CHARA TECHNICAL REPORT

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CHARA's Wobblers: Preliminary Specifications

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1. INTRODUCTION

The basic function of the tilt correction servo will be to keep the interfering beams of the seven optical inputs of CHARA parallel. If the difference in beam tilt is too large, losses in signal to noise ratio will occur in the visibility measurements of the interferometer. The servo must track a star image to a precision of 0.1 of an arcsecond on the sky with a large enough bandwidth to cover the spectrum of tilt caused by the atmosphere and any vibrations of the telescope structure. The range of frequencies required is of the order of tens of hertz extending as far as perhaps 50 Hertz. Due to the effect of the reduction in beam size imposed by the input telescopes, the angle of tilt is increased by a factor of eight (8), reducing somewhat the precision required from the wobbler mirrors. The wobbler mirror position signals, after passing through suitable low pass filters, will also be used as guidance signals for the input telescopes.

This document is a preliminary requirement specification for some of the components of the wobbler system for CHARA. Most data has been based on the wobbler system developed for the Sydney University Stellar Interferometer (Davis et al, 1994; ten Brummelaar, 1994).

2. THE TIP/TILT SYSTEM

There will be seven (7) tip/tilt systems in the CHARA array, one for each telescope. Each telescope will reduce the beam size by a factor of eight (8), producing 12.5 cm beams. These beams will then be directed down an evacuated light pipe for up to 200 m, through an optical path length equalizer (OPLE) of up to 70 m, undergo a second beam reduction by a factor of five (5) and on to the beam combining/detection system. The tip/tilt system must not only ensure that these beams reach the end of the optical chain it must also correct for tilt imposed by the atmosphere. The detector system for the tip/tilt servos will be placed as far back along the optical chain as possible, probably just before the beam combining system. By this time the beam size is 2.5 cm and any tilt in the beam has been magnified by a factor of forty (40). The wobbler mirrors themselves will be as close to the input telescopes as possible. One possibility is that the secondary of each telescope itself becomes the active component, although it is more likely to be the flat mirror directing the beams down the light pipe.

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2.1. Detection System

The input telescopes should be capable of open loop pointing to within a few arcseconds which implies an error of arcminutes at the detector position. The detectors must therefore have a large field of view (which need not be linear at the extremes) as well as a precision of better than 1 arcsecond. The quantum efficiency of the detectors is also very important. When the tip/tilt servo fails, the entire array fails: the limiting magnitude of the interferometer is defined by the tip/tilt system.

No matter which scheme is chosen, the mounts for these devices must allow for correct optical alignment of the detector system internally and with respect to the rest of the instrument optics. These mounts must also allow the vertical/horizontal adjustment of the detectors for alignment of each of the seven beams with respect to each other. An eighth detector will probably be used as a reference for this task.

2.1.1. How Many Pixels?

The first question to be addressed is how many pixels should be used in the tilt detection device? Of the interferometers operated or under construction to date as far as I know only the Mark III used any more than four pixels (Clark et al, 1986). Their performance was no better than the wobbler system used in SUSI. Four pixel devices are commonly called quadrant detectors.

There are a number of reasons for choosing quadrant detectors. First of all, as little light is available, the system has to have the highest quantum efficiency possible. This means photon counting array detectors, such as the PAPA camera (Papaliolios and Mertz, 1982), would not be suitable. In a quadrant detector the light is split into only four pixels, thus ensuring the maximum illumination, and therefore signal to noise ratio, in each pixel. Furthermore, the system must be fast, due to the very short cycle time required. This rules out large pixel number CCD systems due to their comparatively long readout time. Silicon avalanche photodiodes can now achieve high quantum efficiency (Nightingale, 1991), so they would be good candidates for use as single pixel detectors.

The thesis by Buscher (Buscher, 1988) contains an excellent discussion of these problems. In particular he shows in Chapter 5 that a quadrant cell detector is the optimal linear estimate for image position given a noisy input signal. He goes on to show, via a number of numerical simulations, that the knife edge criterion used by a quadrant detector performs as well as the *centroid* criterion which equates the center with the center of gravity of the image. Atmospheric noise, that is, the remaining Zernike coefficients of the wavefront after tilt has been corrected, is also discussed and tested by numerical simulation and is shown to contribute no more than 30% to the error of beam tilt measurement. This error is never large and we may therefore neglect this effect.

