CHARA TECHNICAL REPORT

No. 52 25 August 1997

Telescope and Dome Control Requirements

T.A. ten Brummelaar (CHARA)

1. INTRODUCTION AND GENERAL INFORMATION

The first major Array subsystem to be installed, and the first that we must get online, will be the telescopes themselves and their housings. Apart from the complex issues involved in making the control software correctly point and track the telescopes, a number of other subsystems will need to be properly controlled, including the dome, the dome slit, the tip/tilt system, the acquisition system, the mirror covers, environment monitors, stowing and power up cycles, switching power on and off to various subsystems, monitoring the incoming power itself, and possibly the atmospheric refraction correctors. In this document, I will try to describe all the control requirements for the telescope/dome assembly and, bearing in mind cost and man power issues, try to reach some conclusion about how we might go about developing the control system.

2. SYSTEM ARCHITECTURE

I feel that the best way to approach this control system is as recommended by Tom Schneider, and that is to use three computer systems: one to control the telescope (and perhaps the dome and slit), one to run the tip/tilt servo, and one to do all the other tasks, including supervising the other two computers. The computer controlling the telescope and dome can either be a PC running the 'Telescope Control Software' package (TCS) and bought as part of an integrated package from M3, or it could be a Compumotor type 6250 controller for which we would either need to develop the software ourselves, or have it out-sourced. The tip/tilt control computer would be a single-board computer (SBC), exactly as described in Schneider's report. The remaining computer, the main control computer, is a standard PC and would issue commands to the other computers in the dome. The outside world would only ever talk directly to the master control computer, which would interpret these commands and send the appropriate signals to the other two subsystems.

Here is a list of the subsystems in the dome that need to be controlled:

- The telescope itself.
- Mirror cover.

[1]Center for High Angular Resolution Astronomy, Georgia State University, Atlanta GA 30303-3083
TEL: (404) 651-2932, FAX: (404) 651-1389, FTP: ftp.chara.gsu.edu, WWW: http://www.chara.gsu.edu

- Dome rotation.
- Dome slit and dome cylinders.
- General power switching including the UPS.
- Acquisition system.
- Tip/Tilt.
- Focus and alignment of secondary.
- Possible vacuum relay mirror adjustments.
- Possible cooling/heating systems.
- Environment monitors.
- Safety TV-monitors
- Panic switches.
- Status information.
- Communication with the central scrutinizer.

Each of these subsystems will be dealt with individually, despite the obvious overlap between some of them.

3. TELESCOPE CONTROL COMPUTER

The computer that runs the telescope will be capable of accepting commands from, and reporting its status to, the main control computer, most likely via a serial port connection. It may also be helpful to have a hand-paddle type control capability as well as a local control inside the dome. There are five modes of operation for the telescopes:

1. Stowed.
2. Slewing to a new position.
3. Acquisition mode.
4. Open-loop tracking.
5. Closed-loop tracking.

3.1. Stowed

During the day, or at other times a telescope is not being used, it needs to be slewed to the stow position, which is as yet unspecified, and the control electronics powered down. It is likely that the telescope control computer itself will then be switched off by the main control computer in the dome, but it must then be capable of rebooting and starting the appropriate software to enable it to power up correctly.

3.2. Slewing

The telescope controller must be capable of slewing the telescope to a new position and to new velocities in each axis. It must perform this slew with high accuracy as it will be necessary to move between the science target and a calibrator object on a regular basis. The timing of the slew command is important as all telescopes will be required to move together. Thus, for example, it would be useful to be able to preset the next target and then only be required to issue a 'slew now' command to all five telescopes at once.

3.3. Acquisition Mode

Few telescope control systems can perform open-loop pointing accurately enough to acquire an object first time, every time, especially considering the rather small field of view of our optical system. Some form of search algorithm like a spiral will be required, particularly during the commissioning of each telescope and while we build up enough data for the flexure model. Furthermore a hand paddle interface will be very useful here, if not essential.

