CONTENTS

I. Introduction

1. Outline of the Document

The purpose of this document is to define the User Requirements for the Multi Application Solar Telescope (MAST). As such it is not intended to make engineering design decisions. The requirements as set out are negotiable with the Project Team but will be placed under change control after review.

This document is split into the following parts:

- an introductory part which outlines the content of the document, the goals of the MAST Project and the typographical conventions used;
- a part presenting the constraints within which the requirements must be considered, where they are known;
- a part presenting the safety requirements; a part presenting the scientific requirements; a part presenting the operational requirements; a part presenting the telescope control requirements; a part presenting the documentation requirements.

2. Goals of the MAST Project

The goal of the MAST is to provide a research facility for solar astronomers and to train Indian astronomers and research students in the use of modern optical solar telescopes.

3. Definitions

The following definitions are used throughout this document:

Imaging system is understood to mean the telescope primary and secondary mirrors combinations producing the image at M_4.

Complete system is understood to mean the combination of the telescope primary, secondary and tertiary mirrors, and any folds and correctors.

Image elongation is interpreted as the difference in the FWHM measured along the major and minor axes of a single star image.

Effective guiding is interpreted to mean guiding within 4% of the FWHM of the seeing disk or 0.1 arc-sec whichever is larger.

Telescope enclosure is interpreted as the building that accomodates the telescope.

Telescope failure is intended to mean an unpredicted telescope state which requires human intervention to restore the telescope to normal operation.

Enclosure breakdown means a state that prevents the enclosure from being opened because to do so might cause a failure resulting in the termination of observations or the enclosure being unable to close.

II. Constraints

4. Environmental

4.1 Telescope siting

The telescope will be sited in the existing building of the Udaipur Solar Observatory in the middle of lake Fatehsagar. The site is at an altitude of 300 *metres* above mean sea level. Temperatures at this site range from 10^{O} C to 30^{O} C during the day in winter, and from 20^{O} C to 50^{O} C during summer. The humidity at this site is typically 40% but may be as high as 90% occasionally. Wind speeds of approximately 30 km/hr *(maximum value)* are expected at this site. Udaipur comes under “low damage risk zone”, (seismic zone II in India) which implies that the probability of maximum intensities is less than 5.0 on Richter scale.

5. Safety

5.1 Conformance to international safety regulations

The telescope system shall be CE marked.

III. Safety Requirements

6. Introduction

Vendor should undertake to make adequate provision for the safe operation of the MAST in the design and construction of the telescope system and its associated documentation. However, the safe operation of the MAST is the sole responsibility of Physical Research Laboratory.

7. Security

Vendor to provide information on interface requirements to protect the telescope from earthquake induced vibrations of the pier (natural frequency: 26 Hz).

7.1 Telescope interlocks

Vendor will make provision to stop all telescope motion in the event of an interlock.

7.2 Interlock system

Physical Research Laboratory should take all reasonable measures to use the interlock facilities provided by vendor to protect the telescope, telescope users and maintenance staff from harm.

7.3 Input verification

All telescope requests and data entered should be verified to ensure that they are syntactically and parametrically correct so as to minimise the likelihood of causing the telescope systems harm. Engineering modes will inevitably require careful and informed operation.

7.4 Error logging

Error reports from subsystems should be logged both by the subsystems and should be propagated up to the higher level systems for inclusion in a daily error log.

7.5 Mains supply

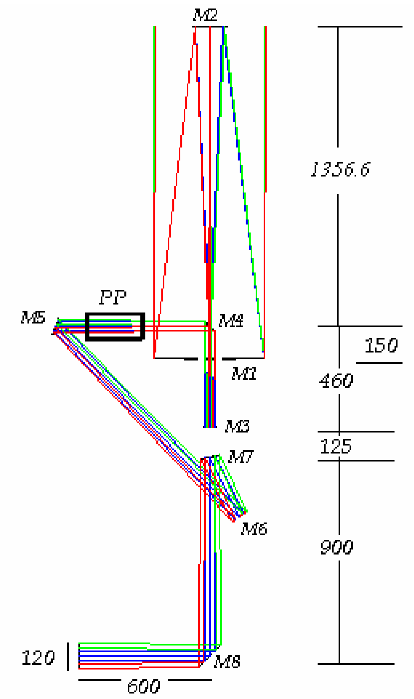
Physical Research Laboratory will ensure Uninterrupted Power Supply at 220 ± 20 V, 50±2 Hz to the telescope with a provision for giving a warning message 5 minutes before the power shut down. In the event of warning, the telescope must be able to place itself in a safe state within 5 minutes.

