CELT Report

The Gemini active-optics wavefront sensors - guidelines for the CELT telescope-control wavefront sensor

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1 Introduction

Because of the very large number of degrees of freedom of the CELT primary mirror (up to 3000), the active mirror-control wavefront sensing will have to be handled by two distinct systems, a telescope-control wavefront sensor (TCWS) for the lowest spatial frequency modes (a few tens) and displacement sensors for the remaining high spatial frequencies. The displacement sensors will be a simplified version of the Keck displacement sensors. The TCWS is likely to resemble the Gemini or VLT active-optics wavefront sensors (aOWSs). This report summarizes information acquired about the Gemini aOWS during a visit to Gemini North (Hilo and Mauna Kea, Hawaii) on September 13, 2000.

2 The Gemini active-optics wavefront sensors

The Gemini telescopes are designed to provide a single focus (Cassegrain). This design makes it possible to install permanent active-optics and adaptive-optics systems and no on-instrument versions of these systems are required. As a result, the aOWSs are part of a permanent acquisition and guiding unit (AGU). The AGU is continuously in use and needed for all instruments; it is treated as a facility instrument. Its design strategy has therefore been to produce a high-quality (and consequently not cheap) instrument that can be relied on for continuous use.

It should be noted that the Gemini AGU serves many more purposes than the control of the primary mirror shape. As the name infers, two of the major purposes of the unit are the acquisition of science objects and guiding on off-axis guide stars - which, at the same time, are used by the wavefront sensors to control the mirror shape. Information in this report does therefore partially refer to a system that is much more complicated than an individual TCWS for CELT needs to be. This information is included nevertheless as it is worthwhile to consider whether a combination of systems such as the Gemini AGU could be useful for CELT.

While the Gemini AGU is now working routinely, its testing phase has not been completed yet and some of the information given below has to be treated as approximate.

2.1 System overview

The wavefront sensors of the Gemini AGU control the active optics system, that is, the system controlling the primary-mirror figure as well as the relative position of the primary and secondary mirrors. There exist three different wavefront sensors:

1. A high-resolution wavefront sensor with 20×20 subapertures. This wavefront sensor is installed on-axis and only used for calibration purposes. It cannot be operated simultaneously with science observations. The calibration is performed only sporadically at the moment and it is not known how often it might be required.

2. A low-resolution wavefront sensor with 6×6 subapertures. This is the wavefront sensor used in standard operation. The proposed TCWS for CELT might be very similar to this system. Unless noted otherwise, the descriptions in the following sections refer to this wavefront sensor.

3. A ultra-low-resolution wavefront sensor with 2×2 subapertures. This system can only be used to control the tip-tilt and focus terms of the mirror system.

All three wavefront sensors are of the Shack-Hartmann type. The Gemini staff also performed one successful test using a curvature wavefront sensor which provided higher resolution of the primary mirror surface distortions than the standard systems. Such high resolution was, however, not deemed necessary and the simpler Shack-Hartmann sensors are largely sufficient for the active optics system. During one calibration phase, the AGU has also been installed at prime focus position in place of the secondary mirror. This enables the Gemini staff to distinguish primary and secondary mirror aberrations. The prime focus operation of the AGU is described in Sebag et al. (2000).

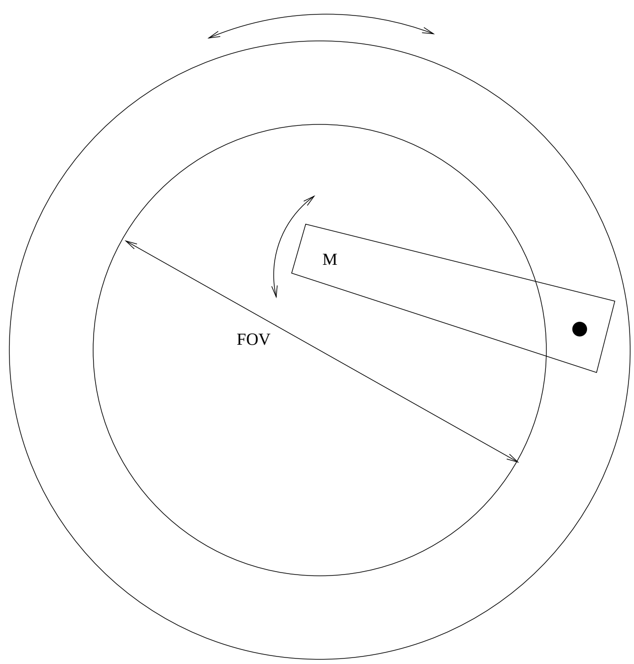

Figure 1: Schematic of the pointing system of the 2 low-resolution wavefront sensors. A rotating arm is mounted on a ring which surrounds the field of view and which is itself free to rotate. The combination of the two rotations allows the point M to reach every point in the instrument plane. A fold mirror is installed at point M. The entire wave front sensor is mounted on the rotating arm.

2.2 Guide star acquisition

A guide star can be selected anywhere in the 6 arcminute field of view of the wavefront sensor. The guide star needs to be centered with "high precision" (no value available) which is done with a 2-degree-of-freedom stage. Two rotating stages permit the wavefront sensor to point to any position in the field of view (see Fig. 1).

The exact limiting magnitude of the guide star is not known yet. According to the Gemini staff, there have not yet occurred any problems finding an appropriate guide star in the field of view. As the wavefront sensors are only used to correct for low-frequency aberrations ($\leq$ 1/60 Hz), the integration time can be increased to adjust for fainter guide stars. In practice, an optimum integration time, t_i, for a given guide-star magnitude is determined. A total of $60\text{s}/t_i$ exposures are then added to produce a one-minute integration so as to average out atmospheric effects.

