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Performance Evaluation of Adaptive Optics Systems

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Abstract. Adaptive Optics (AO) systems improve the resolution of ground based telescopes and allow for long exposure images. Their performance depends on the seeing conditions at the time of observations. In this paper, we evaluate the performance of an AO system under various seeing conditions through simulations. Then we present the wave-front sensing and correction schemes that would be used in the first phase of the AO system to be developed at the Udaipur Solar Observatory.

Keywords : High Resolution Imaging - Adaptive Optics

1. Introduction

Adaptive Optics systems have now become an integral part of any large ground based telescope operating at optical and infra-red wavelengths. They enhance the performance of the ground based imaging system by sensing and correcting a distorted wave-front in real time using a wave-front sensor, corrector and control computer(s). Though the inherent properties of the system such as finite size of the sensing element, limited degrees of freedom of the corrector and its finite response time prevent achieving diffraction limited performance, correcting for a few low order aberrations can improve the performance considerably. Before developing an AO system, one would like to answer issues like the extent of expected improvement under typical seeing conditions, how much is the increase in the Strehl ratio? and how much is the increase in contrast in the case of extended objects? In this paper, we try to answer some of these questions through simulations.

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2. Simulations

We simulate a series of perturbed wave-fronts for a given seeing conditions (r_0) following Kolmogorov theory of turbulence (Sridharan, 2001). Assuming a circular aperture of diameter D and lenslet array of circular aperture d, we estimate slopes of the wave-front over the sub-aperture using the shifts in the images produced by them. We then express the slopes as a linear combinations of the derivatives of Zernike polynomials (Born and Wolf, 1980) using singular value decomposition (Antia, 1991). We reconstruct the wave-front using the estimated co-effficients, subtract it from the initial and obtain the residual wave-front. We estimate the long exposure transfer function and point spread function (psf) from a series of 1024 AO corrected wave-fronts. We convolve the psf with the object of interest (high resolution solar image in our case) before and after AO correction and estimate the increase in the contrast of the image.

3. Low Order AO System for Meter Aperture Solar Telescope

Meter Aperture Solar Telescope (MAST) is a proposed solar telescope equipped with AO system. In the first phase, it is planned to build a low order AO system at the re-imaged pupil plane of the MAST. It is planned to develop a laboratory model using Shack Hartmann wave-front sensor and a membrane mirror. It is planned to implement the AO system at Ca II $\lambda 8542$ with a bandwidth of 0.1 nm. Though the contrast of the features is higher at such lines, signal-to-noise ratio could be a serious issue in locating the peak of the cross-correlation function. To investigate this issue, we performed a 1-d simulation. The number of electrons available per Airy disc, within such narrow bandwidth is ~ 10000. Assuming a spatial sampling of 2 pixels per diffraction limit, this leads to ~ 5000 electrons per pixel. With an analog to digital conversion of 0.032 counts per electron (assuming 8×10^{-6} volts per electron, and 4096 analog to digital units for full well) this leads to ~ 163 counts. The preliminary results indicate that cross-correlations are possible as long as the signal-to-noise ratio is greater than 10.

4. Results

We used three different kinds of lenslet arrays ($D = 101$ cm, $d = 11$ cm, 61 sub-apertures; $D = 99$ cm, $d = 9$ cm, 55 sub-apertures; $D = 101$ cm, $d = 9$ cm, 64 sub-apertures). We found that for $r_0 = 3$ cm, Strehl ratio and contrast increased by factor of 2.33, and 1.84 respectively after correcting for 30 Zernike terms. For $r_0 = 9$ (10) cm, the corresponding factors were 31.22 (35.69) and 4.83 (5.98) respectively.

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