3.4. Open-Loop tracking

Part of the overall plan for the Array control system is to have a program called the 'astrometric model' running on the central scrutinizer in the control room. This model provides positions for all the components in the array so that each subsystem can be close to the correct position before any feedback loops are closed. If the TCS package is used, all that will be required is the target name or catalogue number. If we use the Compumotor system the astrometric model will need to be more complex and provide Alt and Az positions and rates.

3.5. Closed-Loop Tracking

Once the object has been acquired, the telescope control computer must be capable of accepting a tracking error signal from the outside, either from the acquisition system or the tip/tilt system, and perform closed-loop tracking. The main control computer in the dome will probably be required to send these control signals. The TCS package is capable of accepting error signals from commercial systems, such as SBIG cameras, but these use the game, or paddle, port. We need to find out if it is possible to send control signals in another way, preferably through the serial port command channel.

4. MIRROR COVER

While the mirror cover is logically part of the telescope control, it has been separated because it is unlikely that it will be part of either the TCS package or a Compumotor solution. Given that the correct limit switches, motor and gearing is installed on the telescope mirror cover, this should be a simple matter of turning power on or off to the mechanical system. We need to decide who will install and wire up these limit switches in the near future, and to ensure that the motor and gearing system are indeed already part of the telescope design.

5. DOME ROTATION

Again, this could be part of the telescope control system, and, in the case of the TCS package, it is. This should be a matter of moving the dome in one direction or another to a given position. The only added complexity is that the dome must not be allowed to move during an integration of the imaging system. This means it must slew to a position ahead of the telescope and wait there while the telescope tracks. At a time dictated by the central scrutinizer the dome may move forward again to get ahead of the telescope. These operations must be synchronized between all five telescope domes. While the TCS package does include dome control, we need to ascertain whether this kind of functionality is available, specifically if it is possible to prevent the dome from moving at specific times, and whether it can be made to move ahead of the telescope, rather than with it. If we do not use the TCS system, the main control computer in the dome will be responsible for moving the dome and we will have to program this functionality into the system ourselves.

6. DOME SLIT AND DOME CYLINDERS

Since all of the telescopes and their enclosures must be fully operational as a remote facility it is necessary that it is possible to open and close the slit automatically. The slit consists of two parts, an upper and a lower section, which require independent control. The slit can probably be activated by a series of relays or some other switching mechanism controllable by the main control computer. Apart from the slit, the enclosure cylinder walls themselves will be capable of movement, also with upper and lower parts. Once again I will assume this can be controlled via relays or some other computer controlled switching device.

Both of these systems will be operated by the main control computer and will be opened at the beginning and end of each night and when the weather turns bad. The enclosure walls may also need adjustment during the night. If we have a weather monitoring station in the domes it would be a good idea to have the slit and enclosure close automatically if rain is detected.

7. GENERAL POWER SWITCHING INCLUDING THE UPS

The main control computer in the dome must be capable of turning on and off every other subsystem within the telescope enclosures. Furthermore, there must be enough uninterruptable power supply (UPS) resources to at least shut the dome slit and shut the system down gracefully in the event of a power outage during a storm. It is unlikely that the main control computer itself will ever be switched off, except for maintenance purposes.

Some systems, like the slit, may simply consist of turning the power to a given motor on or off. Most of these are slaved to the main control computer and should never be switched on if the main computer is turned off. Simple computer controlled relays or switchable power supplies will suffice for most of these systems. Both the UPS and the hardware for switching power on and off should be controllable via a serial port.

The subsystems within the telescope enclosure can be placed into three groups. The first group consists of those systems essential to computer operation and the protection of the telescope. These essential systems, including the main control computer itself, will use the UPS. The second group are the additional systems needed to operate the telescope. The final group consists of everything else.

At least one light near the dome, and perhaps one inside, switchable from within the control room, is needed for safety. For example, a light could act as a warning to anyone nearby when the enclosure opens and shuts. It would also be helpful if all the lights inside the dome could be switched off by the main control computer.

8. ACQUISITION SYSTEM

The acquisition system hardware resides on the small optical table on the side of the telescope and consists of a pellicle that can be moved in and out of the beam, an imaging lens, and a bare or intensified CCD that provides a video signal to the main dome control computer. The control computer must be able to move the pellicle in or out of the beam and digitize the video signal. This digitized image is sent to the central scrutinizer and the operator is asked to identify the required target. Obviously this must occur in parallel with the search mode of the telescope described above. Linux drivers for many video digitizer boards are available free on Internet (see for example http://www.llp.fu-berlin.de/).

