Adaptive optics system for the IRSOL solar observatory

by

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Abstract

We present a low cost adaptive optics system developed for the solar observatory at Istituto Ricerche Solari Locarno (IRSOL), Switzerland. The Shack Hartmann Wavefront Sensor is based on a Dalsa CCD camera with 256 pixels x 256 pixels working at 1kHz. The correction is obtained by a deformable mirror with 37 actuators and a tip-tilt mirror. A real time control software has been developed on a RTAI-Linux PC. Scicos/Scilab based software has been realized for an online analysis of the system behavior. The software is completely open source.

1. Introduction

The solar observatory at Istituto Ricerche Solari Locarno (IRSOL), Switzerland focuses its activity on precise spectropolarimetric measurements[1] from the near UV to the near infrared. Available instrumentation includes:

- Telescope: Gregory-Coudé (45 cm aperture) (Fig.1)
- Polarimeter: **ZIMPOL**[2,3] **(Zurich Imagig POLarimeter,** polarimetric sensitivity 10^{-5})
- Spectrograph (high dispersion Czerny-Turner, focal length: 10 m, grating 180 mm x 360 mm, 316 lines / mm, blaze 63°)
- Tunable narrow-band filter system based on two lithium-niobate Fabry-Perot etalons.

+ Adaptive optics (AO): tip-tilt mirror and deformable mirror with 37 actuators (presented here)

The **key-instrument is ZIMPOL**[2,3], that reaches a polarimetric sensitivity of 10^{-5} thanks to fast (kHz) polarization modulation/demodulation of the light beam in combination with a special masked CCD.

Even if the observing programs at IRSOL are focused on high polarimetric sensitivity rather than on obtaining diffraction limited high spatial resolution images, it is an actractive advantage to install an **AO system** that allows reaching a good image stability during a long exposure measurement. A typical precise ZIMPOL observation last for few tens of minutes and combines thousands of frames with about 1 second exposure time each.

Thus we decided to install a low cost adaptive optics following the concept and design of the AO system developed by Keller et al. (2003)[4] for the infrared at the McMath-Pierce solar telescope.

