Title: Control System Design Requirements for the WIYN 3.5 Meter Telescope

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Glossary

ADC	Atmospheric Dispersion Corrector
CLI	Command Line Interpreter
CS	Control Subsystem
GUI	Graphical User Interface
IAS	Instrument Adapter Subsystem
LAN	Local Area Network
KPNO	Kitt Peak National Observatory
OSS	Optical Support Structure
NIR	Nasmyth Instrument Rotator
NOAO	National Optical Astronomy Observatories
PFI	Program File Interface
PMS	Primary Mirror Subsystem
SI	Science Instrument
TBD	To be determined.
TBR	To be resolved.
TMR	Tertiary Mirror Rotator
UPS	Uninterruptable Power Supply

1. Purpose & Scope

This document defines the requirements of the Control Subsystem (CS). The CS controls and monitors: the telescope mount, secondary and tertiary mirrors, instrument rotators, dome rotation, mirror covers and other auxiliary equipment associated with the operation of the telescope. It provides appropriate User/Operator interfaces for commanding the telescope and displaying status and diagnostics including daily start-up of the observatory, normal and emergency shutdown of the observatory, and the monitoring and display of environmental data and time. The CS supplies electrical power and data interface cabling between hardware located in the control and computer rooms and mounted on the telescope and in locations around the dome.

Figure 1 shows the plan view of the observatory and the location of major components of the CS. Figure 2 is a block diagram of the control system and schematically shows the major interfaces. A drawing of the telescope identifying the various components and subsystems and definitions of the coordinate systems used for specifying the location and orientation of various components is contained in the System Definition & Configuration document, WODC 01-01.

The requirements in this document represent engineering tasks of varying difficulty. These requirements, separated into two categories, are classified as specifications or goals according to the following definitions:

Specifications describe the design or performance capabilities of the observatory that have been approved by the board to meet the science goals of the project. These specifications have been reviewed by the project staff for technical difficulty and judged to be achievable with the approved budget and schedule. Changes to specifications require a review by the Scientific Advisory Committee (SAC) and approval by the board.

A goal is a performance capability that has been recommended by the SAC but which requires further study and development due to an uncertainty in its technical feasibility or the project's ability to achieve it with the allocated resources. The project staff will design to the goals and report to the SAC when changes are advisable. Proposed modifications will include an assessment of the technical impact and budgetary and schedule implications. Modifications to goals will be approved by the SAC. Goals will be converted to specifications by the SAC as development allows. Goals that cannot be achieved within the approved budget and schedule and which, in the judgment of the SAC, significantly affect the capabilities of the observatory will be referred to the board with the SAC's recommendation.

Requirements that are goals are labeled with a [G]. A [G] at the head of a subsection or category indicates that all requirements included in the subsection or category are goals. Requirements without a G-label are specifications.

2. Telescope mount

The telescope mount is a gimbal structure for supporting and pointing the telescope optics. It also supports the scientific instrumentation. The telescope is designed in an alt-azimuth configuration with the two Nasmyth foci being the principal instrument positions. The two axes are the azimuth and elevation axes as shown on the telescope drawing, Figure TBD of WODC 01-01.

The azimuth axis will be rotated by a pair of drive boxes mounted opposite each other on the rigid pier supporting the telescope. The output capstan of the drive boxes will roll on the perimeter of the azimuth drive disk to move the telescope. This type of drive is called a "friction drive". The elevation axis will use similar drive boxes mounted on the tines of the fork assembly to drive a pair of disks on the Optical Support Structure (OSS).

The rotation of the axes will be measured with incremental encoders: one encoder on the elevation axis and two on azimuth. The two azimuth encoders will be mounted on opposite sides of the azimuth drive disk and summed to get the rotation angle and reject readings due to axis translation common to both.

The incremental positions will be calibrated with electronically readable index sensors. The azimuth index will be positioned to mark the midpoint of axis rotation at azimuth angle 90°. The elevation index will mark elevation angle 75°.

Fail-safe brakes will be provided for the azimuth and elevation axes. Parallel, non-automatic, control of the brakes that override the automatic control will be provided as required for interlocks and shutdown. (Interlock requirements are described in section 14.)

Independent hardware and software limits will protect the telescope against over rotation.

2.1 Azimuth/Elevation Axis Control

The CS shall implement position control loops on the azimuth and elevation axes. The functions that shall be provided include:

- Control signals for the DC servo motors.
- Encoder read inputs.
- Inputs for reading absolute position sensors.
- Control software.
- User interface.

The CS will accept coordinate information and movement commands from the operator through the user interface.

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The CS will generate the appropriate trajectories to point the telescope. Trajectories will be computed to minimize the time required to acquire objects and will take into account the limits on velocities, accelerations, and permitted observing axis limits specified below.

A pointing map will be created to correct the repeatable portions of the following minimum list of error sources:

- Optical misalignment during initial telescope collimation.
- Optical misalignment due to gravitational distortion of the telescope structure.
- Focal plane variations with telescope position.
- Misalignment of the azimuth axis.
- Non-perpendicularity of the azimuth and elevation axis.
- Bearing runout.
- Tertiary rotator misalignment.

Additional terms will be added to correct the following predictable sources of error:

- Atmospheric refraction.
- Encoder non-linearities.
- Instrument rotator misalignment.
- Tilt and misalignment of the science instrument focal surface with respect to the instrument rotator axis.
- Thermal gradients in the structure.
- Pointing errors due to active mirror adjustment.

Separate pointing maps will be stored for each nasmyth focus position together with separate terms that account for misalignment in the instrument mounts. The CS design will allow additional maps to be added as other foci are implemented. The CS will generate and use the pointing maps to correct for pointing errors when repositioning the telescope and tracking.

The CS will provide the capability for tracking both axes at sidereal and non-sidereal rates up to the maximum track rates specified. Non-sidereal rates will be specified as constant velocities in RA and Dec. Tracking uses the same motors and encoders as positioning.

Guiding is defined as corrections to the open-loop tracking of the telescope. The CS will accept pointing error inputs from the Instrument Adapter Subsystem, directly from instruments, or from manual controls, convert these into mount coordinate errors and generate tracking corrections.

The default condition on startup will be both axes stopped, brakes set, tracking and guiding disabled.

The drive controllers will respond to a cancel command by bringing the axes to a stop and disabling tracking. A subsequent move to object coordinates command will re-enable tracking and move the new coordinates unless the coordinates have been entered as altitude and azimuth in which case the tracking will remain disabled.

Audio signals shall be provided to indicate when the telescope is moving. The velocity shall be easily judged from the signals.

The servo controllers, amplifier, and power supply are included in the CS task. The CS will provide inputs for encoders and index sensors, control signals for brakes, power supplies for all of these, cabling, control software and user interface. The motors, encoders, index sensors, and brakes will be supplied by the telescope manufacturer. The selection of motors and encoders and the specification of interface requirements will be coordinated with the manufacturer under the direction of the System Engineer.

2.2 Mount specifications

The specifications in this section have been derived from engineering studies of the telescope mount and are included here for reference in designing the control system.