7.6 Start-up after failure

Following an anomalous telescope shutdown, when power is restored the telescope systems should start up again in an orderly fashion that do not risk the telescope and place it in a safe state to be manually brought back into normal operation. The procedure for bringing the MAST back into normal operation will require human intervention and should only be possible from within the telescope building.

IV. Scientific Requirements

The aim of the telescope is to deflect 6 arc-min portion of the sun into a stationary collimated horizontal beam of about 10 cm diameter. The nominal optical layout is as given in the accompanying figure.



8. System Specifications

8.1 Clear aperture

The clear aperture of the telescope should be at least 500 mm in diameter.

8.2 Output beam specifications

a. Output beam size: 10 to 12 cm dia corresponding to 6 arc-min FOV
b. Output wave-front error @632.8nm: $\lambda/12$ rms on axis, λ /10 rms over FOV, λ /4 ptv

c. Output beam stray light irradiance (after baffling, etc): not more than 0.2 % of solar flux (allowance for twice sky brightness)
d. Stationarity of FOV in output beam: max movement less than .01 arcsec per minute maintained by image de-rotator to be located anywhere after M4
e. Vibration of output beam (seeing excluded): less than 1 arcsec rms in 0 Hz to 1 Hz bandwidth; < 0.5 arcsec rms in 1Hz to 10 Hz bandwidth; < .05 arcsec rms for freq > 10 Hz

8.3 System size

The system length perpendicular to elevation axis (along the direction of pointing) should be no more than 2.0 metres. The system height, reckoned from elevation axis to final collimated beam should be no more than 2 metres.

8.4 System Transmission

Total transmission: more than 50% in wavelength range 400 nm to 900 nm

9. Optical Components:

a. Mirror M1 of ULE
b. All other mirrors of SiC
c. All mirrors with surface accuracy of λ/50 rms, λ /4 ptv (@632.8 nm), not more than 2 nm rms microroughness
d. All mirror coatings with reflectivity 95% or better in 400 nm to 900 nm range, not more than 2nm microroughness
e. All mirror coatings to absorb less than 10% of incident solar flux.
f. M1 front surface to be maintained at temperature of 1^0 C within ambient
g. M1 must have airflow of 1 m/s to 1.5 m/s across front surface
h. All other mirrors must be maintained at temperatures within 0.5 degree C of ambient

10. Provision for polarimeter package

Intermediate collimated horizontal output beam after M4:

a. size: not more than 5 cm dia
b. wave-front accuracy @632.8 nm: λ/12 rms on axis, λ /10 rms over FOV, λ /4 ptv

c. Mueller matrix of M4 (in the range 400-900 nm) with reference to plane of reflection:

$$\begin{bmatrix} 0.95\}^{+0.05}_{-0.01} & 0.03\}^{+0.01}_{-0.03} & 0 & 0 \\ 0.03\}^{+0.01}_{-0.03} & 0.95\}^{+0.05}_{-0.01} & 0 & 0 \\ 0 & 0 & -0.93\}^{+0.01}_{-0.07} & -0.17\}^{+0.01}_{-0.01} \\ 0 & 0 & 0.17\}^{+0.01}_{-0.01} & -0.93\}^{+0.01}_{-0.07} \end{bmatrix}$$

d. Stray light irradiance (after baffling, etc): not more than 0.2 % of solar flux (allowance for twice the sky brightness)
e. Space to be provided (0.15m length, 10 cm diameter) for polarimeter package PP co-axial within 10 arcmin tilt with and 10 micron decentre from elevation axis

11. Mechanical Assembly

a. Mechanical system to hold together the optics and move the telescope in altitude over azimuth configuration
b. Azimuth limits: 85^0 to 275^0 reckoned from the North in the sense NESW.
c. Altitude limits: 5^0 to 88.5^0 (zone of avoidance is 3^0 at zenith)
d. All mechanical members must be maintained within 1^0 C of ambient

12. Pointing, Tracking and Slewing

12.1 RMS pointing accuracy

The accuracy of acquiring the Sun should be < 10 arc-sec and differential pointing accuracy should be < 0.5 arc-sec.

