Wavefront shaping with LCOS devices

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Purpose

Liquid crystal on Silicon (LCOS) spatial phase modulators offer enhanced possibilities for adaptive optics applications in terms of response velocity and fidelity. In this work we will explore the performance of LCOS devices for inducing pure Zernike modes.

Methods

In recent years, different types of phase modulators based on the use of liquid crystal have been developed and tested as aberration correctors and generators [1-3]. This type of device provides an interesting alternative to conventional deformable mirrors. Among the disadvantages of liquid crystal phase modulators, the response speed (traditionally 4-5 Hz) is typically pointed out. This has been overcome in part with the recently developed liquid crystal on silicon (LCOS) technology, which allows up to 60 Hz. Another cited drawback is the requirement of linearly polarized light, although that is irrelevant from the point of view of aberration control [4].

The main advantages of liquid crystal modulators are their high fidelity, which allows open-loop operation, and, possibly more important, their high spatial resolution. The number of independent elements to control the phase in liquid crystal-based modulators is currently 3-4 orders of magnitude superior to deformable mirrors. In addition, phase modulators do not present the continuity constrains that limit the capability of deformation of flexible membranes in mirrors. This feature not only extends the range of achievable phase manipulations to discontinuous surfaces but it also can be exploited to significantly increase the effective stroke by using 2π-wrapped phase maps. The latter feature is only limited by the diffraction related effects that become noticeable as the number of phase cycles increase.

To estimate the range of accurate generation for each Zernike polynomial, sets of images systematically degraded using a LCOS phase modulator were recorded and their theoretical digital counterparts were calculated. Instead of a direct comparison between pairs of images, we estimated the different behavior of the real degradation as compared to the digitally predicted one. In both cases, the degradation was quantified by the correlation coefficient between the degraded and the undegraded (0-aberration) images.

Results

For each Zernike mode, the image degradation reached a limit for a certain coefficient value; further increase in the aberration amount has no additional effect in image quality. This behavior is attributed to the intensification of the 0-order diffraction. These results were used to determine the usable limits of the phase modulator virtually free from diffraction artifacts. The results are particularly important for visual simulation and ophthalmic testing applications, although they are equally interesting for any adaptive optics application with liquid crystal based devices.

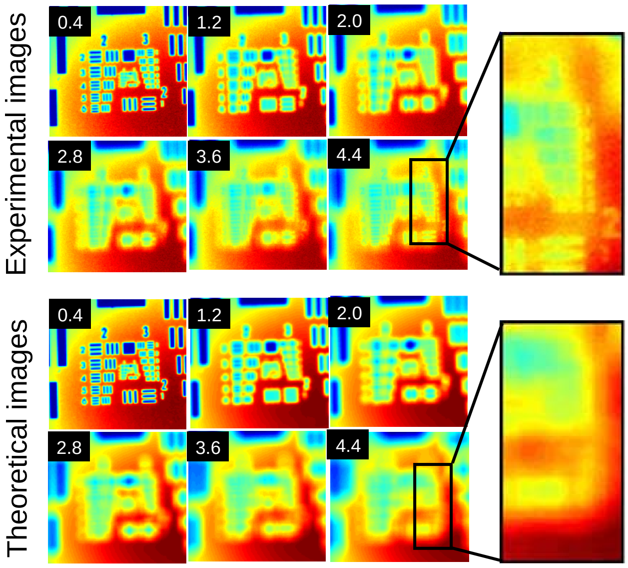

Fig. 1. Effect of introducing different values of pure defocus, Zernike Z(2,0), over the image of an USAF test. The degradation in the experimental images (upper set) reaches a plateau instead of continually increasing.

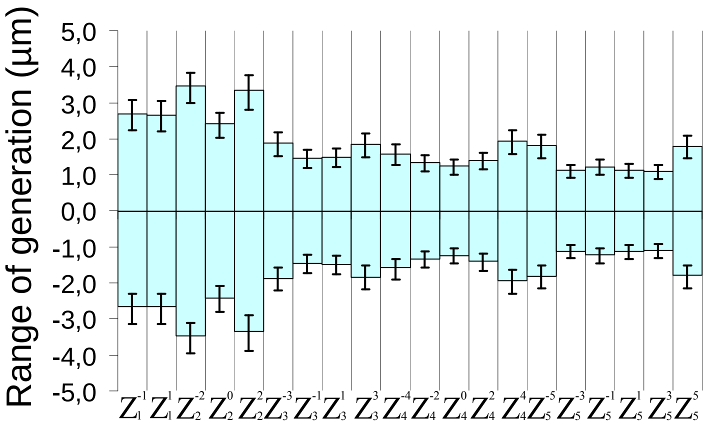

Fig. 2. Ranges of accurate aberration generation, calculated as the coefficient values that produce a 1.5% difference between the experimental and digital correlation. Each value can be understood as the maximum amount of a given polynomial that can be induced by the LCOS phase modulator with no artifacts over the resulting degraded image.

References

1. F. Vargas-Martín, P. M. Prieto, P.Artal, "Correction of the aberrations in the human eye with a liquid crystal spatial light modulator: limits to performance," J. Opt. Soc. Am. A 15, 2552-2562 (1998)

2. S. Manzanera, P. M. Prieto, D. B. Ayala, J. M. Lindacher, P. Artal, "Liquid crystal Adaptive Optics Visual Simulator: Application to testing and design of ophthalmic optical elements," Opt. Express 15, 16177-16188 (2007)

3. 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)

4. P. M. Prieto, F. Vargas-Martín, J. S. McLellan, S. A. Burns, "Effect of the polarization on ocular wave aberration measurements," J. Opt. Soc. Am. A, 19, 809–814 (2002)