2.2.1 Mechanical Properties

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Weight of the OSS Assembly:	32,660 lb.
Rotating weight of the Telescope Assembly:	80,000 lb.
OSS Moment of Inertia about Elevation axis:	5.5e5 lb.-sec^2-in.
Telescope Moment of Inertia about the Azimuth Axis:	1.1e6 lb.-sec^2-in.
Azimuth Total Bearing and Drive Friction:	3640 in-lb.
Elevation Total Bearing and Drive Friction:	1550 in-lb.
Azimuth utility drape torque:	TBD.
Elevation utility drape torque:	TBD.
Elevation Imbalance torque:	TBD.
Maximum wind load:	
Azimuth:	4500 lb-in.
Elevation:	4170 lb-in.
Structural modes and frequencies:	
Fore-aft Translation:	7.3 Hz.
Lateral Translation:	7.6 Hz.
Locked Rotor Azimuth Axis:	8.8 Hz.
Locked Rotor Elevation Axis:	10.6 Hz.

2.2.2 Azimuth and Elevation Ranges

Azimuth Total Mechanical Range:	Limited only by cable wrap-up.
Azimuth Maintenance Range:	±270° about 90° True Azimuth.
Azimuth Observing Range:	±270° about 90° True Azimuth.
Azimuth safe limits:	±280° about 90° True Azimuth.
Elevation Total Mechanical Range:	0° to 92°.
Elevation Maintenance Range:	5° to 90°.

Elevation Observing Range:	15° to 89.6°.
Elevation safe limits:	0.5°, 90.5°.

The "Observing Range" is the range over which the telescope must meet the requirements of Section 2.3. The specifications will be met when tracking objects at sidereal rates with the goal of meeting them at non-sidereal rates as well.

The telescope will be able to point anywhere within the "Maintenance range" for servicing and stow.

Switches set at the safe limits will cause an emergency stop by removing power from the servo motor and setting the brakes as described in section 14 (Interlocks).

Hardware stops with shock absorbers capable of absorbing the energy at rates up to the runaway limit will prevent the telescope from moving outside the "Total Mechanical Range" in elevation.

2.2.3 Accelerations and Rates

The control system will limit accelerations and rates to the following ranges: [G]

Azimuth Accelerations:		$-1°/sec^2$ to $+1°/sec^2$.
Azimuth Rates:		
	Elevation >30°:	-5°/sec to +5°/sec.
	20° < Elevation <30°:	-2°/sec to +2°/sec.
	Elevation <20°:	-1°/sec to +1°/sec.
Elevation Accelerations:		$-1°/sec^2$ to $+1°/sec^2$.
Elevation Rates:		
	Elevation > 85°	-5°/sec to +1°/sec.
	30° < Elevation < 85°:	-5°/sec to +5°/sec.
	20° < Elevation < 30°:	-2°/sec to +5°/sec.
	Elevation < 20°:	-1°/sec to +5°/sec.

The telescope shall meet the tracking specifications of sections 2.3.3 and 2.3.4 for the following range of track rates and accelerations:

Track rates, both axes:	-0.5°/sec to +0.5°/sec.
Track Accelerations, both axes:	$-0.1°/sec^2$ to $+0.1°/sec^2$.

Rates outside the following ranges will be detected as an error condition and cause power to be removed from the drives and the axis brakes applied as described in section 14 (Interlocks):

Azimuth safe rates:		
	Elevation >20°:	-7.5°/sec to +7.5°/sec.
	Elevation <20°:	-2°/sec to +2°/sec.

Elevation safe rates:

Elevation > 85°	-7.5°/sec to +2°/sec.
20° < Elevation < 85°:	-7.5°/sec to +7.5°/sec.
Elevation < 20°:	-2°/sec to +7.5°/sec.

2.3 Performance goals

The following are performance goals to meet the science requirements of the project. The control system shall be designed to provide the level of performance consistent with these goals.

2.3.1. Telescope Pointing and Tracking Accuracy

[G]

The CS will control telescope pointing. Pointing accuracy will be measured at the instrument aperture and include all auxiliary optics contributions.

2.3.2 Absolute Pointing and Offsetting

The CS will have absolute telescope pointing accurate to within 2 arcseconds RMS for nighttime observing measured over the full azimuth and elevation observing range of the telescope. The pointing specification will apply when the active optics of the primary and secondary mirror subsystems are operating and after pointing corrections have been applied.

Absolute pointing will be measured and calibrated by performing a mapping of stars distributed over the observing range and the pointing error will be the RMS of the residual pointing errors. Nightly recalibration using a small number of stars will be permitted to meet the pointing specification. Nightly recalibration should take no longer than 10 minutes.

The procedure for "cold-start" recalibration of the incremental encoders involves slewing the telescope in elevation until the upper soft limit is reached. Next the azimuth is slewed until the azimuth mid-range switch changes state. Both axes are then backed off until an index mark is reached. The encoders are set at these calibrated positions. Repeatability of the index positions will be <5 arcseconds [G]. Final calibration of the incremental encoders will be done with observations of position standard stars.

An offset is a relative move in azimuth and elevation from a known position. Blind offsets rely on the mechanical repeatability of the telescope and encoders and the pointing accuracy of the control system. Offset accuracy is specified for elevations below 85° and is a function of the angular distance moved.

Offsetting accuracy,	offset < 1°:	0.2 arcsecond RMS.
	1° ≤ offset < 10°:	1.0 arcsecond RMS.

The offset pointing error will be measured by selecting 24 pairs of objects uniformly distributed across the sky. Pair separations will be approximately 1° and 10° for the respective specifications. The telescope will be aligned on the first object of a pair and commanded to offset to the second object. The offset pointing error will be the RMS value of the measurements.

Offsets using autoguider inputs rely on the positioning accuracy of the guide probes and the control systems ability to track using the position error information. Positioning specifications for autoguider offsetting are the same as for autoguider tracking given in section 2.3.4.

2.3.3 Open Loop Tracking

[G]

The telescope will open loop track to 0.1 arcsecond RMS or better for periods of time up to 2 minutes and 0.5 arcsecond RMS or better for periods of time up to 15 minutes. Maximum excursions shall not exceed 0.5 and 1.0 arcseconds respectively.

The tracking error will be determined by pointing the telescope at a reference star, tracking open loop for 15 minutes and measuring the pointing error after 2 and 15 minutes. This process will be repeated 24 times on objects distributed over the observing range of the telescope and the maximum and RMS values of the 2 minute and 15 minute trials will be calculated.

2.3.4 Closed Loop Tracking

Closed loop tracking (autoguiding) is defined as tracking a celestial object using an external error signal such as provided by the Instrument Adapter Subsystem or by a Science Instrument. The CS will provide a means for guiding the telescope from these signals.

The error signals will be updated a maximum rate of 10 Hz and will be supplied to the control system in the natural coordinate system of the guider ("guider coordinates"). The "gain" and "bandwidth" of the correction feedback loop will be adjustable in software through the user interface. The telescope shall track the error signal to 90% or 0.05 arcseconds, whichever is greater, within 1 second for an error signal of less than 2 arcseconds [G]. The telescope will perform an offset from the current position to acquire objects with guide errors greater than 2 arcseconds.