Quadrant detectors have therefore been chosen for the baseline design of the wobbler system for the CHARA Array. See proposal appendix O for some useful formulae for use with quadrant detectors. There are three possible schemes under consideration: optical pyramids, CCD cameras (binned into four quadrants) and a bundles of squared off optical fibers.

2.1.2. Optical Pyramids

Optical pyramids split the image of the star into four parts by focusing the stellar image onto two separate knife edges, one vertical and one horizontal. Each knife edge is created by a prism made from two optically contacted rhombs and constructed from BK-7 glass coated for best transmission in the blue. Two lenses are also required to image the vertical edge of the detector onto the horizontal edge. The pyramid design is based on the pyramids used in an interferometer which was originally built by R. Q. Twiss at the National Physics Laboratory (UK) and later rebuilt at the Italian outstation of the Royal Observatory, Edinburgh and was also used in the Sydney University Stellar Interferometer (SUSI) in Australia. Refer to figure (1) for a drawing of the detector optics.

The alignment procedure of the optical pyramids must ensure that:

- The image is properly focused onto both knife edges. If the image is not correctly focused the detector sensitivity will be reduced.
- The optical axes are normal to the prism surfaces. Since the knife edges are within glass, dispersion will result in the image being spread across the knife edge if the light is not incident normally. This will also reduce detector sensitivity.
- The horizontal edge is parallel to the optical table surface and at the correct height.
- The vertical edge is normal to the horizontal edge.

This scheme offers a large field of view, although not linear beyond $\pm 2''$, and a quantum efficiency largely determined by the light detectors used at the back end, probably avalanche photodiodes. Optical pyramids also form something very close to 'true' knife edges, with very small dead zones between the active areas.

The disadvantages of this system are the large amount of glass the beam must pass through, the tricky nature of alignment and the probable high cost of manufacture.

2.1.3. Optical Fiber Bundle

This scheme is similar to that used for the Multi-Telescope-Telescope built by the CHARA group at GSU. Four fibers are bundled together to form a quadrant cell. The advantages of this method lie in the simplicity of the system; little alignment will be required. Unfortunately, as fibers are circular a large dead zone will be created if they are simply bundled together into a quadrant detector. The fibers will therefore have to be squared off before they are joined, a procedure that may be more difficult than it seems. The other disadvantages are the small field of view, the difficulty in getting light into the fibers and the fact that this scheme has never really been proven.

2.1.4. CCD Camera

CCD cameras are probably the most common form of detection scheme in tip/tilt systems for interferometers. A relatively small array is required. For example the IOTA group use 24×24 arrays, breaking it up into four large pixels for acquisition and then using only the central four pixels for fast guidance. The advantage of this scheme is that it is well understood and tested. The disadvantages may lie in signal to noise problems and the speed at which the CCD's can be read. The availability and performance of small pixel number CCDs should be investigated as well as the possible cost.

2.1.5. Discussion

It is my feeling that their are too many unknowns and too little experience in using optical fibers to make them a viable option, although further experience with the MTT may change