12.2 Open loop tracking accuracy

The RMS tracking accuracy, measured during open loop tracking (using calculated co-ordinates as reference) for a duration of at least 10 minutes, must be better than 0.25 arc sec and better than 0.05 arc-sec for 1-sec period under all operating conditions.

12.3 Closed loop tracking accuracy:

The closed loop tracking (using solar limb as reference) must allow for an exposure of one *hour* with an image elongation of no greater than 0.1 arc sec.

12.4 Maximum slewing speed

The maximum slewing speed should be 2^0/ s on altitude and azimuth axes.

12.5 Wind resilience

Requirements (8.2.b through 8.2.e) should be maintained in winds of up to 30 km/hr with the telescope outside an enclosure. Physical Research Laboratory must ensure that any enclosure does not result in increasing wind speeds experienced by the telescope, compared with those incident outside the enclosure, as a result of wind tunnel effects.

12.6 Adjustment and Alignment

Tip-tilt secondary mechanism or Active optics system must be provided for maintaining the specified quality of output beam under all operating conditions

13. Operating Conditions

13.1 Operating temperature range

The **MAST** is required to operate at temperatures between 10^0 C and 50^0 C.

13.2 Operating humidity range

The telescope is required to operate at relative humidities between 0% and 90%.

13.3 Operating wind speed range

The telescope is required to operate at wind speeds of up to 30 km/hr outside the enclosure.

13.4 Operating altitude

The telescope is required to operate at an altitude of approximately 300-1700 m above mean sea level.

14. Telescope Failure Rates

14.1 Mean time to failure (MTTF)

The telescope system MTTF should be greater then 2000 *hours* of operation.

14.2 Mean time to effect repair (MTTR)

The telescope system MTTR, when repairs are undertaken by suitably qualified and appropriate engineers, should be no greater than 4 hours.

15. Thermal Output

Heat dissipation in the vicinity of the telescope will be kept to a minimum (no more than 1 kW), subject to the constraints of cost. All electronics will be designed for low power consumption and minimum heat dissipation.

15.1 Total telescope heat dissipation

Total telescope heat dissipation excluding solar heating should be ≤ 300 W.

16. Telescope Enclosure

The telescope enclosure is the responsibility of Physical Research Laboratory. The vendor must provide the requirements for installation of the telescope. An interface requirement document should be generated.

V. Operational Requirements

17. Operating Modes

Three modes of control will be available for the MAST:

- Engineering mode - a mode for engineers to access and control all aspects of the telescope system.

- User mode - a mode for astronomers to access and control the telescope interactively for the acquisition of scientific data.

- Super User mode

17.1 Disabling telescope control

A lockable physical switch will be provided to disable telescope movement. The status of this switch will be visible to engineering status software. Access to engineering status will be possible in both switch positions.

17.2 Local engineering control

Facilities must exist for local engineering control of all telescope subsystems.

17.3 Enabling engineering control

Engineering control will be enabled by a physical switch at the telescope console. The status of this switch will be visible to engineering status software.

17.4 Local and remote interactive control

Facilities must exist to enable an astronomer to interactively use the telescope for the acquisition of scientific data at the telescope. It must not be possible to endanger the telescope infrastructure when using this mode.

17.5 Change of operating modes

It should be possible to change between the three operating modes of the telescope without a complete shutdown of the telescope.

17.6 Changeover procedures

There will be a defined procedure for changing the operating mode of the telescope. The unauthorised change of observing mode must not be possible.

17.7 Duration of changeover

The time taken for a change between observing modes should not exceed 5 minutes.