2.3.5 Maximum Times to Reposition Telescope

[G]

The time to reposition the telescope is defined as the time to move between two positions within the azimuth and elevation observing range ending up with the telescope pointing and open loop tracking within specifications. The time to reposition shall not exceed the following:

Offsets up to 0.5° and $\Delta Az < 1°$:	3 seconds.
Traverse angle <10° and $\Delta Az < 10°$:	20 seconds.
Between any two allowed positions:	100 seconds worst case.

Worst case includes the situation where the azimuth is required to rotate more than 360° to avoid cable wrap-up.

2.3.6 Unbalanced torque's

The control system shall be designed to operate in the presence of unbalanced forces on the azimuth and elevation axes due to wind and utility drapes. The projected DC magnitudes of these torque's are specified in section 2.2.1.

2.4 Position Limit switches and Azimuth Midrange Switch

Two sets of position limit switches will be provided for each axis. The "hard" limits will be activated when the telescope exceeds the safe ranges specified in section 2.2.2. When activated in either axis, they remove power from the drives and apply the brakes (see section 14, Interlocks). The control system shall be able to read the state of the hard limits.

The "soft" limits will signal the CS that the end of the observing range is approaching. The soft limits will be activated for the following angles:

Elevation soft limits:

Lower:	$\phi \leq 32°$.
Upper:	$\phi \geq 73°$.

Azimuth soft limits:

Lower:	$\theta \geq 270°$.
Upper:	$\theta \leq -270°$.

The azimuth axis will also be provided with a "midrange" switch at 90° true azimuth. The midrange switch will change states as the telescope moves past to indicate which side of 90° the telescope is positioned.

The control system will provide inputs, interlocks and cabling for limit switches. The switches will be provided with the telescope.

2.5 Velocity Limit Switches

The velocities of the elevation and azimuth axes will be limited to the "safe" values specified in section 2.2.3. In normal operation, the maximum rates permitted under software control are less than the "safe" rates and no error condition exists. Velocity transducers on the axes will detect a runaway condition and cause the CS will bring the telescope to a controlled stop by shutting off the servo power and applying the brakes. Position switches on the elevation axis will be used to select the appropriate trip velocities as specified in 2.2.3. These are in addition to the position switches described in section 2.4. The control system will detect when an over-velocity condition occurs and signal the operator.

The operation of the "safe" velocity limits shall not depend on the axis control hardware and software in such a way that a single point failure of the system could cause an uncontrollable runaway condition of either axis.

The control system will provide inputs, power, cabling and interlocks for implementing the velocity limit switches. The switches and transducers will be supplied with the telescope. The selection of transducers and switches will be coordinated with the telescope mount task.

2.6 Brakes

Fail-safe brakes will be provided for the azimuth and elevation axes. The brakes will bring the telescope to a controlled stop under the following conditions: (1) UPS power failure, (2) hard limit switches activated on azimuth or elevation axes, (3) axis rate limits exceeded, and (4) operator initiated emergency stop (including control panel shutdown). These conditions will be detected independently of the drive controls and computer and cause power to be removed from the telescope drive motors and the brakes to be set.

The telescope brakes will also be used to prevent motion of the telescope when the servo motors are powered down. Normally the brakes shall be applied only after the telescope has been brought to a stop with the servos. Power to the servo motors will be removed when the brakes are set.

The CS shall provide:

- Control signals for the brake.
- Interlocks as described in section 14.

Brakes will be provided with the telescope mount and be designed to decelerate the axes at $5°/sec^2$ and bring the telescope to a controlled stop before mechanical stops are reached.

2.7 Telescope Balance Sense

The control system will provide a means of sensing the current in the drive motors and making it available to the operator as a tool for balancing the OSS and general diagnostic tool for measuring drive performance of both axes.

The required accuracy for sensing the current is TBD% or TBD ma whichever is greater.

3. Secondary Mirror

The secondary mirror will be mounted in a cell and suspended from the Secondary Support Truss facing down towards the primary mirror. Three linear actuators will attach to the back of the mirror in a triangular pattern. These will define the position of the mirror parallel to the optical axis and its tilt in two directions. The mirror will be restrained from moving laterally.

The gap between the outside edge of the mirror and the cell will be sealed and a vacuum applied to the back of the mirror to support its weight.

The CS will provide for the following secondary mirror functions:

- Three axes of stepper motor actuator control.
- Limit switches for the stepper motors.
- Three axes of LVDT position sensors.
- On/off control for the vacuum support.
- Operator interface.
- Autofocus.
- Autocollimation.
- Diagnostic telemetry from the position and vacuum controllers.

Operation of the secondary mirror will be transparent to the user after initialization. The operator will select the desired setting of the mirror at the start of an observing run on the basis of focus and collimation measurements. Default settings will be used from the previous night and current structure temperature for the initial set-up. The operator will also select the operating mode: autofocus/autocollimation or manual. The CS will control the mirror position according to the mode and monitor its position.

Pointing accuracies due to motion of the secondary are included in and will be consistent with the previously defined telescope pointing and tracking requirements. Actuator motions during tracking shall be coordinated to avoid image motion exceeding what is allowed by the requirements in section 2.

The electrical control for the stepper motors, inputs for position sensors, inputs for limit switches, power supplies, cabling, operator interface and control software are part of the CS task. The motors, position sensors, and limit switches will be supplied as part of the secondary mirror subsystem. The specification of actuator and position sensor resolution and interface requirements will be coordinated with the secondary mirror task.

3.1 Secondary Mirror Position Specifications

[G]

The following are the positioning specifications for the Secondary Mirror subassembly that are included here for reference. The CS design should not degrade the performance of the mechanical design.

The axial position (focus) and two rotational degrees of the freedom (tip-tilt) of the secondary mirror will be defined by three linear actuators driven by stepper motors. The actuators will be arranged in a triangular pattern on the back of the secondary in a pattern TBD. Focus and tilts will require the coordinated motion of all three actuators. Position sensors will be provided at each actuator.

Actuator range:	± 4 mm from nominal.
Actuator step size:	0.16 μm.
Step rate:	0 to 400 steps/sec.
Position sensor resolution:	TBD.

3.2 Autofocus & Autocollimation

Focus and collimation errors will be corrected by piston and tilt motions of the secondary mirror. Two modes of autofocus and autocollimation will be provided. In the open-loop mode, focus and tilt corrections will be calculated from the elevation angle and OSS structure temperature. These will be used to derive corrective motions of the position actuators. The temperature sensors, read electronics, and control software are all part of the CS task.

A closed-loop autofocus capability will also be provided to take external focus information from the Instrument Adapter Subsystem or directly from the Science Instrument and produce the appropriate focus motions of the actuators. This capability will override open loop operation when enabled. The minimum update period is 30 seconds.

Focus offsets up to the maximum permitted by the secondary travel will be permitted to accommodate (1) adjustment error in the focus probe, (2) differences in the focal plane position of the science instrument from the nominal position, (3) filters, and (4) intentional defocus for focus calibration. Adjustment errors of the focus probe will be stored and become the default values on startup. Focus offsets under (2) and (3) will be stored in the instrument configuration and will be automatically applied.

