Multiple guide star tomography demonstration at Palomar observatory

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Abstract

This paper gives an overview of the multi guide star unit (MGSU) tomography instrument at the Palomar Observatory, and presents some initial results from the data collection and analysis that took place during January and February of 2006.

Introduction

The multi-guide-star unit (MGSU) is a tomography validation experiment carried out at the Palomar Observatory. The aim is to make synchronous wavefront measurements on 4 stars within a 60″ field of view, then use three channels to make a prediction for the wavefront at the fourth position, where the fourth wavefront sensor (WFS) acts as a "truth" sensor.

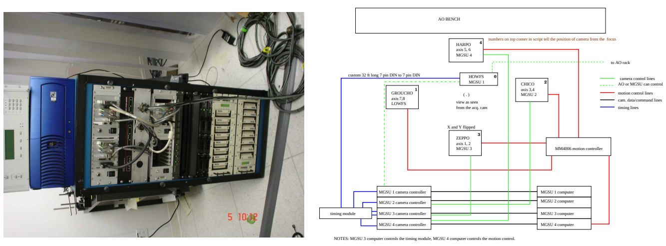

Figure 1: Left: MGSU electronics rack, 8-channel motion controller, test PC, camera controller, NPS, 4 1U Dell PCs, 3.2 TB of data storage on 2 RAID disks. Right: control schematics diagram.

System description

The MGSU operates together with the high-order wavefront sensor (HOWFS) of the Palomar AO system as a single synchronized unit. The main features of the MGSU are (see also Figs. 1 and 2):

- 4 low-noise 64 × 64 pixel SciMeasure CCDs
- 16 × 16 sub-apertures per camera head
- 3 steerable pick-off arms to acquire stars
- synchronized frame recording from up to 2 kHz

The SciMeasure cameras have a measured $3e^{-}s/sec$ read noise at 500 Hz. A custom timing module is used to trigger the recording sequence in all cameras (MGSU+HOWFS) synchronously, as shown in Fig. 1.

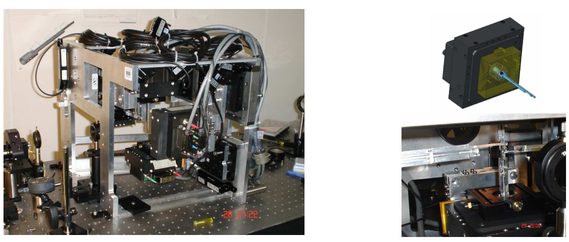

Figure 2: Left: MGSU as built: 4 WFSs mounted on X/Y translation stages. Right: 3D rendering of pick-off arm (top); closeup of three arms in position in the MGSU (bottom).

Field tests

The instrument has been successfully deployed on the 200″ telescope at Palomar during two observation runs in January and February of 2006. An asterism spanning 45″ and V magnitude 8.43-10.21 was selected, and data recorded at 32-256 fps with fast-steering mirror (FMS) loop closed. The principal goal of the data analysis is to measure the tomographic wavefront estimation error. By comparing various wavefront reconstruction algorithms on both the MGSU data and simulated data, we can assess the validity of current theoretical models.

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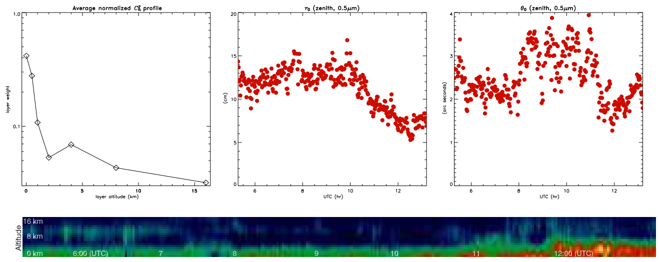

Figure 3: MASS/DIMM data for 10-11 Feb 2006 MGSU data collection run. Left: average normalized C_n^2 profile. Center and right: time evolution of r_0 and θ_0. Bottom: evolution of C_n^2 (logarithmic altitude scale).

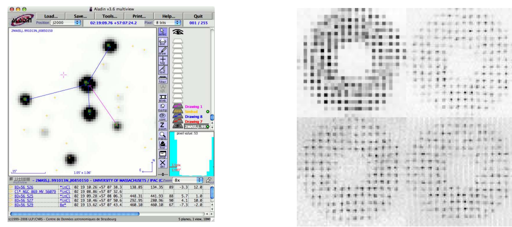

Figure 4: Left: asterism in Aquila (SAO 23181) used for 10 Feb 2006 MGSU run (blue arrows; intended to use star at purple arrow, bot too faint). Right: sample WFS spots from the four cameras.

Data analysis

Sample results of the analysis are shown in Fig. 5. The wavefront w was here estimated from the MGSU measurement v through the linear sequence:

$$w = HG^{+}\widehat{u}, \quad \widehat{u} = Ev, \quad E = \langle uv^{t}\rangle\langle vv^{t}\rangle^{-1},$$

where G^{+} is the pseudo-inverse of the HOWFS interaction matrix, and H is a set of influence functions. E is the statistical Wallner least-squares tomographic estimator, where u is the HOWFS centroid vector. For one data set (UT0335 2/10/06) of 40000 frames recorded at 256 fps (FSM loop closed) and 1.27 air masses, this estimation returns a residual error of 231 nm, out of 598 nm total estimated from the HOWFS.

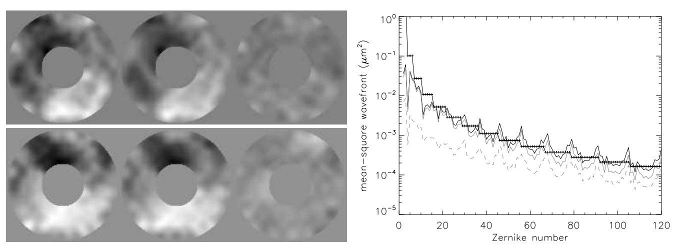

Figure 5: Left: two sample analysis frames, with the FSM loop closed on the HOWFS. Left pupils: wavefronts reconstructed from HOWFS ("truth" wavefront). Center pupils: wavefronts estimated from MGSU. Right pupils: residual wavefronts. Right: mean-square wavefront error per Zernike coefficient (pluses: Kolmogorov theory; solid: HOWFS estimate; dashed: residual error).

Future work

Work currently being pursued for the data analysis include:

- MAP and analytical/simulated Wallner estimators
- cross-validate with predictions from simulation
- expand analysis to additional data sets that cover different atmospheric conditions