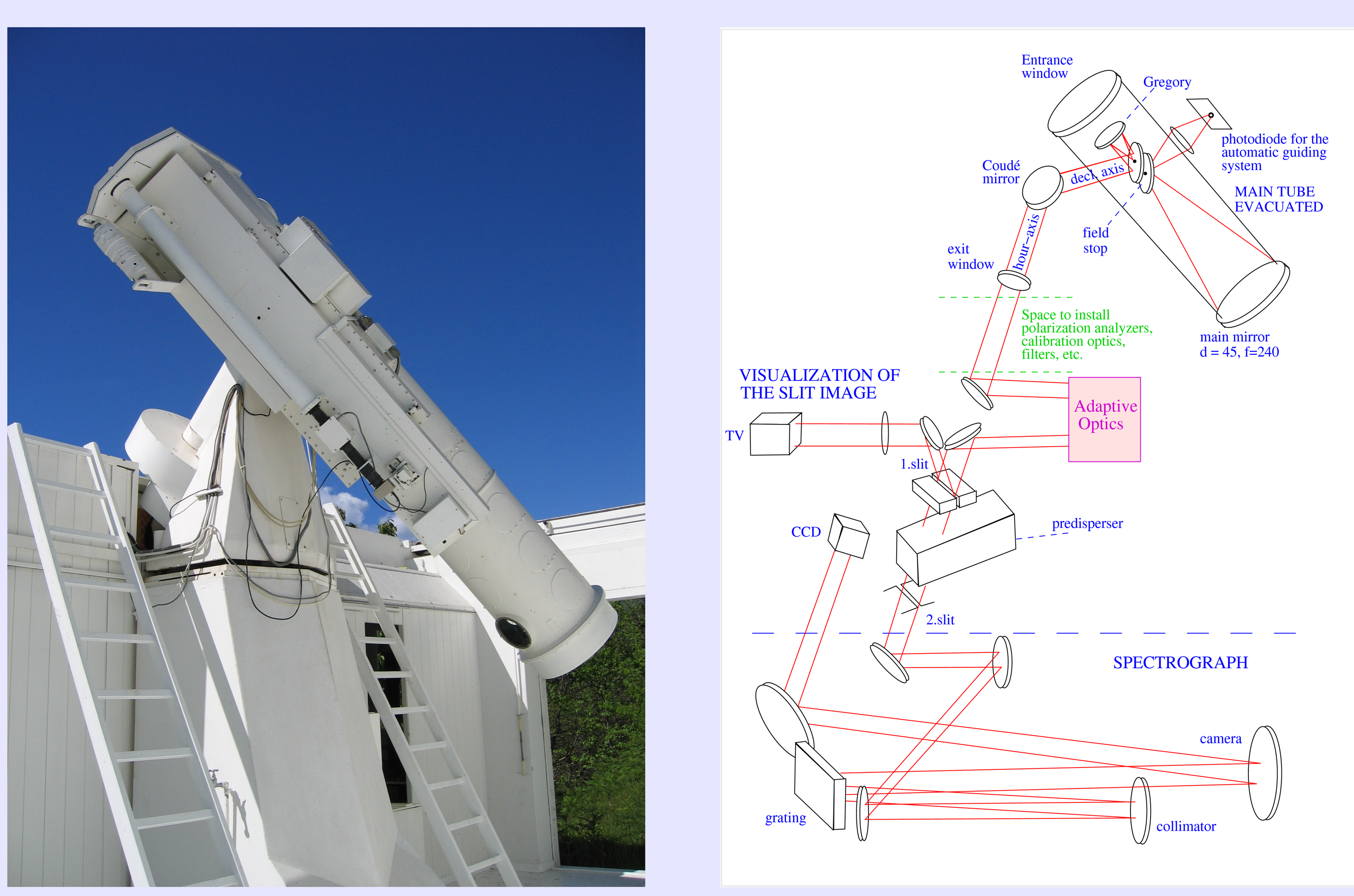

Fig.1 The 45 cm Gregory Coudé Telescope @ IRSOL and the optical scheme for observations with the spectrograph

2. The AO system

Basic features of the AO system:

Tip-tilt mirror: Three-piezoactuators PSH8, Piezosystem Jena

Deformable mirror:
37-actuator, 15 mm diameter, membrane micromachined deformable mirror, Okotech

Wave-front sensor:
Shack-Hartmann wave front sensor, Dalsa CA-D6 CCD camera 256x256 pixel, 1kHz frame rate, and special lenslet array generating 16x16 subapertures on the CCD

Reconstruction and Control platform: 2 GHz pentium running Linux **Real Time** RTAI

Online analysis tools: based on scicos/scilab allow an immediate graphical visualization e.g. of the applied corrections

Software:

- The software is completely open source
- RTAI allows to add hard real-time and determinism capabilities to the normal Linux OS.
- In order to allow the calculation speed needed for a closed loop at 1 kHz, MMX and SSE instructions provieded by Pentium III are used to efficently calculate the sum-of-absolute differences between reference and images for various displacements and to correct for dark and flat field. The needed algorithms have been developed by Keller et al.(2003)[4]
- The software allows to select a single axis correction mode that works very well for limb tracking.

2.1 The optical design

The optical design is shown in Fig.2. Some remarks:

- The folding mirror (FM1) and the beam splitter (BS) form a block that can be simply removed if one wants to observe without AO.
- The spherical mirrors (SM1 and SM2) form a telecentric system so that the optical characteristics of the light beam are the same with or without AO.
- Tip-tilt mirror (TT) is re-imaged on the spectrograph grating so that tip-tilt corrections don't move the beam on the grating.
- The image of the pupil is created between TT and Deformable Mirror (DM).
- A glass parallelepiped (SP) allows to shift the beam before the field stop (FS) of the Shack-Hartmann wave front sensor. This allows selecting the subframe on which the correction is applied. It is convenient to use it also for scanning or for choosing the limb distance in limb tracking mode. The SP movement is controlled by a step motor or manually.
- The Lens L1 focus the pupil on the micro lens array (MLA).
- A copy of the system is available in laboratory for tests and characterization.