A closed-loop autocollimation capability will be provided to take collimation information from the Primary Mirror Subsystem (PMS) and produce the appropriate tilt motions of the actuators. This capability will override open-loop operation when enabled. Minimum update period is 30 seconds.

Motors shall be turned off when not operating to minimize heat dissipation at the top of the telescope. The mechanical design will ensure that the secondary position does not creep with motor power off.

Autofocus and autocollimation modes may be enabled/disabled independently of the other.

4. Tertiary Mirror

The tertiary mirror is rotated to switch between the Nasmyth and bent Cassegrain instruments. The CS will rotate the tertiary mirror about the OSS Z_0 axis to direct the beam to any one of the three foci. The required functions are:

- Rotator motor control.
- Position latch solenoid/motor control.
- Rotator position sense.
- Latch position sense.
- Control software.
- Operator interface.

The operator will command the tertiary to rotate to one of three fixed positions. A sensor will tell the control system when the position has been reached and a positive latching/locating mechanism will insure the tertiary is properly aligned as specified below. The sensor type is TBD. A sense switch will be provided to indicate when the latch is in position. The status of the operation and the tertiary position will be made available to the operator on the System Status Display.

An on-axis instrument position below the primary mirror requires a folding mechanism to remove the tertiary from the beam. This uses an actuator mechanism for tilting the mirror and position sensors and latch mechanisms at the ends-of-travel.

The CS task includes drive power for motors and latches, inputs for position sensors, power supplies, cabling, control and operator interface software. The motor, index/latching mechanism, position sensor, mechanical and optical elements of the tertiary rotator will be supplied as part of the Tertiary Mirror Rotator (TMR) Subassembly. The specification of interface requirements will be coordinated with the TMR task.

4.1 Tertiary Rotation Specifications

[G]

The following are the positioning specifications for the TMR subassembly rotation mechanism and are included here for reference. The CS design must not degrade the performance of the mechanical design by its action.

Range:	180°.
Indexed positions:	0°, 90°, 180°.
Time to switch beam:	< 30 seconds worst case.
Accuracy:	< 30 arcseconds.
Repeatability:	< 4 arcseconds.

4.2 Tertiary Folding Mechanism Specifications

The following are specifications for the TMR subassembly folding mechanism:

Positions:	Two (2): "Down" & "Up".
Time to switch beam:	< 30 seconds.
Accuracy in down position:	< 30 arcseconds.
Repeatability in down position:	< 4 arcseconds.

Position accuracy in the folded up position is not critical.

5. Instrument Rotators

The CS will provide controls for the two Nasmyth Instrument Rotators (NIRs). The CS will implement a position control loop to provide instrument rotation to automatically match the rotation of the field at the focus. The CS will also provide the capability of positioning an NIR at a user commanded angle independent of the telescope motion.

The following functions need to be provided:

- DC servo motor control.
- Brake control.
- Position encoding.
- Index position read.
- Center toggle switch input.
- Limit switch sense.
- Control software.
- Operator interface.

The NIR will operate in either manual or automatic mode as selected by the operator. In automatic mode, the instrument rotation will be transparent to the user after initialization. At any time the operator may reinitialize the rotator angle, command the rotator to move to a specified angle or command the rotator to rotate by a fixed incremental angle. When rotating by a fixed increment, the amount of track rotation lost during the move is added to the final position.

In manual mode, the rotator can be commanded to rotate to a specified angle or by a specified increment. The default startup condition of the rotator will be with the motor stopped and the brake set.

The instrument rotator angle will be initially set from a reference position in the rotator. The reference position will be provided by a Sony Magnesensor and will be located near the midrange of rotation. The rotator will be moved under CS control towards the center position as indicated by the center toggle switch. Once the center switch changes state, the rotator will be moved in the appropriate direction to encounter the index position and the encoder will be set.

The rotator position relative to the reference mark will be monitored and shown on the System Status Display. Recalibration of the rotation angle zero point by the operator from observations of star pairs will be permitted.

Software limits for the rotation range will by default be the full observing range of the rotator. The operator will have the option of entering a more restricted range to limit, for example, cryogen dumping.

Software and hardware for the NIRs will be developed in a standard fashion to the degree possible to facilitate future expansion to the modified Cassegrain and folded-Cassegrain foci.

The CS will provide pointing and tracking correction to compensate for mechanical misalignments in the rotator.

The accuracy of the position angle control will be measured by selecting pairs of stars on opposite sides of the field and measuring the relative rotation of the two images with guide probes (a) after a repositioning of the rotator and (b) while tracking the telescope. Development of a procedure and software for measuring rotator accuracy is included in the CS rotator task.

The motor controller, read electronics for encoders, control for a brake, inputs for limit switches, center toggle switch and the index position sensor, cabling, control and operator interface software will be provided as part of the CS task. The motor amplifier and power supplies are also included. The motor, encoder, index sensor, and limit switches will be supplied as part of the NIR Subassembly. Interface requirements will be coordinated with the NIR task.

5.1 Instrument Rotator Mechanical Specifications

[G]

The following are the mechanical specifications for the NIR subassembly and are included here for reference. The CS design should not degrade the performance of the mechanical design by its action. The two rotators will be identical with the following properties:

Max. Moment of Inertia (loaded):	TBD kg-m^2
Max. Track Speed:	-0.5°/sec to 0.5°/sec.
Max. Rotation rate:	-5°/sec to +5°/sec.
Max. Acceleration:	-1°/sec^2 to +1°/sec^2.
Non-perpendicularity to elevation axis:	10 arcseconds.
Offset from X_0 axis:	0.001 inch.
Accuracy:	5 arcseconds.
Mechanical Range:	±180° about the index position.
Limit switch positions:	-180°, +180° Nominal.
Center switch position:	0° nominal.

Limit switches will actuate before the mechanical limits are reached.

The center switch will actuate before index position is reached. A deadband in the switch mechanism design will be provided to ensure that this is true regardless of rotation direction.

6. Mirror Covers

The mirror covers extend in front of the primary mirror and protect it from dust and falling objects. Two accordion style covers are required. The CS will provide the controls for opening and closing the covers. The functions that need to be provided are:

- Motor control.
- Limit switch sense.
- Control software.
- User interface.

The mirror covers will operate in response to a command from the operator. The times to open or close the covers are not to exceed 30 seconds. Switches in the open/closed position will signal the control system when the motion is completed and turn off power to the motor. The status of the mirror covers (open/moving/closed) will be displayed on the system status monitor.

The CS task will include power and control for the drive motors, inputs for reading the limit switches, cabling, control software, user interface software and coordination of interface requirements. Motors and switches will be supplied with the covers.

7. Flat-field Lamps

Two banks of four lamps will be mounted on the telescope to project a flat-field illumination on a screen mounted on the inside of the dome. The CS will provide control signals to individually switch banks and inputs for verifying the status of each lamp. The CS will also provide power for the lamps and sensors.

Specifications:

Lamp power, bank 1:	TBD V, TBD amps.
Lamp power, bank 2:	TBD V, TBD amps.
Sensor type:	TBD.

8. OSS Counterbalance

Two powered counterweights will be provided for fine balance of the OSS. Positioning of the counterweights shall be through the Control System. The required functions are:

- DC Motor control.
- Limit switches.
- Position encoder.
- Control software.
- User interface.