18. Access to the control systems

18.1 System user access

A system of levels of user access to systems should be established to prevent unauthorised users from altering performance or safety-critical parameters.

18.2 Local access for engineering status

Facilities must exist for local engineering access to all telescope subsystems to obtain status information, regardless of the mode of operation. Access must not disrupt the normal operation of the telescope.

18.3 Remote access for engineering status

Facilities must exist for remote engineering access to all telescope subsystems to obtain status information, regardless of the mode of operation. Access must not disrupt the normal operation of the telescope.

18.4 Software engineering access

Facilities must exist for authorised software engineering access to the control software. The use of these facilities must not disrupt the normal operation of the telescope.

18.5 Super user access

Facilities must exist to allow updating of TCS tuning parameters by authorised users for astronomical quality control. The use of these facilities must not disrupt the normal operation of the telescope.

19. Status information and alarms

19.1 Error trapping and reporting

All software systems must be fault tolerant and reliably report informative error messages to the user interface when failures occur.

19.2 Error handling

All software systems must handle failures, either recovering the system failure or closing the system down in a controlled way.

19.3 Logging of errors and status

All system errors and status changes will be logged.

19.4 Status alarms

During interactive use, both visual and audible alarms should be used to indicate fault conditions.

19.5 Telescope status and the user interface

The user interface should be designed in such a way as never to compromise the operating safety of the telescope and to maximise the visibility of the status of the telescope to the user.

20. Engineering Mode Operation

20.1 Engineering interface access

The engineering interface should be accessible locally at the telescope and remotely at authorised sites and to authorised users only.

20.2 Information monitoring

The engineering interface should allow the monitoring of all encoder outputs, digital and analog signal lines and Power Supply Unit (PSU) voltages.

20.3 Local parameter modification

The ability to set certain predefined parameters locally should be provided.

21. Interactive Mode Operation

21.1 Interactive Mode user interface

The user interface shall be both command line and GUI based.

VI. Telescope Control Requirements

22. Telescope System

We have the following general requirements for the MAST system:

22.1 Control of power

The power to the MAST system should be capable of manual operation or operation under computer control.

22.2 Power monitoring

Drive currents, encoder positions, limit switch trips and PSU voltages should be monitored and the ability to log the results provided.

22.3 Power safety

Appropriate actions to make the telescope safe should be carried out if any of the monitored items in 22.2 exceed predefined limits.

22.4 Alteration of limit settings

"Final-line-of-defence" limits should be alterable by hardware settings or, if by software, only on site.

22.5 Hardware limit recovery

Recovery from or resetting of a hardware limit-switch trip should only be possible by human intervention from within the telescope enclosure.

22.6 Software Limit recovery

Attempted recovery from software limits should be possible remotely by authorised users.

23. Telescope Control System (TCS)

23.1 TCS General Requirements

The primary responsibility of the TCS and its associated subsystems is the control of telescope movements to allow pointing and tracking, and to act as a uniform interface for high-level modes of operation.

23.2 TCS computer

All inputs/outputs from the control system should be interfaced to a computer running on a stable Operating System (OS). TCS computer should be provided with appropriate hardware and associated software, which could be used to acess or alter all the control functions.

23.4 Position and Status information

The TCS computer should make available all position and status information to other computer systems which require it.

23.5 TCS software

The TCS computer should be provided with a software which should act as user interface to all control functions. The source code and documentation should be provided along with. For easy access of the telescope control functions, a Graphical User Interface (GUI) should also be provided.

Note: See Appendix **A** for schematic of the control systems

24. TCS Interfacing to Other Systems

An appropriate interface software which should communicate with TCS computer should be provided and documented to allow telescope control from an Observatory Control System, which will be developed by Physical Research Laboratory.

25. TCS Co-ordinates

25.1 Co-ordinate entry

The TCS should accept co-ordinates as mean RA (0.01 seconds of time) and DEC (0.1 seconds of arc).

25.2 Non sidereal tracking rates

The ability to set non sidereal tracking rates in RA and DEC should be provided. Non sidereal motions should be specified in seconds of time per second in RA, and in arc-sec per second in DEC.