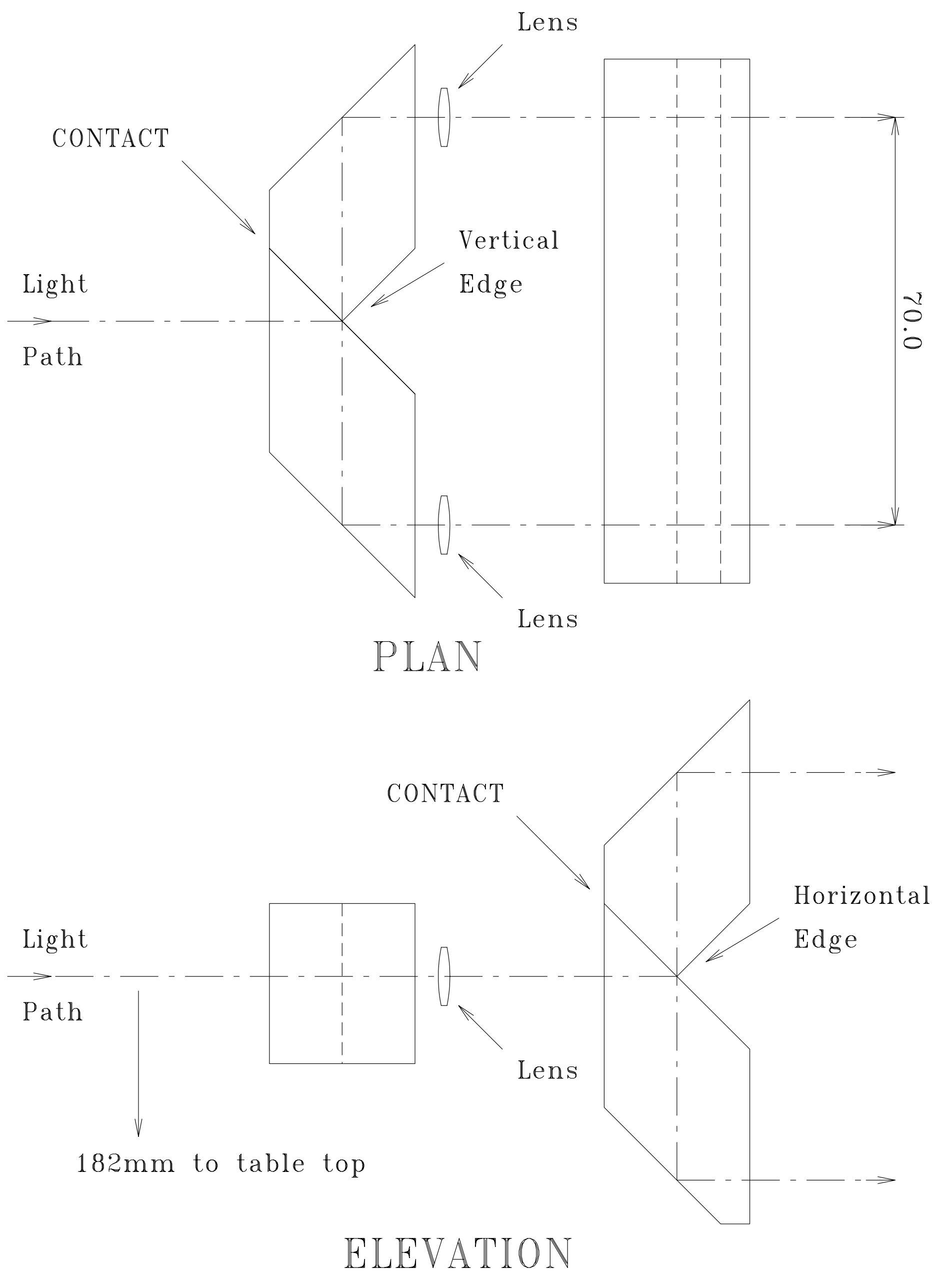

FIGURE 1. Plan and elevation of quadrant detector optics used in SUSI. The dashed line represents the light path through the optical system. Dimesnions in mm.

this. The choice therefore, is between a CCD system and an optical pyramid.

The CCD wins over the pyramid due to the simplicity of the system, the ease of alignment and the fact that off the shelf products are available. The pyramids win over the CCDs due to their better signal to noise, speed (depending on the back end detectors, which also offers an easy upgrade path) and small dead zone. I think cost will be the decider here and suspect that a CCD system will be cheaper.

2.2. Tip/Tilt Mirrors

If the secondaries of the telescopes are chosen for implementation of tilt correction they should form a part of the telescope requirement specification. It is, however, likely that the telescope manufacturers will supply only the secondary optics and mounting arrangement. The drivers for wavefront tilt correction will therefore need to be purchased and installed separately. If the input flats to the light pipes are chosen only a single contract will be required.