The counterweights will compensate for imbalance of the OSS parallel to the optical axis. Limit switches will be provided to limit the travel of the weight. Absolute encoders will measure their position. The CS will provide a lookup table for various telescope/instrument configurations that may need to automatic movement of the counterweights to compensate balance changes during, for example, tertiary fold-up or mirror cover operation.

The CS will provide motor control and power, cabling, read inputs for the position encoders and limit switches, and control software and user interface. The control software will move the counterweights in response to position commands from the operator and for automatic balance control. The motor, encoder and switches shall be provided as part of the telescope.

9. Dome

The CS will control the azimuth rotation of the dome. The following functions are required:

- Azimuth motor control.
- Absolute encoder input.
- Brake control.
- Actuator control for rotation locks.
- Control software.
- User interface.

Two modes of operation will be available to the user. In AUTO mode the dome will automatically track the telescope. During telescope repositioning operations, the dome will move to the target position taking the shortest distance. The dome operation will be transparent to the user in this mode.

In MANUAL mode the operator will control the dome position through the CS by using the console or the portable controller.

The operator will select the mode from the console. MANUAL mode will be the default on startup. On startup the dome will be stopped and tracking will be disabled.

The startup procedure for observing will involve releasing the dome rotation clamps and enabling the servo system. The shutdown procedure will involve rotating the dome to its stow position, turning off the servo system and activating rotation clamps.

A cancel command will stop rotation and disable tracking.

The CS task will control the dome rotation motors using commercially produced motor controllers supplied with the dome. The CS task will provide encoder inputs, control signals for the rotation clamp actuators, inputs for sensing the status of the rotation clamps, cabling, control software for all of the above, and the user interface. The CS will also provide power for the encoder. The motors, controllers, absolute encoder and clamp mechanisms will be supplied by the dome manufacturer.

9.1 Dome Mechanical

9.1.1 Dome Positioning

The dome will be driven by two AC motors mounted 180° apart on the enclosure base. The motors will be operated by a pair of variable speed AC motor controllers operating in parallel to provide synchronous motion. The motor controllers and cabling to the motors will be supplied by the dome manufacturer. The CS will command dome motions and read status information via serial and parallel interfaces supplied with the controllers.

An absolute encoder mounted on the enclosure base will measure the dome azimuth angle. The encoder resolution is ≤ 1 cm at the mounting position of the encoder, nominally at a radius of 24' from the center of the dome.

The CS will provide the capability to automatically synchronize the dome to the telescope position and maintain a clear field-of-view during telescope tracking and guiding. The dome position error when synchronized will be controlled by the software with the finest level of control approximately ± 3 cm RMS when measured from the center of the dome opening to the telescope optical axis.

The dome servo system will be designed to operate in the presence of wind torque on the dome structure.

The CS will also provide the capability of positioning the dome to a commanded position independent of the telescope position with an accuracy of $\pm$ 5 cm. measured at the dome encoder.

9.1.2 Brakes and Clamp Mechanisms

The azimuth drive motors will be provided with failsafe brakes to maintain the dome position when not tracking. The brakes will be designed to prevent unwanted dome motion in wind speeds up to the maximum observing conditions. The brakes will automatically disengage when power is applied to the motors and engage whenever the motors are stopped.

A separate pair of failsafe clamps will engage the dome drive plate and prevent rotation under all conditions. The two clamps will operate in parallel and will be used for stowing the dome. The clamps will be spring actuated and pneumatically released using the building 100 psi air supply. Pressure to the clamps will be controlled by an electrically actuated solenoid valve. In normal operation, the dome will be brought to a full stop with the servos before the clamps are applied. A pressure switch will sense when the clamps are engaged. Power to the servos will be removed when the clamps are engaged.

Parallel control of the clamps that overrides the automatic control will be provided as required for interlocks. (Interlock requirements are described in section 14).

The CS will provide control signals and power for the clamp actuators, inputs for reading the clamp sense switch, interlocks, cabling, control software and user interface. The brakes, clamp mechanisms, solenoid valve and switches will be supplied by others.

9.1.3 Mechanical Properties

Estimated mechanical properties: [G]

Rotating Weight of Dome:	80,000 lb..
Moment of Inertia:	TBD.
Rolling friction:	TBD.
Break-away friction:	TBD.
Max. Wind Torque, shutter open, observing:	TBD.
survival:	TBD.

9.1.4 Dome Motions

[G]

Azimuth Rotation range:	Unlimited.
Maximum Acceleration Rate:	$\pm$ 0.75°/sec^2
Maximum Rotation Rate:	$\pm$ 4°/sec.
Minimum Track Rate:	TBD.
Stow Position:	120° true azimuth.

The dome rotation drive will use two variable speed AC motors each driving a friction wheel through a gearbox and chain. The friction wheels will be preloaded against a circular plate mounted around the perimeter of the dome.

A 'soft-start' shall be provided as part of the motor control to take out jerk in the chain and gearbox. To minimize power dissipation while tracking, the dome will move in discrete steps and the power will be turned off while stopped. As long as the telescope is unvignetted by the dome, reduced velocities and accelerations will be used to minimize wear on the drive mechanisms. The actual values will be determined during testing of the dome structure.

9.2 Dome Manual Control

A portable controller will be provided for rotating the dome. It will provide the following functions:

- Rotate CW.
- Rotate CCW.
- Rate control.

The portable controller will plug into permanently mounted connectors located (a) near the drive controllers, (b) outside on the maintenance platform, and (c) in two locations on the observing floor near the drive motors. A fifty foot cable will be provided with the controller.

A keyed panel mounted switch near the drive controllers will select between automatic and manual control.

The CS task will provide the portable controller, cabling, and mode control switch.

10. Time Standards

The Control Subsystem (CS) will obtain time from the KPNO UTC distribution network. Distribution of time signals derived from UTC is also part of the CS task. The frequencies supplied will be as a minimum:

1 Hz, 1 kHz.

The CS will contain software to maintain an internal clock to provide time information in the event that the UTC network is interrupted. The CS will not be required to generate time signals in the absence of UTC unless doing so is necessary to provide its other functions.

11. Environmental Data

The CS will monitor temperatures on the telescope structure. Sensors will be placed in 16 places about the telescope and have an accuracy of 0.3°C over the operating temperature range of the telescope.

The CS will obtain wind velocity and direction, temperature and humidity data from a weather station that samples the weather outside the dome. The required range, accuracy and sampling rate are:

Temperature range:	-15°C to 45°C
Accuracy:	TBD.
Wind speed:	TBD.
Accuracy:	TBD.
Sampling rate:	TBD.

Survival conditions:

Temperature:	-20°C to 50°C
Wind speed:	150 mph.
Humidity:	100% rain, ice, snow.
Altitude:	6838'.

Temperature sensors, weather station, cabling, control software and user interface are included in the CS task.

12. Operator Controls

The CS will provide User/Operator interfaces for commanding the telescope, commanding peripheral equipment, displaying status and diagnostics, starting up of the observatory, normal and emergency shutdown of the observatory, and displaying environmental data. Control will be from control terminals, a control panel and portable controllers. For normal operation, the operator will only be required to work from a single keyboard.