25.3 Rotator position angle

It must be possible to specify rotator position angle in terms of position angle on the sky, or mount position angle.

25.4 Rotator zero points

The ability to adjust the rotator zero-points should be available to a suitably authorised user.

25.5 Arbitrary rotator position mode

The ability to specify a 'floating' rotator position should be provided; *i.e.* the TCS does not set the rotator to a particular position angle when it goes to an object, but when it gets there it tracks from where it is.

25.6 Altitude and azimuth

The ability to set the telescope at specified Altitude and Azimuth co-ordinates is required.

26. Pointing Model

26.1 Zeroset

A start-of-day Zeroset routine should be provided based on Almanac values.

26.2 Start-of-day pointing calibration

A start-of-day pointing routine should be provided. This should calibrate the basic parameters of the telescope pointing model. This routine should operate without user supervision.

26.3 Basic pointing model adjustment

The basic parameters of the telescope pointing model (encoder zero-points and horizontal collimation error) should be adjustable by authorised users.

26.4 Logging of calibration data

The necessary logging should be provided to allow a full pointing calibration to be carried out by hand.

26.5 Detailed pointing model adjustment

Other pointing model parameters should only be alterable by authorised users.

27. Slews and Offsets

27.1 Keypad

The ability to slew the telescope at a user defined rate in RA and DEC should be provided with a "keypad" like interface.

27.2 Offset accuracy

The ability to carry out a relative offset of up to 20 arc-min from the current telescope position, and with an accuracy consistent with the accuracy of open-loop tracking specified in Requirements 10.2 and 10.3, should be provided.

27.3 Offset modes

The ability to perform both tangent plane and RA, DEC offsets is required.

27.4 Offset timing

The time taken for the telescope to stabilise after initiating an offset is to be less than 2 seconds for an offset of 1 arc-min and less than 5 seconds for an offset of 5 arc-min.

28. Telescope Status Display

28.1 Telescope status update

A telescope status display should be provided and updated automatically at least once per second. It is understood that remote performance of the status display will depend upon the performance of the wide area network being used and therefore must be an average performance.

28.2 Display information

The status display should include at least the following information:

- Mean and apparent requested RA and DEC and corresponding airmass.

- Current telescope RA and DEC and corresponding airmass.

- Requested and current rotator angle.

- Current Mount Co-ordinates.

- Current time to an accuracy limited by the display refresh frequency in any of UT, LST, Local Civil Time.

- Mirror cover status.

- Oil pressure status.

- Mirror support status.

- Requested and current telescope focus (value).

- Telescope motion status (Tracking, Slewing, Parked, Stopped).

• Time to any software limits (rotator, altitude, azimuth).
Any mechanism that takes longer than 1 *second to* reach its requested position must be indicated by a "MOVING" status. If a mechanism has failed, a "BAD" status must be indicated.

29. Time

29.1 Time distribution

The current UT and LST will be served by the TCS via the Local Area Network to an accuracy of approximately 1 second RMS.

VII. Documentation

30. User documentation

A complete set of user documentation in English will be provided for the MAST. One complete set of documentation will be printed and bound and the same documentation set will be provided in PDF format on CD-ROM.

30.1 Engineering support documentation

A complete set of engineering support documentation will be provided with the MAST to facilitate local engineering fault finding and rectification.

30.2 Scheduled maintenance documentation

A complete set of scheduled maintenance documentation will be provided with the MAST in order to maintain the optimum performance of the telescope and minimise the risk of operational failures.

30.3 Design documentation

Interface and assembly drawings will be provided with the MAST to enable support engineers to rectify operational failures.

VIII. Installation and Training

Vendor should provide training for specified number of personnel for operation and maintenance of the telescope. Vendor should also install the telescope after ensuring that all interface requirements are as per vendor's specifications. Vendor must also demonstrate the proper performance of the installed telescope by means of mutually agreed tests.

