Design for Solar Multi-Conjugate Adaptive Optics at the New Solar Telescope/Big Bear Solar Observatory

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ABSTRACT

The Sun is an ideal target for the development and application of Multi-Conjugate Adaptive Optics (MCAO). A solar MCAO system has being developed by the Big Bear Solar Observatory team and European partners for the 1.6m diameter New Solar Observatory, with the purpose of extending the corrected science field of view to 1Arcmin. A detailed optical system design and optical performance for such a system is presented and discussed here. The numerical simulations, which fed this optical system design are presented in more details in Langlois et al [1] in this conference.

Keywords: Multi-Conjugate Adaptive Optics, Solar Astronomical Instrumentation, Optical System Design.

1. INTRODUCTION

The system designed here is fully based on a system designed in 2004/05 for the Dunn Solar Telescope at the National Solar Observatory (DST/NSO) [2] and [3]. In order to extend the size of the corrected science field of view (FOV), with respect to the classical AO field of view, a Multi-Conjugate Adaptive Optics (MCAO) system has been simulated [1] and designed here to be implemented at the Big Bear Solar Observatory (BBSO), New Solar Telescope (NST) – a new 1.6m off-axis solar telescope. As discussed by Moretto, Langlois and Rimmelle in [4], a solar MCAO system using tomographic wave-front reconstruction requires a collimated beam with optical conjugations to different altitude layers, above the telescope. Seeking optimal performance, the deformable mirrors should be positioned at the conjugates of each nominal altitude of the turbulence.

In this paper, we describe and discuss the performance of such an optical layout for the NST/BBSO MCAO system. Making use of 3 Xinetics™ deformable mirrors of 85mm clear aperture, it imposed the system to several constraints during the optical optimizations. The optical challenge is to optimize the optical position and the conjugate altitude footprints dimensions.
Figure 1– The NST/BBSO 1.6m off-axis telescope and the tables set up to the MCAO system.

The system design here is divided in three sections: conjugation relay, science beam and wave-front sensing beam. The main requirement is to find optically an optimum conjugation position placed on a collimated beam that re-defines the NST’s exit pupil. We define in this way the conjugation section of the system. Following the conjugation section, the collimated beam (from the exit pupil) is re-focalized and a beam-splitter separates the beam into two parts: the science (data) branch section and the Shack-Hartmann wave-front branch section.

Figure 2– The NST/BBSO MCAO optical configuration. The input optical beam is the NST’s tip/tilt port defined by an exit pupil. From T/T up to DM3 we defined the conjugation section, and forward DM3 we defined the science branch and the wave-front sensor section. Flat fold mirrors could be set up to fit the system to NST optical tables available to MCAO system, as shown in Figure 1.
2. OPTICAL DESIGN & PERFORMANCE

The input light beam to the NST/BBSO MCAO optical system is in the tip/tilt port which consist of an exit pupil of 45mm in diameter, following such port we optimize across an 1.00 Arc-min FOV the conjugation, science and wave-front sensing sections as shown in Figure 2. The optimal optical relay system has three conjugate positions for the deformable mirrors DM1 conjugated to 6km altitude, DM2 conjugated to 3km and DM2 conjugated to the ground (i.e. the exit pupil conjugate). Such altitudes, have been estimated through simulations by Langlois et al [1].

In order to guarantee such optimum conjugate positions we make use of a set of lenses and a collimator (COLL) – a spherical mirror – to produce an optimized collimated optical beam following the F/53 focal port as shown in Figure 1. The set produces workable positions for the DMs-train DM1, DM2, and DM3 on the collimated beam. Figure 3 shows the footprint plots and diameter values on the deformable mirrors DM1, DM2 and DM3 conjugated to 6, 3 and 0km altitude. The collimated is set to half the full DM diameter in order to correct the full 1 Arc-min field of view up to the 6 km altitude DM. These collimated footprints across the FOV were constrained during the optical optimization of the set of lens + COLL. The mean diameter values are 45mm ± 1mm on the three DMs, resulting in an excellent exit pupil distortion control on the footprint diameter for each field position $F_n$, as shown in Figure 3. Following the collimated beam, which defines the exit pupil on DM3, the science branch has also been optimized. As it was done for the DST/NSO MCAO optical system; making use of an off-shelf doublet (MG LAO379) the collimated beam is re-imaged to a F/53 focal beam optimized up to a 2.5Arc-min FOV and is imaged on a 2Kx2K Camera. The science branch F/53 focal plane produces diffraction-limited images across 2.5Arc-min FOV and across wavelength range from 537.5nm to 562.5nm.

Figure 3 – Optical performance for the system conjugation section. The footprints on the deformable mirrors DM1, DM2 and DM3 are calculated across each field position – the nine color positions showed in the left bottom corner of figure – $\Sigma \text{Dia } F_n$ with $n=1$ to 9. Each field position footprints on the three deformable mirrors are 45mm, e.g. the exit pupil diameter.

3. WAVEFRONT SENSOR SECTION

The NST/BBSO MCAO system makes use of three Xinetics™ deformable mirrors with square geometry, clear aperture of 85mm, 349 actuators and 5mm pitch. A 45mm diameter footprint (Figure 2) on DMs results in 8 actuators (7 sub-apertures) per diameter. The F/53 focal plane is re-collimated to a 8mm diameter exit pupil making use of an off-shelf doublet (MG LAO267). The 8mm exit pupil is sampled by a microlens array of 1x1mm square, matching the DMs actuators setup of 8 actuators per diameter, as shown in Figure 4. Such lenslet setup produces diffraction-limited images on the CMOS camera across the 25nm bandwidth filter centered on 550nm.
Figure 4—A Correlating Shack-Hartmann wave-front sensor is adopted for the wave-front sensor section. The F/53 focal plane is re-collimated to a 8.0mm diameter exit pupil. Such exit pupil is sampled by a micro-lens array of 1x1mm square, matching the DMs actuators setup of 8 actuators per diameter.

For the sake of the comparison, we reproduce here the preliminary results obtained with the DST/NSO MCAO system, which we developed in 2004/2005 [2] and [3]. Figure 5 shows the first results with tip/tilt and MCAO closed loop, where the sequences of Shack-Hartmann data for three sub regions of 18x18 Arcsec² on a CMOS camera is reproduced in Figure 5(A) and on the Xedar camera is reproduced in Figure 5(B).
Figure 5 – Reproduction from DST/NSO MCAO [2] showing solar wavefront sensing principal. These results were obtained with ground tip/tilt closed loop and wavefront measurements on the three sub regions across a 1.25 Arcmin a (A) the wavefront sensor camera and (B) a Xedar science camera.

4. CONCLUSIONS AND WHAT NEXT
The optical design presented in this paper confirms the possibility to build a visible solar MCAO system delivering high performances over the 1 arcmin FoV. This design proposes the use of a wide field WFSs based on a Shack-Hartman WFS handling both low order and high order at the same time. This approach is very similar to nighttime MCAO approach but differs significantly from recent solar system designs [5] and [6]. Those usually have two independent loops: one controlling the pupil DM with high order wavefront sensor and another one controlling the high altitude DMs with a low order wavefront sensor. In these systems WFS are not all located behind the DM’s making them blind to downstream DM deformations. The proposed design presents the advantage of setting the WFS before the DM allowing straightforward control of the MCAO loops. The current design could still be improved by increasing the order of the correction to allow high Strehl (> 30%) in the cases of bad seeing conditions.

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REFERENCES