Diffractional treatment of curvature sensing in segmented-mirror telescopes

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ABSTRACT

Discontinuities in the wavefront phase or amplitude affect curvature sensor (CS) response. These discontinuities may be the result of an improper alignment of the elements of a segmented mirror in either piston or tip-tilt. We describe the CS response with an analytical approach based on the Fresnel approximation of the diffracted field and show that a CS is capable of detecting misalignment among segments. The response model that we present leads to a fast algorithm for the measurement of segment positions. As an application, we focus on piston co-phasing. The paper concludes with the characterization of the integrated curvature signal, which simplifies the analysis of the CS response to misalignments. The low processing time and principal memory requirements of the algorithm make it suitable for extremely large telescopes (ELTs).

Keywords: Active optics, segmented mirrors, curvature sensors, ELTs, Fresnel diffraction

1. INTRODUCTION

Curvature sensing in astronomy was first applied by Roddier.[1] The simplest form of this device consists of two defocused detectors, both placed at the same distance on either side of the focal plane of the telescope. The detectors respond to the illuminance on each pixel, but the measurements at the two positions are combined into a response signal proportional to the local curvatures of the wavefront.

The main use of the CS is in wavefront sensing for astronomical adaptive optics (AO) purposes. It has some advantages over other devices: first, the output of the CS matches the control signal for bimorph deformable mirrors, thereby reducing computing time in applying corrections; and second, it is adjustable in spatial resolution and gain, the defocus length of the detectors being adjusted. This degree of freedom allows us to adapt the CS to the strength of atmospheric turbulence, or to optimize the correction in closed loop.

Actual implementations of CSs based AO systems have been mostly employed for low order corrections in the infrared and demonstrate the validity of the concept. However, there is no system of this type operating in segmented mirror telescopes. The increasing importance of the technique of segmentation prompts the study of the performance of curvature sensing in this kind of telescope. The main distinction between the two types of mirrors is found at the borders of the segments, where residual polishing errors or improper alignment introduce a high spatial frequency component in the wavefront.

Of the six degrees of freedom in the position of each segment, three for the position of the center of gravity and another three for the orientation, only three are critical for the quality of image formation.[2] These are called *piston*, the translation perpendicular to the surface of the segment, and two rotations denoted as *tip-tilt*, with rotational axes in the plane of the mirror. These types of misalignment also affect the response of the CS and need to be considered in the use of a CS in a segmented mirror telescope. If an AO system uses a Shack–Hartmann sensor conjugated to the pupil of the telescope, it seems simple to avoid the complications of segment borders by simply disregarding the information of the subapertures crossed by an edge. This is not so straight in curvature sensing, since the contribution of the high-order aberrations is spread owing to diffraction.

Some authors (e.g., Roddier[3]; Millman, Redding & Needles[4]) have studied curvature sensing using a diffractional approach. Their analysis , however, is valid only for monolithic mirrors. Generalization to segmented

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