Wobbler mirrors are quit common now, although no commercial off the shelf mirror is available in the large size required for the CHARA Array. The mirror must handle a 12.5 cm beam. In the case of the input flat this will be at a 45° angle, implying a mirror with a diameter of at least 17.5 cm. In the case of the secondary, based on the original CHARA proposal, the size of the mirror will be of the order of 24×4 cm implying a mass of approximately 4 kg. The bandwidth specifications for the two versions will be the same, although the positioning precision and minimum/maximum throw specifications will be slightly different. The following specifications assume the flat mirror will be used, but also form a baseline specification for using the secondary.

2.2.1. Throw

Assuming that the telescopes will create no more than a 5 arcsecond open loop pointing error and the atmosphere could add up to another 1 to 2 arcseconds error, the throw of the mirrors must be at least $(5+2) \times 8 = \pm 56$ arcseconds. Based on experience at the Sydney University Stellar Interferometer (SUSI), a maximum throw of some four to five times this minimum will be required to make up for inevitable tracking problems and alignment errors. A maximum throw of some ± 5 arcminutes will therefore be necessary.

2.2.2. Bandwidth

The bandwidth of movement must be large enough to track the atmosphere and any vibrations in the telescope structure so should be at least 25 Hz and over small angles (that is, across the minimum throw) and possibly as high as 50 Hz. The bandwidth for full throw need not be as high. Furthermore, no large resonances should exist within the usable bandwidth of the device.

2.2.3. Pointing Precision

In order to get the beams all the way through a light path of the order of 300 m and not have the beams misaligned by more than 0.5 mm, the precision of positioning must be of the order of 0.3 arcseconds. This should be regarded as an upper bound on the precision required and it would be an advantage to have better than this. As these mirrors are also the device used to send the beams down the light pipes the mounts used should allow larger adjustment, which may need to be motorized, although not at the high bandwidth required for tilt tracking.

2.2.4. Mirror Quality

The mirror surface will be required to be as highly reflective as possible and functional over the entire waveband of the CHARA Array (400 to 2500 nm). The surface should also be as robust as possible. While it will not be inside the vacuum system and will be largely protected form weather extremes it will be outside of the main optics building and difficult to remove and re-coat. The coating should therefore be very stable.

2.2.5. Pathlength Changes

A final requirement for both versions of wobblers is that they introduce as little phase change into the optical beam as possible. Any extra path length introduced or removed from the beam will affect fringe visibility. Furthermore, an introduction of pathlength by the wobblers can cause the OPLE servo to move. This, in turn, can cause a change in tilt causing a corresponding change in the wobbler servo. In this way the two servos can end up fighting each other, a situation to be avoided. No more than a small fraction of the coherence length of the light signals should be introduced into the beam when moving the wobbler mirror. This coherence length depends on the chosen optical bandwidth of the instrument but as a starting figure the change in pathlength should be kept to a few microns, and hopefully less.

2.2.6. Discussion

The major factor in driving the design of the wobbler mirrors is where they will be placed; at the telescope secondary or just before the input of the light pipes?

From the point of view of image stability at the back end, the mirrors should be as early in the optical change as possible, making the secondary an attractive solution. The mirror specifications may also be relaxed somewhat in this case due to a possible larger beam size. This mirror will, however, be larger and heavier than the flat alternative.

The major problem with using the secondary, as I see it, is that more than one contractor will be involved with the system. The specifications for the telescopes and the wobblers will be mixed up as will the wiring for communications. The potential for the two subsystems not fitting together correctly looms large. Furthermore, who will combine the two parts?

More discussion should take place to resolve this issue.

3. CONCLUSION

A preliminary set of specifications was set out for the major components of the seven tip/tilt servos for the CHARA Array. Quadrant detectors have been chosen for tilt detection which will probably be small pixel number CCDs, although optical pyramids should be further investigated. The specification of the wobbler mirrors is closer to being finalized, although a decision has yet to be made between using the telescope secondary or the light pipe input mirror.

4. REFERENCES

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