Once the target is identified, the system needs to perform some kind of centroiding on the object and produce an error signal for the telescope system. The origin for this error signal will change from night to night and will need to be a programmable variable. Normally the origin will be found by looking at a laser beam sent from the BCL/OPLE area and using the centroiding routine to find the spot.

During commissioning of the system, it is likely that the pellicle will be left in the beam at all times so it will be possible to monitor the telescope performance from within the control room. It may also be possible to use the acquisition system as a low frequency tip/tilt detector at the initial stages of Array development. Naturally video frame rates will be the maximum possible, but much less than that is adequate for acquisition.

9. TIP/TILT

The tip/tilt system is a high-speed digital servo with a cycle time of the order of one millisecond. The mirror position signal used for this servo is produced within the BCL by the tip/tilt detector/servo system and will be sent directly to the tip/tilt SBC via a serial line sent through a pair of optical fibers. The SBC will then take this signal, convert it to the appropriate voltages for the three piezos, and send that information to the piezo high voltage amplifiers. The connection between the SBC and the PZTs will be via three DACS, either custom built or purchased from Physik Instrumente.

Several modes of operation are necessary for the tip/tilt. Possible commands are to return to the zero position, track the incoming mirror position signal, or perform dithering operations for system checks. The SBC must also perform a filtering operation of the mirror position and send the result to the main dome control computer for use as a tracking signal for the telescopes as described above. The filter can be as simple as a 'bang-bang' threshold, where an error signal is sent whenever the tip/tilt mirrors are close to their stops, alternatively it could be a low pass filter. It will also be necessary to be able to log the output positions of the tip/tilt mirrors in order to calculate an estimate for the seeing parameter r_0.

One attractive possibility is to use the Physik Instrumente high voltage amplifier box itself as the SBC. This unit has a serial interface and three DACs that allow remote operation of the PZTs. Thus if the serial line is connected directly to this unit, no extra computer is necessary. All of the calculations between X/Y position and the three PZT voltages must then be performed by the detector/servo computer in the BCL, but this is not necessarily a disadvantage; it means there is only one set of code to write and debug. Furthermore, the telescope tracking signal and r_0 estimates will also be done within the detector/servo computer in the BCL and sent to the telescope itself via the dome main control computer. This greatly simplifies the telescope control software (and of course makes the tip/tilt detector/servo software more complex) and may not have the high bandwidth we will eventually require. The maximum baud rate of this device is 19,200, and 9 bytes of ASCII are required to set each axis, implying a maximum refresh rate of some 79Hz, and a Nyquist limit of about 40Hz. This will probably be enough in the first instance and is something we can get up and running very quickly. If we want to start with the simplest possible system the serial data for the PZTs could be sent via the main control computer through the Ethernet connection. Assuming a 50% efficiency of a 10 Megabit line, this data would only use 4% of the available bandwidth.

10. FOCUS AND ALIGNMENT OF SECONDARY

Apart from the PZTs that perform the small high speed movements of the secondary for tip/tilt correction, there are three motorized micrometers that enable focusing and gross alignment of the secondary mirror. These are controlled either from a card placed in the main dome control computer itself, or preferably (but at more expense), in a stand alone box with a serial port for communications. The internal card comes with DOS drivers and nothing else, so new drivers will need to be developed for any other OS, although they may be available for NT and/or Linux if we search around. It is partially for this reason that the stand alone box is more desirable. Another reason to choose stand alone units is that they contain their own power supplies and will not depend on the power supply in the computer itself.

The main dome control computer needs to be able to allow someone either near the telescope itself, or in the control room, to move these micrometers. Most often this will be for focus and will only consist of moving all three together, although on occasion it will mean some differential motion for alignment purposes.