12.1 Control Panel Functions

- Drives — Applies power to dome, telescope drives, and releases brakes. Momentary action required for recovery from an Emergency Stop or the off-condition. Keyed switch with three position control: Off-On-Start. Certain safety interlocks as described in section 14 may override the "on" condition.

- Emergency Stop — Removes power from dome and telescope drives and applies the brakes. See section 14, "Emergency Stop".

12.2 Console

The Console will be the principal control terminal for user interface to the CS and will consist of a workstation and associated peripherals. The CS will provide a graphical and command line user interfaces on the Console for entering commands and receiving positioning and status information.

The software design will be such that the user interfaces may be implemented on other terminals. Local terminals will be connected to the observatory LAN. The CS will also be capable of connecting to remote terminals over the mountain LAN. Control by the other terminals will be enabled and disabled by commands from the Console. The software will be fully interlocked to prevent undesired states or unauthorized access to the controls.

The terminal, its disk and all required peripherals and software are included in the CS task.

12.3 System Status Display

Displays will provide position and status information for the telescope and dome. UTC and local sidereal and civil time, and the state of various subsystems necessary for the operation of the telescope will also be displayed. Information will be presented on two fixed format pages. Paging method is TBD as part of the design. Fault conditions will be highlighted to bring them to the operator's attention. Status and fault information will be displayed on both pages.

A display will be provided in the control room for the operator. Cabling for additional displays will be provided on the Observing Floor, Second Level of the enclosure, Spectrograph Labs, Observers Office, Control Room, and Computer Room.

The following minimum set of items will be included in the display:

<u>Page 1</u>

- Object name.
- Right Ascension.
- Declination.
- Epoch.
- Offsets from set coordinates.
- Universal time.
- Sidereal time.
- Telescope azimuth angle.
- Zenith distance.
- Dome position.
- Tertiary position.

- Secondary mirror position.
- Counterweight positions.

Page 2

- Universal time.
- Instrument name/configuration.
- Instrument rotator angles.
- Guide probe 1 location.
- Guide probe 2 location.
- Sky brightness increment.
- Airmass.
- Air temperature.
- Wind speed.
- Wind direction.
- Humidity.

Status/fault Information

- Telescope tracking.
- Dome tracking/stopped/latched.
- Dome vignetted.
- Instrument rotator tracking/stopped.
- Approaching/reached telescope limit.
- Approaching/reached rotator limit.
- Mirror cover open/closed.
- Instrument lift unsafe.
- Autofocus/collimation enabled.
- Primary mirror active.
- Flat field lamps on/fault/off.
- Autoguider enabled.

The CS task will include providing the signal, cabling, the operator's display, and software for generating the display.

12.4 Telescope Manual controllers

Manual control of the telescope is required in a number of places around the observatory. Portable manual controllers, "hand paddles", will be provided for this purpose. This section lists the functions and locations where control is required. In all cases, manual control will operate through the telescope computer.

The CS task will include providing the hand paddles, control signals, switches, cabling and the user interface.

12.4.1 Functional Requirements

The hand paddle will provide the following main functions:

- Move the telescope mount in coordinate A.
- Move the telescope mount in coordinate B.
- Rotate the selected instrument rotator.
- Focus.

Mount motion commands will be interpreted according to a software settable mode as (1) equatorial, (2) alt-az, or (3) guider coordinates. On system initialization, the default mode will be equatorial coordinates.

Multi-speed control at rates set by the software will be provided for all main functions. A minimum of three speeds is required for each. The slowest speed will be the default speed. In addition, a jogging mode will provide a constant offset for a momentary actuation of a motion command. The preset rates and offsets will be changeable by the system operator. After 10 seconds of no motion commands, rates will revert to the default rates.

A software switch will select the instrument rotator. On system initialization, the default selection will be "none".

The required hand paddle auxiliary functions are:

- Select coordinate mode.
- Select rate.
- Select rotator.

The hand paddle will display the following (coded) information:

- Coordinate mode.
- Selected rotator.
- Selected rates.

12.4.2 Locations.

Hand paddle connectors will be provided at the following locations:

a. Observing floor near the instrument lift.
b. Second level within cable reach of the azimuth drives.
c. Spectrograph laboratory rooms (3 locations).
d. Control room.

Non-coincident control is required in the spectrograph lab and the above requirement could be satisfied with a single hand paddle and daisy chained control line.

Fifty foot cables will be provided for (a) and (b). Twenty foot cables will be provided for (c) and (d).

12.5 Graphical User Interface

The CS task includes a Graphical User Interface (GUI) for the Console. The GUI will run in a windows environment and provide access to all of the commonly used functions for operating the telescope.

Other terminals connected to the observatory LAN and remote terminals will be able to control the telescope using the GUI when remote operation is enabled.

Commands will be grouped logically by function within windows. Seldom used commands may be placed in windows that can be temporarily closed during observing.

A window connected to the Command Line Interface will be provided for access to the extended command set and diagnostics.

The minimum set of commands provided with the GUI is listed below. Commands marked with an asterisk ("*") are not available remotely.

12.5.1 General Commands

- * Enable remote terminal.
- * Enable manual controller.
- • Cancel command.

12.5.2 Auxiliary Commands

- * Open/close mirror covers.
- * Rotate tertiary. (Computer generated sequence)
- • Turn on/off flat-field lamps (signal IAS).

12.5.3 Secondary Mirror Commands

- * Power on/off vacuum supports.
- • Enable autofocus mode.
- • Select open-loop/close-loop focus mode.
- • Manually set focus and tilts.

12.5.4 Instrument Rotator Commands

- * Power on/off servo.
- • Initialize position from index position. (Computer generated sequence)
- • Rotate to position angle.
- • Rotate by fixed angle.
- • Stow.
- • Set software rotation limits.
- • Enable/disable rotator track.

12.5.5 Dome Commands

* Stow/unstow. (Computer generated sequence)
* Enable/disable tracking.
* Rotate dome to azimuth angle.

12.5.6 Telescope Positioning Commands

* Power-on servos ("Start").
• Initialize encoders from index position. (Computer generated sequence)
• Set encoders.
• Select catalog/observing list.
• Get coordinates from catalog/observing list.
• Enter Guide star coordinates.
• Get guide star coordinates from catalog/observing list.
• Select coordinate system (equatorial, mount) & epoch.
• Enter coordinates.
• Enter offset value.
• Enter proper motion.
• Add coordinates to observing list.
• Move to object coordinates.
• Return to previous object.
• Cancel move.

12.5.7 Track/guide Commands

• Enable/disable tracking.
• Enable manual/auto guiding.

12.5.8 Instrument Adapter Commands

• Initialize probes.
• Input probe positions.
• Move probes.
• Manually position probes (proportional control).
• Adjust camera gain (proportional control).
• Insert/remove calibration unit.
• Turn on/off calibration lamps.
• Initialize ADC.
• Rotate ADC.
• Insert wavefront sensor.

12.5.9 Primary Mirror Commands

* Select standby/full thermal control.
* Disable/enable active mirror control.
• Perform wavefront reduction/optics recalibration.

