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Analysis of Holographic Wavefront Sensing Performance for Extended Sources

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Abstract: We present a sensitivity analysis of holographic wavefront sensing to extended sources due to spot elongation. Overall, the holographic wavefront sensor (HWFS) tolerates spot elongations at the expense of less sensitivity of the main Zernike mode and the appearance of a moderate amount of crosstalk.

OCIS codes: (010.1080) Active or adaptive optics; (010.1285) Atmospheric correction; (010.7350) Wave-front sensing; (090.1760) Computer holography.

1. Introduction

The Holographic Wavefront Sensor (HWFS) [1] has shown to be a promising alternative to traditional wavefront sensing techniques such as the Shack-Hartmann or Pyramidal WFSs since it provides with the main benefit of optical computing: speed. In contrast to zonal WFSs that require reconstruction of the wavefront from the measurements, The HWFS is able to directly measure the Zernike modes of the incoming wavefront in a prompt manner. This fact may present an interesting benefit to high speed adaptive optics (AO) loops, such as in the compensation for atmospheric aberrations in large telescopes.

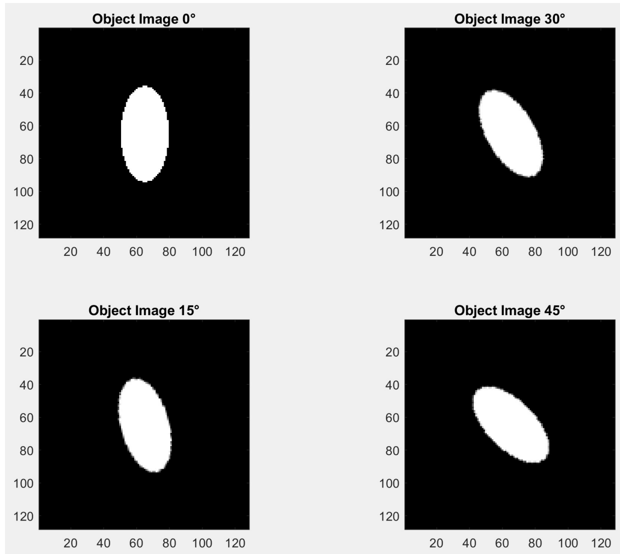
Nonetheless, the next generation of Extremely Large Telescopes (ELTs) presents an additional nuisance. Since ELTs have the obligation of using AO to take advantage of the potential resolution their gigantic apertures offer, the use of artificial laser guide stars (LGS) are mandatory to characterize the fluctuations of the turbulent volume fro tomographic AO corrections. However, and given the width of the sodium layer that is stimulated by the LGS system, the large aperture of an ELT observe artificial guide stars as elongated sources instead of point sources [2]. In this work, and inspired by demonstrations of the HWFS to rapidly estimate dynamic wavefront aberrations [3], we aim to investigate the effects of elongated sources to the HWFS performance to see if it can be a valid choice for the future ELTs.

2. Simulations and Results

The HWFS works by projecting a collimated wavefront onto several pairs of transmissive thin holograms that have been recorded with the same force of a positive and negative Zernike coefficient aberration. After a Fourier transforming lens, the intensity of each Zernike mode is recorded by a detector. The estimation of the measured Zernike strength is given by computing the difference between the positive and negative intensities, as described in [4].

We simulate the response of a HWFS in the case of elongated sources. For that, we used elliptical shaped sources, resembling the cigar shape frequently obtained in the giant telescope simulations. As shown in Fig. 1, the HWFS has been tested with input sources at four different rotational angles: 0, 15, 30, 45 and fifty different elongations varying on a linear scale from a unitary dimension one (point source object) to dimension fifty, covering the whole available room at the detector. All input objects have been normalized to have unit energy.

The holograms are simulated as phase masks programmed with the different optical aberrations, similarly to Ghebremichael et al. [1]. The aberrations were analitically computed using Zernike polynomials from Defocus, $z = 4$, to Oblique Trefoil, $z = 10$. For the characterization of the HWFS, we analyzed the outcome of the response of the available Zernike modes in our simulated HWFS to a single Zernike order as the input wavefront aberration. For every input Zernike mode, the input strength of the wavefront has been varied from a value of minus one to the maximum value of plus one, obtaining response curves similar to those found by Kong et al. [4].



#1. Extended object sources used in the simulations for a given elongation level.

A linear response has been taken as the ideal system response. From the response curves, a linearity coefficient ε has been computed as follows:

$$\eta = 1 - \frac{\sigma(x-y)}{/\sigma(x)}$$

in order to prove the efficiency of the sensor. The vectors x and $y$are the ideal response and the measured HWFS intensity response, respectively. The closer to one (absolute value), the better the response.

In this way, by having a single coefficient for every mode of the HWFS response curve, we can understand the variations of the HWFS efficiency with respect to variations of the source shape and rotation angle. For a given size and rotation angle, we can generate comparisons of the response of the HWFS as seen in Fig. reffig2, where the diagonal displays the linearity coefficient with respect to the same Zernike mode. An ideal HWFS would have an identity matrix, where an output mode only responds to the given input mode. In the particular case of the presented HWFS, there is always an amount of crosstalk, even for the point source case.