Until now, guide stars down to magnitude 13 have been used. Note: The magnitudes given in the appendix "Acquisition Camera Sensitivity" refer to the acquisition camera and not to the wavefront sensors (guiding system).

2.3 Optical and mechanical design

Copies of technical drawings of the system were provided by the Gemini staff. They are not included in this report because we do not currently dispose of any descriptions of the components shown on the drawings. However, overviews over certain aspects of the system can be found on the acquisition and guiding section of the Gemini website (see Section 4 for address). As the system is still in its testing phase, some information is not yet available, on the website - or, as a matter of fact, known in general. More information might be posted in the near future (a lot of information was added from August to October 2000).

Note: Some of the appendices refer only to the acquisition camera system and not to the active-optics wavefront sensors. They are nevertheless included as they might be useful for other parts of the CELT design.

General design comments:

- Due to its status as a facility instrument, the Gemini AGU required approximately the budget and time of other facility instruments, that is in the case of Gemini, approximately $1 million and 3 years. There is no apparent reason why it should not be possible to keep the CELT TCWS, which resemble only a small part of the Gemini AGU, much simpler and on a lower budget. It needs to be decided, however, what status (facility instrument, auxiliary system, on-instrument wavefront sensors) the CELT TCWS shall attain. As mentioned before, it is also worthwhile to consider whether a combination of systems into a more complicated instrument would be advantageous for CELT. These decisions will have an important influence on the cost and time required for the design and construction of the TCWS.
- The entire Gemini AGU was sub-contracted. This is again based on the facility-instrument philosophy which requires complete optical, mechanical, thermal, etc. analyses that were too complicated to be performed by the small Gemini team. The design and construction of the system was first split between the Royal Greenwich Observatory (RGO) and Carl Zeiss Jena GmbH. When the RGO was shut down, Zeiss took over the entire design and construction.

- There were no major pacing items in the design.
- Main lesson learned: Plan a detailed and sufficiently long testing phase. This was neglected for the Gemini AGU.
- The Gemini system provides an image derotator but no pupil derotator, as such a system is not necessary for a monolithic mirror telescope.

2.4 The CCDs

The two low-resolution wavefront sensors use Marconi (formerly EEV) CCDs #39 (80×80 pixels). The high-resolution wavefront sensor uses a Marconi CCD #47 (1024×1024). They were chosen for their low readout noise and perform approximately according to their specifications (available on the Marconi website). The exact choice of the CCDs is not critical. Data sheets for the Marconi CCD39 and CCD47 are attached to this report. Also attached is the acquisition camera detector section from the Gemini website (which is the same as the high-resolution wavefront sensor camera).

2.5 Image processing

- Dark frame is subtracted.
- No flat-field correction is performed because acquisition is supposed to start immediately when the telescope is pointed to a new star.
- Centroiding algorithm for Shack-Hartmann sensor: standard quad cell. algorithm
- No cosmic-ray protection.
- No wavefront reconstruction; influence matrices are used directly to find the actuator commands for the primary mirror. The influence matrices were determined during the calibration phase.

2.6 Operation and performance

Note: The Gemini AGU is still in its testing phase and some of the statements in this section need to be considered preliminary.

- Apart from the choice of the guide star which needs to be chosen manually for each object of observation, the system is completely automated. Once a guide star is selected, the wavefront sensor points to it automatically and acquisition can begin immediately. A guide star can be chosen from a number of standard catalogs (ESO, Hipparchos, ...).
- Operating bandwidth: $\approx 1/60$ Hz
- No adjustments for seeing effects are provided.
- Duty cycle: 100%
- No information about open-loop performance or error measurements are available at this time.

3 Conclusions

Technically, the TCWS does not provide any major problems and should easily be feasible with current technology. The number and location of the CELT foci will have an important effect on the design and cost of the TCWS. Having several foci might require a number of on-instrument wavefront sensors. On the other hand, if the TCWS is provided as a facility instrument, high reliability should be one of the main concerns, making the specifications more demanding and more expensive than what would be necessary for on-instrument wavefront sensors. The best compromise of the possible solutions needs to be found based on the general optical design of CELT. It should also be considered whether it would be advantageous to combine the TCWS with other systems as it is done in the Gemini AGU.

4 References

Gemini Prime Focus Wavefront Sensor, J. Sebag, D. Walther, P. Gigoux, J.M. Oschman, C. Cavedoni, Proc. SPIE Vol. 4004 (2000).

The acquisition camera section of the Gemini website:
http://www.gemini.edu/sciops/telescope/acqcam/acqIndex.html

5 Attachments

- Marconi CCD47 and CCD39 specification sheet (47.ps and 39.ps)

Gemini website sections:

- Acquisition camera introduction
(http://www.gemini.edu/sciops/telescope/acqcam/acqIntro.html)
- Acquisition and guidance unit layout
(http://www.gemini.edu/sciops/telescope/telAandG.html)
- Acquisition camera performance and use
(http://www.gemini.edu/sciops/telescope/acqcam/acqPerformance.html)
- Acquisition camera sensitivity
(http://www.gemini.edu/sciops/telescope/acqcam/acqSensitivity.html)
- Acquisition camera filters
(http://www.gemini.edu/sciops/telescope/acqcam/acqFilterList.html)
- Acquisition camera detector
(http://www.gemini.edu/sciops/telescope/acqcam/acqDetector.html)