12.6 Command Line Interface

A Command Line Interface (CLI) will provide access to the complete set of telescope functions and diagnostics. It will include, in addition to the commands provided with the GUI, commands for:

- Specifying the system configuration.
- Reading positions, limit switches and status information.
- Setting seldom changed rates.
- Setting software limits.
- Updating pointing correction parameters.
- Setting the mask and directing output for the engineering data logger.
- Accessing low level diagnostics.
- Command line interface for PMS and IAS.
- Reading motor current in the mount drives.

12.7 Program File Interface

The Program File Interface (PFI) will be implemented in a second development phase of the control system. The PFI will use the syntax of the CLI but will include additional control structures to allow unattended ("programmed") operation of the telescope. PFI commands would normally be entered into a file that would be executed by the telescope and science instrumentation at the appropriate times.

The following capabilities are required:

- Execute CLI commands.
- Forward Science Instrument commands to the Science Instrument.
- Forward Instrument Adapter commands to the Instrument Adapter Subsystem.
- Check the status return for all commands.
- Branching.
- Loops.
- Pause/signal for operator intervention/input.
- Maintain observing log.

Development of the PFI will be undertaken after completion of the other CS tasks. The implementation of the CLI should provide the appropriate hooks and handshake signals for this expansion.

13. Subsystem Interfaces

The Control Subsystem will provide for the following interfaces in addition to those required for the CS task.

13.1 Electrical Supplies

Hardware supplied as part of the CS task will be provided with power supplies as required. Power supplies for the following hardware controlled by the CS task are also included:

- All encoders except those with internal supplies.
- Sensors.
- Limit switches.
- Servo and stepper motors.
- Actuators.
- Valves.

13.2 Observatory LAN

A local area network (LAN) will be provided as part of the CS task for connecting the various subsystems associated with control. At a minimum these will include the Primary Mirror Subsystem (PMS), Console, Instrument Adapter Subsystem (IAS), Science Instruments (SI), and the router to the mountain network. Taps for connecting to the LAN shall be provided in the control room, shop, computer room, observer's office, spectrograph lab, second enclosure level, and observing floor.

13.3 Primary Mirror Subsystem

The Primary Mirror Subsystem (PMS) contains all the controls for the active supports and thermal control of the primary mirror. In addition to maintaining the correct forces on the axial supports, the PMS will control the mirror position in piston and two axes of tilt and lateral translation parallel to the Y_O axis. The thermal controls will maintain a uniform mirror temperature.

Mirror figure sensing and the computation of collimation errors will be accomplished in the PMS using a wavefront sensor in the Instrument Adapter or, optionally, in the science instrument.

The PMS is the responsibility of the NOAO 3.5-M Mirror Group. The CS interface to the PMS will be through the Observatory LAN and will be coordinated with the PMS task.

13.4 KPNO WWV Time Distribution Network

The UTC time signal is encoded in standard IRIG format and broadcast around Kitt Peak on coaxial cable. A commercially available receiver/decoder is available that outputs the time as TTL compatible BCD. The receiver/decoder and interface for reading the BCD output is included in the CS task or, optionally, an interface for receiving IRIG directly may be substituted.

13.5 Instrument Adapter Subsystem

The instrument adapter attaches to the NIR and provides a mounting surface for the Science Instruments that attach to it. In addition, the Instrument Adapter Subsystem (IAS) provides the following functions:

- Acquisition/guide probe.
- Focus/guide probe.
- Wavefront sensor.
- Wavelength calibration sources.
- Atmospheric Dispersion Corrector (ADC).

The guide probes are mounted on x-y stages and will be moved around the beam by commands from the CS. The probes will be able to track independently of the telescope tracking to allow guiding on objects at non-sidereal rates. Non-sidereal track rates will be specified as constant velocities in RA and Dec.

The output of the imaging detectors in each probe will be analyzed by the IAS and track/focus error signals will be sent to the CS over a bus(es) TBR. Camera control, the real-time display of guide frames, and cursor control will all be part of the IAS task. The raw image frames will be available over the observatory LAN. The output of the wavefront sensor will go directly to Primary Mirror Subsystem over a bus TBD and will be reduced by the PMS.

The CS will send commands to the IAS to insert calibration sources and to set the ADC.

The IAS will return position and status information for all functions.

The user interface for the IAS will run on the CS Console and be included in the CS user interface. The IAS user interface shall be designed to run on other, possibly remote terminals. The specification of this interface and the interface(s) between the IAS and CS is part of the CS task.

13.6 Mountain Ethernet LAN

Ethernet on Kitt Peak is distributed between buildings by fiberoptic cable using proprietary FiberCom WhisperLan transceivers that interface to the in-building subnets. The CS shall provide a connection to the Mountain LAN through a router to isolate WIYN local traffic from the rest of the system. (A PC/AT with two network cards is being used as a router at other nodes on the net.)

13.7 Science Instrument & Data Reduction Computers

The control system will interface to Science Instruments over the Observatory LAN. Instruments in planning will use SUN SPARC stations running UNIX and C. Communication will be by TCP/IP.

The control system will make information necessary for maintaining observing records and controlling exposures available over the LAN to the SIs. This should include but is not necessarily limited to:

- Telescope position and status.
- Secondary mirror position.
- Tertiary rotator position.
- Status of flat-field lamps & calibration sources.
- UTC and sidereal time.
- Instrument rotator position and status.
- Weather data.

The control system will accept status from the SI. Status information will include such items as:

- Instrument ID.
- Instrument configuration.
- Observation in progress.
- Otherwise busy.
- Duration of current activity.
- Observation done.
- Ready.
- Error.

The control system will maintain a configuration file for each instrument with such information as:

- Instrument ID.
- Focus offsets for various filters and instrument configurations.
- Coordinates of focal surface center relative to the instrument mount.
- Orientation and scale for guide probes.
- Counterweight position.
- Instrument rotator software limits.

Some instruments may supply their own track error signals to the control system. The bus that will be used for transmitting the signals is TBR. The CS will receive the signals and generate the appropriate tracking corrections. Defining the interface to the SI is part of the CS task.

13.8 Remote Stations

The CS will interface to remote stations over the mountain LAN and possibly by dedicated leased lines. The CS will make the following available to the remote stations:

- Telescope and dome control as specified in section 12.
- Position display and status information included in the System Status Display.
- Access to SIs and the IAS.

The interface specification but not the implementation of remote stations is included in the CS task.

13.9 Uninterruptable Power Supplies

Power for critical loads will be supplied by two battery backed up uninterruptable power supplies (UPS) as specified in section 16.5.

The CS will monitor the condition of the UPSs over RS232 connections and report error conditions to the operator.

CS connection to the 110 VAC power will be via standard 3-wire grounded spade plugs. Outlets will be provided by the telescope and enclosure contractors near CS power supplies. UPS outlets will be color coded orange.

14. Interlocks

Interlocks will be provided for the safety of personnel and equipment. Independent hard wired and computer controlled interlocks will be provided where necessary to prevent unsafe situations as a result of a single component or subsystem failure. The following is a list of required interlocks. Interlocks required for human safety are marked with a cross ("†").