11. POSSIBLE VACUUM RELAY MIRROR ADJUSTMENTS

At least some of the mirrors within the lightpipe relay system will be controllable from within the BCL/OPLE. This may consist of using a telephone to chat with someone physically near the mirror, sending a video signal down the fiber for a person adjusting the mirror to view locally, or actual remote control via the main dome control computer. The actuators are likely to be New Focus Picomotors, and so will be interfaced to the computer via simple TTL pulses, possibly produced by the printer port.

It is likely, though, that these mirrors will not have to be adjusted regularly, and so it is not a high priority to have them as part of the dome/telescope control system.

12. POSSIBLE COOLING/HEATING SYSTEMS

There may be HVAC systems in the domes that will need to be switched on and off remotely. This will either be via a serial port connection to the HVAC unit (if it is clever enough to have a serial port) or simply cycling the power.

It will also be necessary to have heating and/or cooling in the electronics rack inside the bunker. Hopefully this can be controlled by a simple thermostat, although it may be helpful to have this monitored and/or controlled by the main dome control computer.

Another possibility is simple cooling fans in the telescope enclosure. These can be controlled in the same manner as the dome slit and lights, that is, using a switchable power supply controlled by the main control computer.

13. ENVIRONMENT MONITORS

As for the electronics rack, there may be environment monitors within the dome or above it; for example, a weather station or thermistors on the telescope itself. It is likely that these will once again interface via serial port. It is more likely that such monitoring systems will not be part of the initial setup but will be added at some future time.

One form of environment monitor we will want to install early on in telescope commissioning is smoke detectors in the bunkers and the telescope enclosures themselves. These should either be wired directly into an independent alarm system or monitored by the main control computer.

14. SAFETY TV-MONITORS

It is desirable to have a number of inexpensive TV cameras (probably CCDs) distributed around the telescope so that an operator can see what is going on from within the control room. Since a digitizer board is already necessary for the acquisition system, it should be relatively simple to multiplex several cameras to the same board. Most boards have the built-in ability to deal with several input signals. The resulting digitized images can be transferred via the Ethernet connection between the main dome control computer and the central scrutinizer. This will not be real-time, but one image per second or so should be more than adequate.

15. PANIC SWITCHES

For safety reasons, a number of kill switches need to be placed in various locations within the telescope enclosures. These should stop any motion of the telescope when pressed and should also probably be large and red. If we decide to use the Compumotor solution, this will simply be a case of wiring the switches to the appropriate connection on the controller box. TCS also has this kind of capability, although it is part of the software, rather than the motor drives themselves, and therefore less functional as a safety device.

A similar function must also be available in the control software itself, i.e. a ‘stop everything now’ command, usable from within the dome, the bunker and the control room, will be a good safety option.

16. COMMUNICATION WITH THE CENTRAL SCRUTINIZER

Since we are planning to run optical fibers between the central facility and each telescope bunker, the current plan is to adopt Tom Schneider's recommendation and use a TCP/IP connection through a pair of fibers between the main dome computer and the central scrutinizer. Any of the OS choices will be able to deal with this relatively easily, and the only real-time signal between the BCL and the telescope will be the tip/tilt mirror signal which will be running through a separate fiber pair as a serial signal.

An associated issue is correct synchronization of the system clocks of these various devices. The tip/tilt signal timing is controlled by the computer running the tip/tilt detector and servo in the BCL/OPLE. All other timing functions will be performed locally, in the first instance probably by the internal clock on the main computer CPU. If we use Linux, or another Unix flavor, many standard packages exist for clock synchronization via Ethernet. There are, undoubtedly, similar programs available for other operating systems, although at an added cost.

17. STATUS INFORMATION

The operator will need to be able to monitor the status of all systems within the dome. This should be relatively easy given a TCP/IP link to the main dome control computer, and it implies that this control computer should have this information at hand. This means we need to find out how much status information is available from the TCS package via the serial link.

Given this type of status information, we may make some of it available on a wider basis via Internet or even a web page, both for P.R. purposes and for remote monitoring of the site by Atlanta personnel.