Appendix : A

Schematic of Telescope control system

A.1 Telescope Control Requirements:

The basic control system can be divided into three subsystems:
(i) Telescope and feed optics control system: (CS1)
(ii) Adaptive Optics control system: (CS2)
(iii) Back-end Instrument control PC: (CS3)

A.1.1 Telescope and feed optics control system (CS1):

CS1 Software/Hardware should de designed & developed by the vendor

The devices that are interfaced to this system are listed below:
(a) Alt-Az motor drive units working in close-loop with either encoders or Guider signals.
(b) Position encoders on Alt-Az axes.
(c) Control unit of active secondary mirror.
(d) A/D card for reading parameters like temperature etc at various locations (*To be specified by USER*) in the telescope.
(e) Control and acquisition Cards for any device that is part of feed optics.
(f) Optional input parameters like GPS timing, Guider error signals etc (*To be specified by USER*).
This system can be a dedicated stable computer system, which accepts all the above devices. There should be extra room for adding more control cards. All devices attached to CS1 should be designed to provide the access to following parameters and functions via RS232/GPIB interface from at least 100 feet.

User mode access (locally/remotely):
(i) To read/write current settings of the encoder and speed settings of motors.
(ii) To read current settings of active secondary control unit.
(iii) To read weather parameters at various locations.
(iv) To read parameters of feed optics control units.

SuperUser Mode access (locally/remotely Password protected)
In addition to User mode previliges the SuperUser mode allows

(i) To enable/disable a remote User and override current settings of all the devices.
(ii) To enable/disable remote control of single or all units.

(iii) To RESET the power supply of all connected device control units and CS1 to bring the system to halt.

(iv) Super User is not allowed to update the software code or device drivers etc. The Cabinet of CS1 is physically locked so no device/card is accessible to SuperUser. This can be done in Engineer Mode only, as described below.

Engineer Mode access (Locally only):

In addition to SuperUser mode privileges the Engineer mode allows

(i) Access to the software code to be updated or changed.

(ii) Access to update the device drivers and firmware.

(iii) Access to add/remove hardware devices.

Where applicable, the modes will be made available to remote user. The services will be available to the client by server via some standard network programming protocol. Software Development Kit (SDK) with full technical support and examples must be supplied to user.

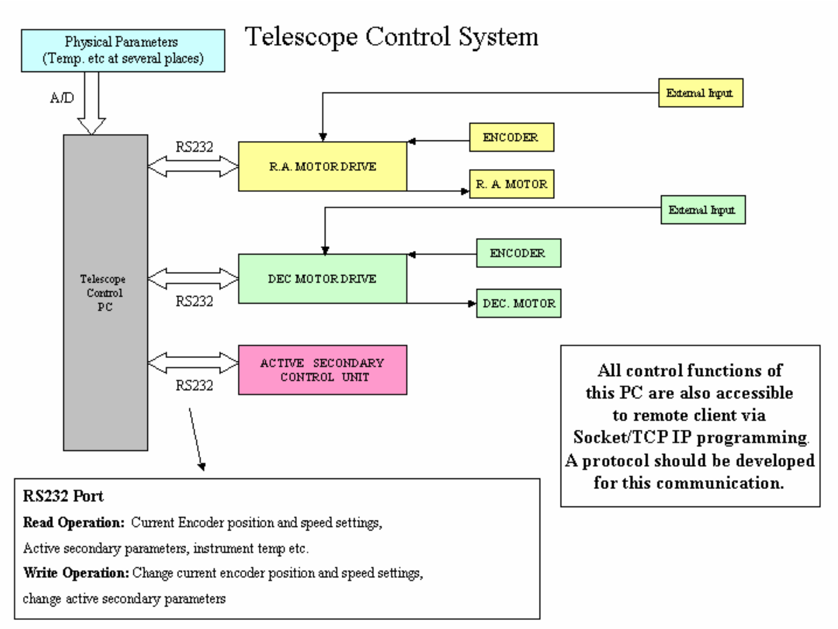
A.1.2 Adaptive Optics Control System (CS2):

