid crystals, though some previous results obtained in the context of high resolution retinal imaging [1] have shown the ability of modulating correctly and simultaneously wide spectra.

Since the AO system is intended for visual purposes, in this work we have analyzed its performance through the study of extended images. Using traditional optical metrics or functions associated to point images is theoretically correct, no doubt, but they does not account for the actual working conditions of the eye. Therefore, we have characterized the tolerance and impact of the manipulation of wavefronts at different wavelengths through their effect on images. This technique has been previously demonstrated in characterizing the ability of an LCOS device reproducing aberrations [2] with success.

We have selected the two-dimensional correlation coefficient for comparing and obtaining quantitative information about the degradation of images, and their possible change across wavelengths. The latter accounts mathematically for the difference among images, being one in case of identical images and zero in the case of no coincidence at all.

In the experiment several images are initially degraded through the generation of several aberrations. For the sake of simplicity we have selected several Zernike polynomials.

The central wavelength selected for phase wrapping was 543 nm.

Results

Spectral emission of the microdisplay was characterized, essentially corresponding with regular RGB found in regular devices. Several measurements of aberrations were programmed at green, blue and red color. Images were retrieved under each color, together with the white illumination. Those images were degraded with defocus, astigmatism, coma aberration, trefoil, spherical aberration and high order aberrations. Comparison across wavelengths are presented, via the two dimensional correlation. In all cases, for the range of use in the human eye, degradation is below the natural chromatic aberration of the eye. Subjectively, the differences were not possible to detect for subjects. In the most dramatic case, occurring between wavelength at the tails of the spectrum and that at the center the difference in degradation of the images was inferior to 10%. The practical significance of such discrepancy even decreases when the spectral response of the human visual system is taken into account.

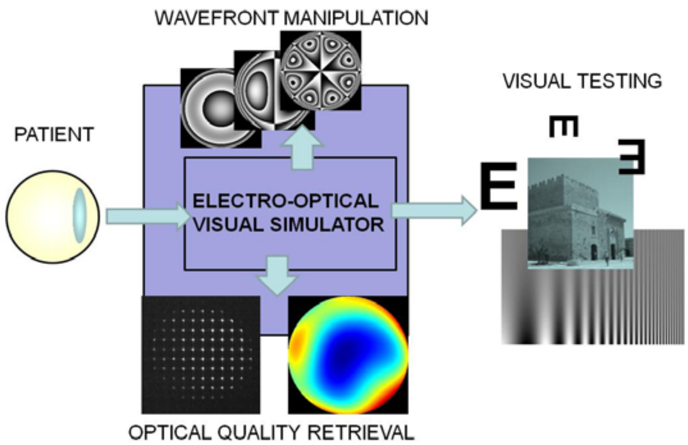

Fig. 1. Squematic diagram showing the operation of the Visual Simulator in white light

Conclusions

For visual oriented applications, the range of tolerance to small and even moderate deviations of the wavefront modulation at the tails of the spectrum from that programmed at the central wavelength is less demanding than in the case of retinal imaging [1]. The employed detector in any case arises as the ultimate responsible; the retina exhibits a significant tolerance to chromatic aberration, as it is evident in everyday vision with chromatic aberrations of up to 2 D for the visible portion of the spectrum. In this work the employment of white light illumination in combination of a LCOS device has been demonstrated. The presented technology offers the possiblity of realistic visual testing, with the ability of manipulating wavefronts in the entire visible range, simultaneously to the presentation of tests.

References

1. E. J. Fernández, B. Povazay, B. Hermann, A. Unterhuber, H. Sattmann, P. M. Prieto, R. Leitgeb, P. Ahnelt, P. Artal, W. Drexler, "Three-dimensional adaptive optics ultrahigh-resolution optical coherence tomography using a liquid crystal spatial light modulator," Vision Res., 45, 3432–3444 (2005).

2. E. J. Fernández, P. M. Prieto, P. Artal,. "Wave-aberration control with a liquid crystal on silicon (LCOS) spatial phase modulator", Opt. Express, 17, 11013–11025 (2009).