18. HARDWARE LIST

The distinction between the control system and other subsystems within the telescope enclosures is not clear in a number of areas. For example, the high-voltage amplifiers for the secondary piezo drives can logically be placed within the tip/tilt budget. The extra money required to add the serial interface board to these amplifiers can either be placed within the tip/tilt budget, or added to the control system cost. Similarly for the micrometer motors for alignment and focus. In both cases I have placed the entire cost of the drive electronics and interface equipment into the control system budget, while I assume the cost of the micrometers and PZTs themselves will be placed within the telescope budget.

The cost of the computers has some uncertainty as well. Several people have recommended rack-mount industrial computer systems, which are significantly more expensive than standard domestic PCs. The main difference between the industrial and the domestic units are the electric shielding and the power supplies. In Schneider's report he quotes a figure of \$3.5K for such a device, whereas the current TCS quote is for \$12K, including all the various controller cards that go in it. I will stay with the figure used by Tom Schneider,

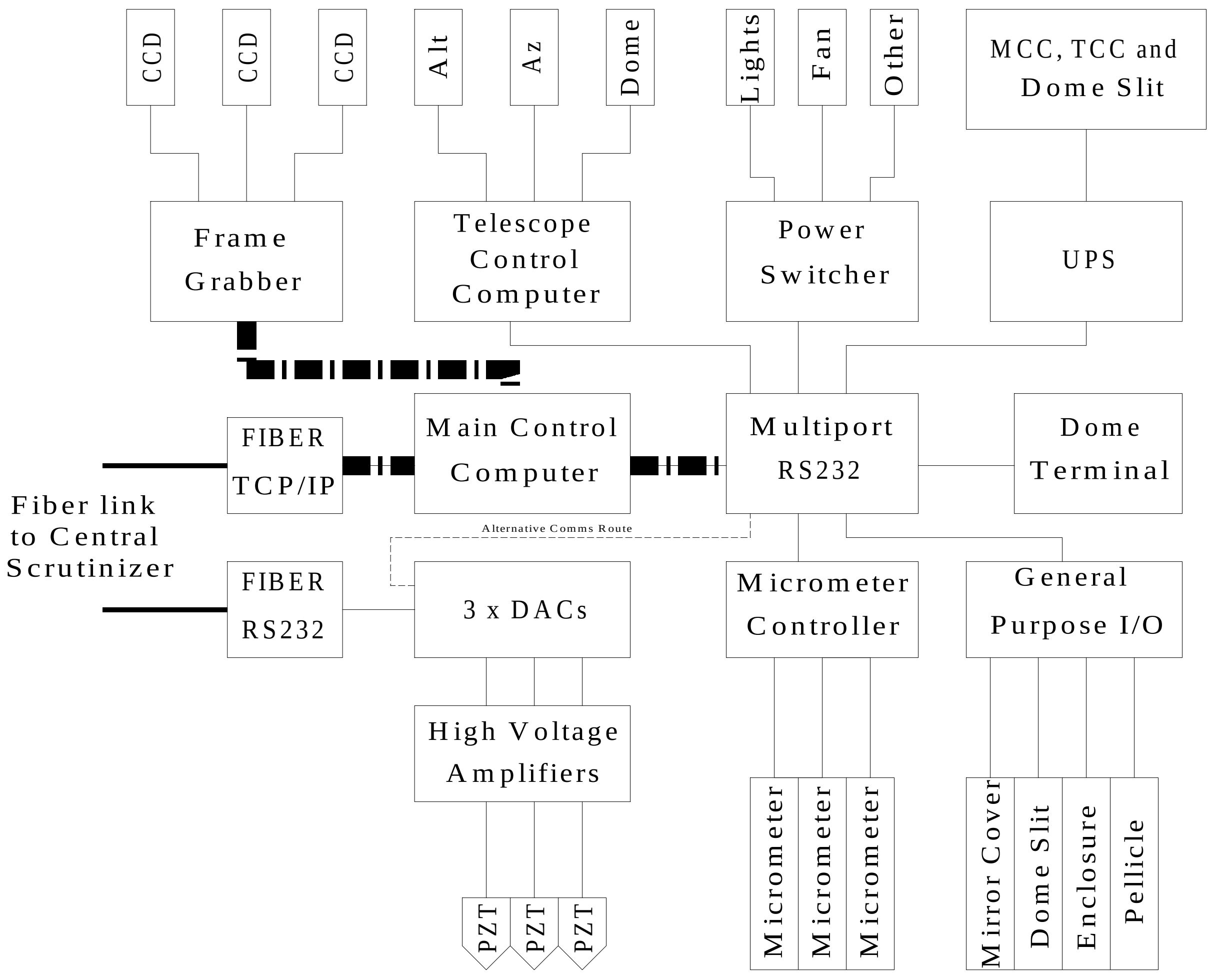

FIGURE 1. Schematic of the telescope control system hardware.