Additional remark: the Spectrograph Slit (SS) block can be moved away on rails when observing with the Fabry Perot filter system

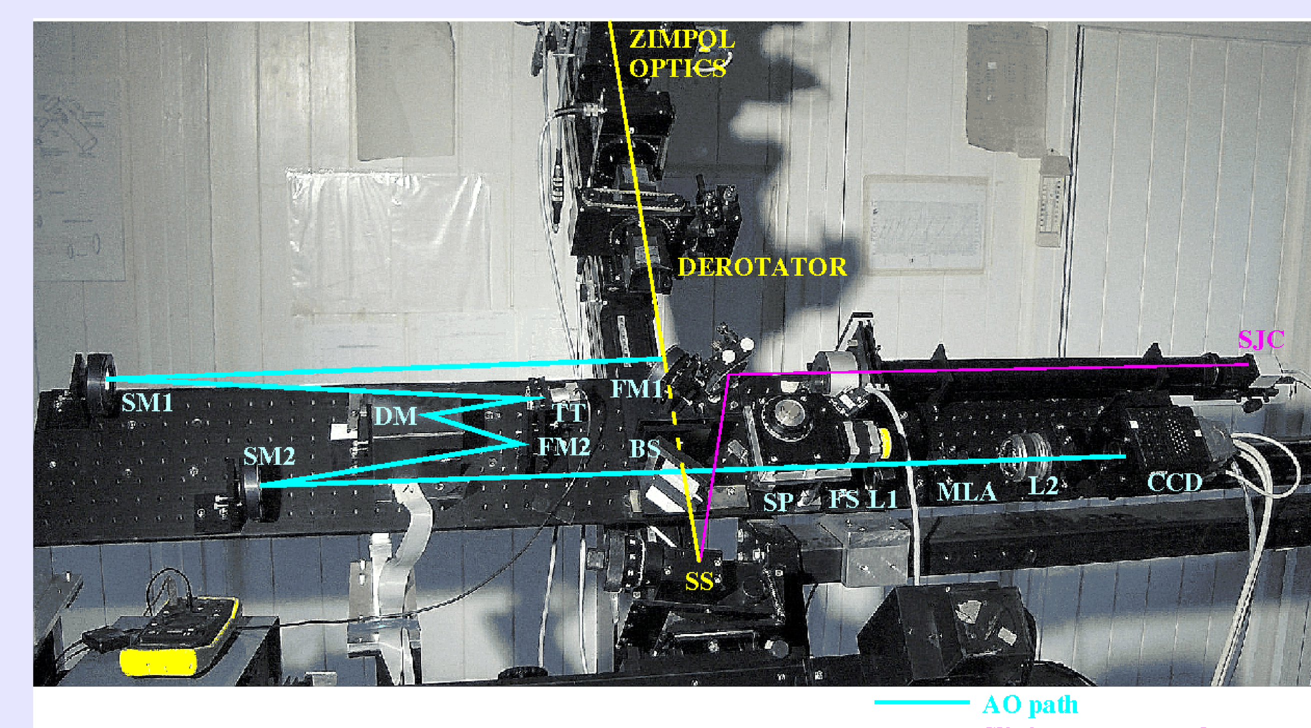

Fig 2: The optical bench with the AO system. (For details see text).

3. Results from tests with AO

In Figure 3 we show an example of observations of a small sunspot group with the AO with average seeing conditions in open and in closed loop. The images have been obtained averaging 60 frames of 30 ms exposure each, recorded with the slit-jaw camera (SJC) at a frame rate of 2Hz. The oscillation of the center of gravity of the largest spot on the right is plotted on Fig. 4. One can see a clear improvement in the image stability when the AO is in closed loop.