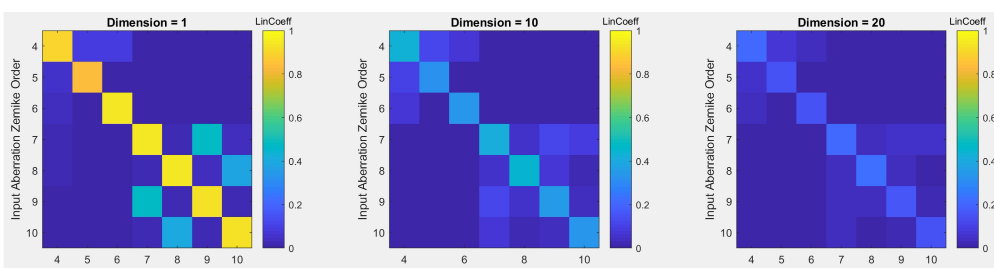


Fig. 2. Linearity response maps for the HWFS at different elongations. For each matrix, the corresponding input/output Zernike modes are represented by its number ($z = 4$ to $z = 10$)located at the bottom/left, respectively.

For larger objects, the magnitude of the linearity coefficient decreases. However, this decrease is somehow proportional to all the other modes, being the corresponding Zernike mode always the dominant mode of the HWFS.

Another way to visualize the HWFS behavior is presented in Fig. 3, where we produced a different plot where by for the same input Zernike mode (in this case vertical coma, $z = 7$), we present the evolution of the linearity coefficient with respect to the spot size, which is repeated for different source rotations. It is noticeable, as in all the other cases with different input aberrations, that the HWFS has the best efficiency when the holograms Zernike order equals the input aberration. As a general feature, the linearity tends to decrease rapidly when the dimension of the object increases. In

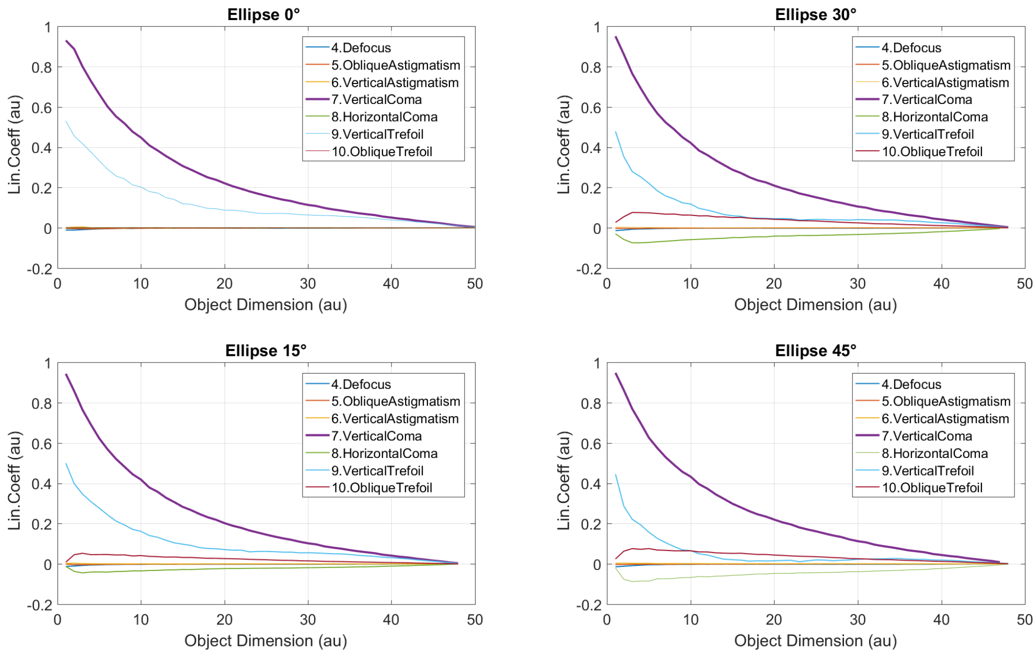


Fig. 3. Linearity response of the HWFS for the Zernike mode Vertical Coma ($z = 7$) as input at different levels of elongation of the source object and for different rotations.

this particular case, we can observe that a particular aberration is also being sensed as a dominant crosstalk element, and crosstalk from other modes show up when rotating the source. It has been seen that the behaviors of the curves obtained when the holograms order is equal to the input aberration order dont change significantly applying angles rotation to the source object.

3. Conclusion

We presented the analysis of simulated results for a HWFS system that is subject to elongated sources. Despite presenting a moderate degree of crosstalk, even for point sources, the HWFS present a good correlation (measured by the linearity coefficient) between the incoming wavefront modes and the measured modes. However, the linearity gets affected by an increased elongation of the source–and only very slightly by a rotation of the source–although all modes are proportionally affected. As a conclusion, the HWFS can be used for elongated spots, but it has to be normalized according to the degree of elongation to deliver reliable aberration measurements, which is subject to further investigation.

Acknowldgements

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References

[1] F. Ghebremichael, G. P. Andersen, and K. S. Gurley, "Holography-based wavefront sensing," Appl. Opt. **47**, A62–A69 (2008).
[2] L. Gilles and B. Ellerbroek, "Shack-hartmann wavefront sensing with elongated sodium laser beacons: centroiding versus matched filtering," Appl. Opt. **45**, 6568–6576 (2006).
[3] G. Andersen, P. Gelsinger-Austin, R. Gaddipati, P. Gaddipati, and F. Ghebremichael, "Fast, compact, autonomous holographic adaptive optics," Opt. Express **22**, 9432–9441 (2014).
[4] F. Kong and A. Lambert, "Improvements to the modal holographic wavefront sensor," Appl. Opt. **55**, 3615–3625 (2016).