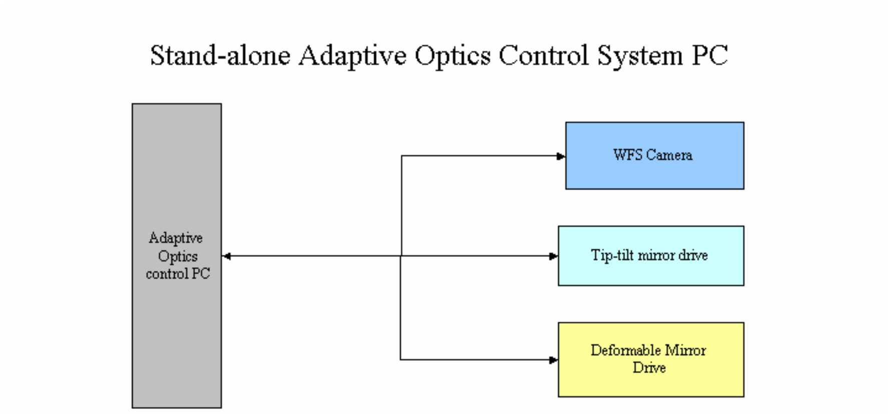
The CS2 system will be ***developed in-house*** by Physical Research Laboratory and will be completely a stand-alone system. The CS2 cannot be controlled remotely.

A.1.3 Back-end instrument control System(CS3):

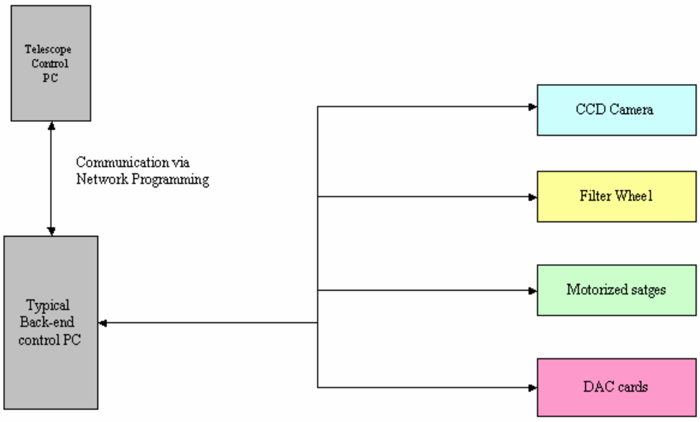
This system will be responsibility of Back-end developer**.** The developer will develop CS3 in order to control the instrument locally or remotely. In order to interact with telescope, the developer must use the protocol supplied by vendor of CS1.

So, the GUI or control interface for user will have one component to interact with the back-end instrument and another component, which accesses CS1 in either User or SuperUser mode to read/control the telescope and feed optics system and peripherals. However, in extreme case where the developer is not familiar with network programming or is unable to use vendor supplied software for controlling CS1, the terminal of CS1 can be extended (using KVM switch + extender) to the control room of CS3 and then one can control CS1 & CS3 from two terminals sitting near each other.


Telescope Control System
Physical Parameters
(Temp. etc at several places)
A/D
Telescope
Control
PC
RS232
R.A. MOTOR DRIVE
ENCODER
R. A. MOTOR
External Input
DEC MOTOR DRIVE
ENCODER
DEC. MOTOR
External Input
RS232
ACTIVE SECONDARY
CONTROL UNIT
RS232
All control functions of
this PC are also accessible
to remote client via
Socket/TCP IP programming.
A protocol should be developed
for this communication.
RS232 Port
Read Operation: Current Encoder position and speed settings,
Active secondary parameters, instrument temp etc.
Write Operation: Change current encoder position and speed settings,
change active secondary parameters


Stand-alone Adaptive Optics Control System PC
Adaptive
Optics
control PC
WFS Camera
Tip-tilt mirror drive
Deformable Mirror
Drive

Back-end control PC serves as a Master Control PC



All devices attached to this PC are part of Back-end instrument and can be controlled locally by a GUI.
The GUI contains two modules

(i) Module for controlling the back-end instrument components connected locally to the PC.
(ii) Module for controlling peripherals connected to Telescope PC remotely via TCPIP/Socket protocol.