Image-based wavefront correction for space telescopes

Orestis Kazasidis, Sven Verpoort, and Ulrich Wittrock

Abstract

We investigate image-based wavefront correction with active optics for future large space telescopes. We use an image-sharpness metric as merit function to evaluate the image quality, and we use the Zernike modes as control variables. In severely aberrated systems with several $\lambda$ of aberration and low Strehl ratio, the Zernike modes are not orthogonal to each other with respect to this merit function. We discuss the physical causes for this non-orthogonality and its implications.

Image quality

Image quality can be assessed by various criteria. The PSF, the MTF, and wavefront maps deliver more than a single number. The Strehl ratio, the RMS wavefront error, and image-sharpness metrics deliver a single number and allow ranking of different optical systems. Their global optimum is for zero aberration, but their ranking can differ for large aberrations. The Strehl ratio ($S$) becomes multiple-valued with respect to the RMS wavefront error ($\sigma$) for $\sigma > 0.2\lambda$. Each curve has a different constant astigmatism $0^\circ (z_4)$. Defocus ($z_3$) increases with $\sigma$ along each curve.

Method

Image-based wavefront correction without wavefront sensing is a blind optimization where an algorithm iteratively adapts the surface of the active element. The performance of the correction is determined by: 1. the merit function, 2. the control domain, and 3. the algorithm.

Results

Balancing astigmatism ($z_4$) with defocus ($z_3$)

Adding defocus of $z_3 = \pm z_4/2$ in the presence of astigmatism $0^\circ$ leads to better MF.

Balancing trefoil ($z_9$) with coma ($z_6$)

Adding coma x of $z_9 = z_6$ in the presence of trefoil $0^\circ$ leads to better MF.

Balancing astigmatism ($z_4$) with trefoil ($z_9$)

Adding trefoil $0^\circ$ of $z_9 = \pm 2z_4/3$ in the presence of astigmatism $0^\circ$ leads to better MF.

Conclusions

- In certain cases, when adding a Zernike mode, the merit function is improved, although the RMS wavefront error increases. In all examples shown in this poster, the improvement of the merit function comes with an increase of the Strehl ratio. However, it does not always come with an improvement of the contrast at a certain range of spatial frequencies.
- The non-orthogonality of the Zernike modes should be taken into account when designing the algorithm for image-based wavefront correction, because it may slow down the process or lead to premature convergence. If the algorithm optimizes the Zernike modes separately, several iterations over all the Zernike modes are required to ensure that the global minimum is found.

Relevant literature


Münster University of Applied Sciences, Photonics Laboratory, Stegerwaldstr. 39, 48565 Steinfurt, Germany
Email: kazasidis@fh-muenster.de

Examples of 2D landscapes of the merit function calculated for the PSF. Left: centered at zero aberration. Right: centered at a random aberration.

What is the merit function in the control domain like?

Algorithm design
e.g., line search, evolutionary algorithm