which matches figures found on the web, for the main controller computer. I will assume that we will use the TCS package for the telescope control computer and will include their figure of $12K, although I am sure we will be able to reduce that substantially.

The costs of running cables between the various subsystems and their controller's is also difficult to estimate, so I have added the somewhat arbitrary figure of $2545 for the cabling. Furthermore, the rack system itself has been included in the control system costs.

Some things will not be included in this cost estimate, for example the environment monitors and weather station, as they are assumed to be 'optional extras' that can be installed at a later date. I assume we will use the PI controller box as the tip/tilt SBC while the RS232 to fiber connection has been left in, even though it would be possible to do without it for a while. The text terminal in the dome is not included as I have assumed we can scrounge text terminals from within the campus.

Some quotes I have received seem outrageously expensive. For example, Physik Instrumente wants $3728 just to add a serial port and three DACs to their high voltage amplifier (which itself at $6755 is already pretty costly). I have found a rack-mounted device by a company called BayTech called their 'M-Series' that can hold up to six units; each unit can be multiple DACs, TTL pulse, ADCs and so on. Such a unit with 8 DACs and 8 TTL circuits (for throwing relays, for example to open and close the slit) retails for $1400. I have included this instead of the Physik Instrumente price. The cost of the Physik Instrumente micrometer control unit is also rather high, but I see no way to reduce that, unless we use the PC card version instead of the rack-mount version. However, I am opposed to using PC cards for these sort of things for the reasons outlined above.

TABLE 1. Control System costs.

Component	Cost
Telescope Control Computer (From TCS)	$12000
Main Control Computer (From TS)	3500
Multiple RS232 interface board ($500) — included in MCC	—
10/100M Ethernet Card ($100) — included in MCC	—
Fiber/TCP-IP interface (2×$690)	1380
Fiber/RS232 interface (2×$360)	720
Rack, thermostat and cooling fans (Guess)	1000
Uninterruptable Power Supply (???? Watts)	1000
Power switching unit	300
Video Digitizing Board	1700
TV/safety monitors (3×$333)	1000
Micrometer Controller Unit	4700
High Voltage amplifiers	6755
General Purpose DAC & I/O system	1400
Cabling	2545
Total for 1 telescope	$38000
Total for 5 telescopes	$190000
TCS package (including source code)	75500
Tom Schneider's Estimate	67600
Grand Total	$333100
Total cost per telescope	$66620

19. RECOMMENDATIONS

Writing a complete telescope control and pointing system is not a trivial task, and I believe we should push for the TCS solution as a fully installed system, including source code. We need to find out a little more about the functionality of this software, especially as controlled via a serial port as we intend to use it.

Apart from the video digitizer board, it is possible to make all of the systems within the telescope enclosures controllable via a simple RS232 serial port. I believe that this is the model we should follow as it simplifies many of the interface issues. Multitasking operating systems, like Unix, are very good at running multiple serial ports and routing information between them. Furthermore, we could also run a simple serial line from the bunker to the dome and use a text terminal (or a laptop) for local control within the dome.

I also think we should buy one of the computers we intend to use as the main control computer in the near future as well as the general purpose DAC, the power switching unit, the UPS, the digitizer board, and the multiport serial card. A great deal of utility code can be developed without the telescope, for example checking communication speed with the PI high voltage amplifiers, controlling the secondary micrometers, testing Linux on these devices and communication protocols can be developed and tested.

Given this model, we should investigate the probable cost of having the rest of the control software written by a commercial contractor. The option of writing the rest ourselves should also be seriously considered. There are a number of people within the Array group with enough coding experience to do this; it is only a question of man-power versus outside costs.