† Emergency Stop: Hardwired control removes power from the telescope and dome drives and sets brakes in response to activation of an "Emergency Stop" button or shutdown of the system key lock. "Emergency Stop" pushbuttons will be provided in the control room, on the observing floor, on the second level and inside the pier. Pushbuttons will remain activated until manually reset. An emergency stop will be detected by the control system and cause a software reset of the drive controls for the telescope and dome. System restore requires activation of the key lock on the console.

• UPS Power Fail: Causes an Emergency Stop.

† Dome drive maintenance switch: A key lock will be provided on the dome drives to manually lock out power to the drive.

† Telescope drive maintenance switch: A key lock will be provided on the telescope drives to manually lock out power to the elevation and azimuth drives.

† Instrument lift platform: Removes power from the telescope drives and sets the telescope brakes when the platform is extended. Interlock control and cabling to the platform is included in the CS task. The platform-extended switch will be provided with the platform.

• Azimuth limits: Cuts power to the telescope drives and sets the brakes when a "hard" limit of rotation is reached. Manual override allows backing out of the limit.

• Elevation limits: Cuts power to the telescope drives and sets the brakes when a "hard" limit of rotation is reached. Manual override allows backing out of the limit.

- † Elevation runaway: Removes power from the telescope drives and sets the brakes in response to a runaway condition of the OSS as described in section 2.5. Maximum velocities are specified in section 2.2.3, Accelerations and Rates.
- † Azimuth runaway: Removes power from the telescope drives and sets the brakes in response to a runaway condition of the OSS as described in section 2.5. Maximum velocities are specified in section 2.2.3, Accelerations and Rates.
- Instrument rotator limits: Cuts power to the rotator drive and sets the brake when limit switches are activated. Manual override allows backing out of the limit. Independent interlocks shall be provided for each rotator separately.
- Tertiary rotation: Prevents tertiary rotation when the mirror covers are not in the open position.
- Tertiary unsafe: Prevents operation of the mirror covers or rotation of the tertiary when the tertiary is folded up.
- Mirror cover: Prevents operation of the mirror cover when the tertiary mirror is unsafe for cover closure: ie. not in a Nasmyth position or mirror tilted up.
- Dome Inhibited: Removes power from dome drives when rotation clamps are engaged.

15. Utility Software

This section describes utility software that will be provided as part of the Control Subsystem task in addition to the software necessary for controlling the various telescope and dome subsystems and interface software described above.

15.1 Coordinate transformations

The control system task will include all necessary software for transforming coordinate systems from equatorial and galactic coordinates to mount and focal plane coordinates. Time and epoch conversion and reduction of celestial coordinates for precession, aberration, nutation, refraction and proper motion will be provided. Reduction to focal plane coordinate will correct for optical distortion of the field. The user will input catalogue positions to the CS and the CS will use these routines in pointing the telescope.

15.2 Generating pointing maps

The CS task will include the software necessary for acquiring the data for generating pointing maps and other corrections to the pointing. Programs will be provided for reducing the data and incorporating the new corrections in the system. Means for saving and retrieving files with correction data and an identifying header is required.

15.3 System diagnostics

System diagnostic software necessary for verifying system performance as specified herein is included in the CS task. It will include:

- Pointing and tracking performance.
- Focus stability.
- Dome pointing and tracking.

Additional software will be provided at the subsystem level for checking the operation of motors, encoders, sensors, switches, etc. These diagnostics will be available at the system level through the user interface and at the subsystem level through a terminal connected at that level or by other means.

15.4 Engineering data logs

The CS will create a process for time tagging and logging engineering data from the Control System, Primary Mirror Subsystem, Instrument Adapter Subsystem and any other connected subsystem that sends to the logger. The CS task will define a standard format for the data and a masking mechanism for letting the operator select what data is recorded.

Engineering data that will be generated within the CS include:

- Configuration changes.
- Telescope moves.
- Dome moves.
- Track corrections.
- Focus corrections.
- Environmental data.
- Error conditions.

16. General Design Requirements

16.1 Environments

Portions of the control system will be installed in three temperature zones:

Zone 1: The Control Room, Instrument Lab, and Computer Room will be conditioned spaces maintained at near normal office temperature and humidity.

Zone 2: The Telescope Enclosure and Mechanical Room will be unconditioned and ventilated to maintain temperatures and humidity near conditions outside the observatory.

Zone 3: The Spectrograph Lab on the ground floor of the enclosure will be unconditioned but well insulated and sealed to maintain a constant daily temperature for instruments.

Operating Conditions to Meet Specifications

Zone	Tmax. (°C)	Tmin (°C)	Humidity
1	30	10	90% non-condensing
2	40	-15	98% non-condensing
3	25	0	90% non-condensing

Storage temperature: -15 to 50 °C
Altitude: 6838'

Lightning storms at the site are violent and occur frequently at certain times of the year.

16.2 Design Guidelines

- The Control Subsystem must meet the functional and performance goals.
- "Human engineering" will be built into the user interface to provide a system that is intuitive and easy to use.
- A flexible design is required to accommodate future upgrades with minimal added cost.
- The design will emphasize rapid fault isolation and minimum down time for observing.
- Ease of maintenance is a requirement for hardware and software. The design must take into account the expertise and level of support that is anticipated at the observatory.
- Safety should be designed into the system from the beginning. Hardwired interlocks are required wherever human safety is concerned or wherever damage caused by a control system failure would jeopardize or result in substantial loss to the project.
- Standard bus structures and communication architectures will be used. Widely used standard languages and operating systems will be adopted for the software.
- Existing hardware and software will be used where possible to reduce the development time and cost to the project.
- The Control Subsystem must be built within the budget approved for this part of the project.

16.3 Hardware Standards

- Commercially produced circuit boards will be favored over custom designed boards.
- Cabling is an initial expense and maintenance problem that should be minimized. Serial, party-line, communication between subsystems should be used wherever possible.
- High reliability connectors will be used and cables will be strain relieved.
- Mechanical design will be ruggedized to industrial standards.
- Spares will be provided to allow repair of equipment by board replacement. Board repair will be accomplished off-line.
- Computers will provide a port for maintenance terminal support including a user interface for performing maintenance and diagnostic functions.
- Equipment will be energy efficient. Waste heat production will be minimized in the dome.

16.4 Chassis and panels

The following panels and/or chassis will be provided as part of the CS task:

- Equipment installed in the computer room will be mounted in standard 19" EIA instrument racks with ventilating fans and power strips. Cabling from the computer room to the telescope enclosure and control room will be in overhead cable trays and enter the instrument racks from above.
- Equipment installed in the telescope enclosure will be mounted in standard 19" EIA instrument racks or wall mounted panels with power strips and a duct for connecting to the ventilation system. Cable routing is TBD.
- Controllers mounted on the telescope will be in instrument cases with ducts for connecting to the telescope ventilation system.
- Workstations and their associated peripherals and displays are normally supplied with cases and sit on counter tops. No special mounting provisions need be made.

16.5 Electrical power

Electrical power is an expensive and scarce resource at the WIYN site. The control system will be designed with power efficiency as a goal.

Two types of power are provided at the WIYN site: Mountain Power and UPS Power. The system will be designed to continue operating through a commercial power failure without interrupting the observation.