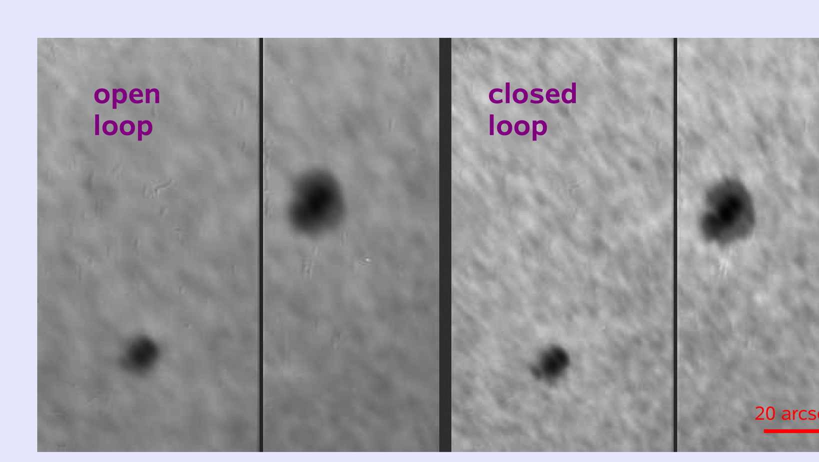

Fig.3 Sunspot group observed in open and closed loop. Images obtained averaging 60 frames recorded during 30 seconds.

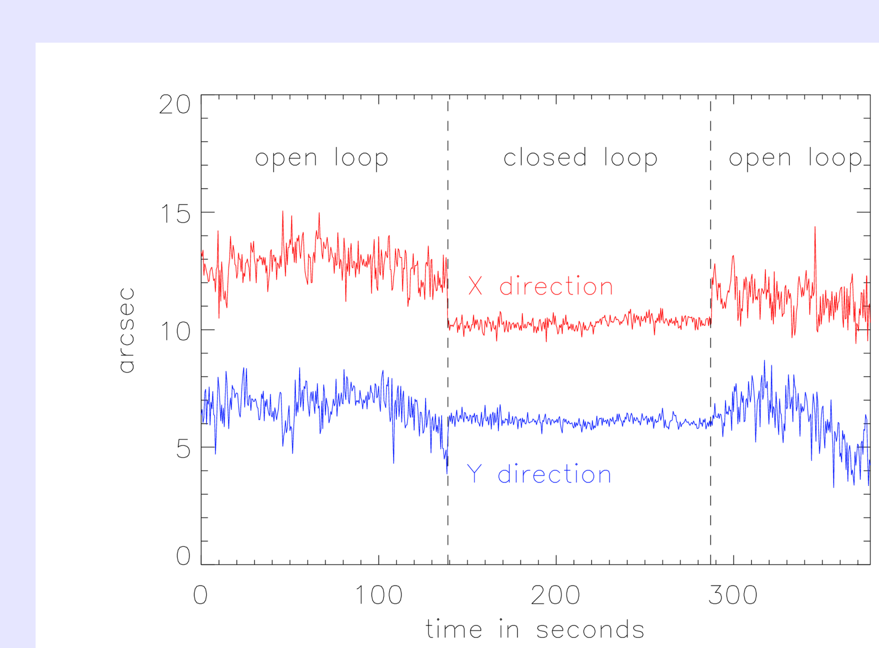

Fig.4 Movement of the center of gravity of the largest sunpot shown in Fig.3

4. Concluding remarks

We could successfully test our AO system at IRSOL on sunspots and for limb tracking. First scientific observations have been obtained taking advantage of the limb tracking system[5].

Our AO system shows that the concept of the system, that has been originally developed by Keller et al.(2003) for the infrared AO at the McMath-Pierce telescope, works as well in the optical range. New features that were added to the IRSOL AO, with respect to the original Keller's design, include the installation on a Real Time OS (RTAI), the inclusion of online analysis tools, and a reorganization of the software in a modular form which allows a more efficient development

In future we plan to further work on the optimization of the system, taking advantage also of the presence of a copy of the system in the laboratory.

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