GNAO Adaptive Optics System

AOS System Control Architectural Design

******* WORK IN PROGRESS - DO NOT REFERENCE *******

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Document Acceptance and Release Notice

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Applicable Documents

Applicable Documents are those documents containing information that is considered binding in the context of this document. Unless otherwise specified, the latest version of the Applicable Document shall be used. In case of conflict between an Applicable Document and this document, this document shall take precedent.

	Document #	Title	Vers
[AD-01]	TBA	AOS Subsystem Specification	TBA
[AD-02]	TBA	AOS Control Requirements	TBA
[AD-03]			
[AD-04]			
[AD-05]			

Reference Documents

Reference documents are those documents that are included for information purposes only. They may provide additional background or context, but are non-binding in the context of this document.

	Document #	Title	Vers
[RD-01]	TBA	GNAO Concept of Operations	TBA
[RD-02]	TBA	GNAO Control System Architecture Design	TBA
[RD-03]	TBA	GNAO Control Software Core Architectural Design	TBA
[RD-04]	N/A	https://redis.io/	N/A
[RD-05]	N/A	https://docs.epics-controls.org/en/latest/guides/EPICS_Intro.html	N/A

Definitions

The following terms used in this document are defined as follows:

Abstraction - Abstraction is the process of hiding the internal details of an application from the outer world. Its main goal is to handle complexity by hiding unnecessary details from the user. That enables the user to implement more complex logic on top of the provided abstraction without understanding or even thinking about all the hidden complexity.

Encapsulation - Encapsulation refers to the compartmentalization of functions to ensure that no part of a complex system depends on the internal details of another part.

EPICS - Experimental Physics and Industrial Control System. A set of Open Source software tools, libraries and applications developed by the particle accelerator community to create distributed soft real-time control systems for scientific instruments and facilities. See the EPICS documentation site [RD-05] for further details.

EPICS IOC - Input/Output Controller. The I/O server component of EPICS which provides a database of process variables used to control hardware components. Almost any computing platform that can support EPICS basic components like databases and network communication can be used as an IOC. See the EPICS documentation site [RD-05] for further details.

REDIS - An open source, in-memory data store widely used as a database, cache, streaming engine, and message broker. See the REDIS home page [RD-04] for further details

Secured State - For any device, mechanism or assembly the term "secured state" refers to a state whereby it can be left unattended for an indefinite period of time without risk of damage to the device or telescope facility.

Purpose

The purpose of this document is to record the current state of the GNAO Adaptive Optics Control System Architecture Design.

Scope

The scope of this document is limited to the AOS Control System architectural design and the trade studies performed in support of this design.

Executive Summary

The AOS System Controller (ASC) is a collective name for all of the control software required to automate and operate the GNAO Adaptive Optics Facility. The ASC is being developed as part of the overall System Controller Work Package, and relies on the AOS work packages to define the hardware to be controlled.

This document presents an Architectural Design for the AOS System Controller. An architecture design is the first step in the design solution process, undertaken as part of the Preliminary Design phase. It defines the overall system framework, identifies and organizes the major software and hardware components, and shows how these components will work together to satisfy the system requirements.

A series of Use Cases are presented that show how the architectural elements will work together to deliver the required system functionality.

Requirements

Requirements for the AOS System Controller can be found in the GNAO AOS Control Requirements document [AD-02].

Specific functionality required to support the GNAO operating models will be added here when the system operating models and associated AOS "in-house" work has been defined.

GNAO Control Architecture

The Adaptive Optics System is a subsystem of the overall GNAO Facility, its dedicated control system is an integral part of the GNAO Facility control architecture, as shown in Figure 1 below.

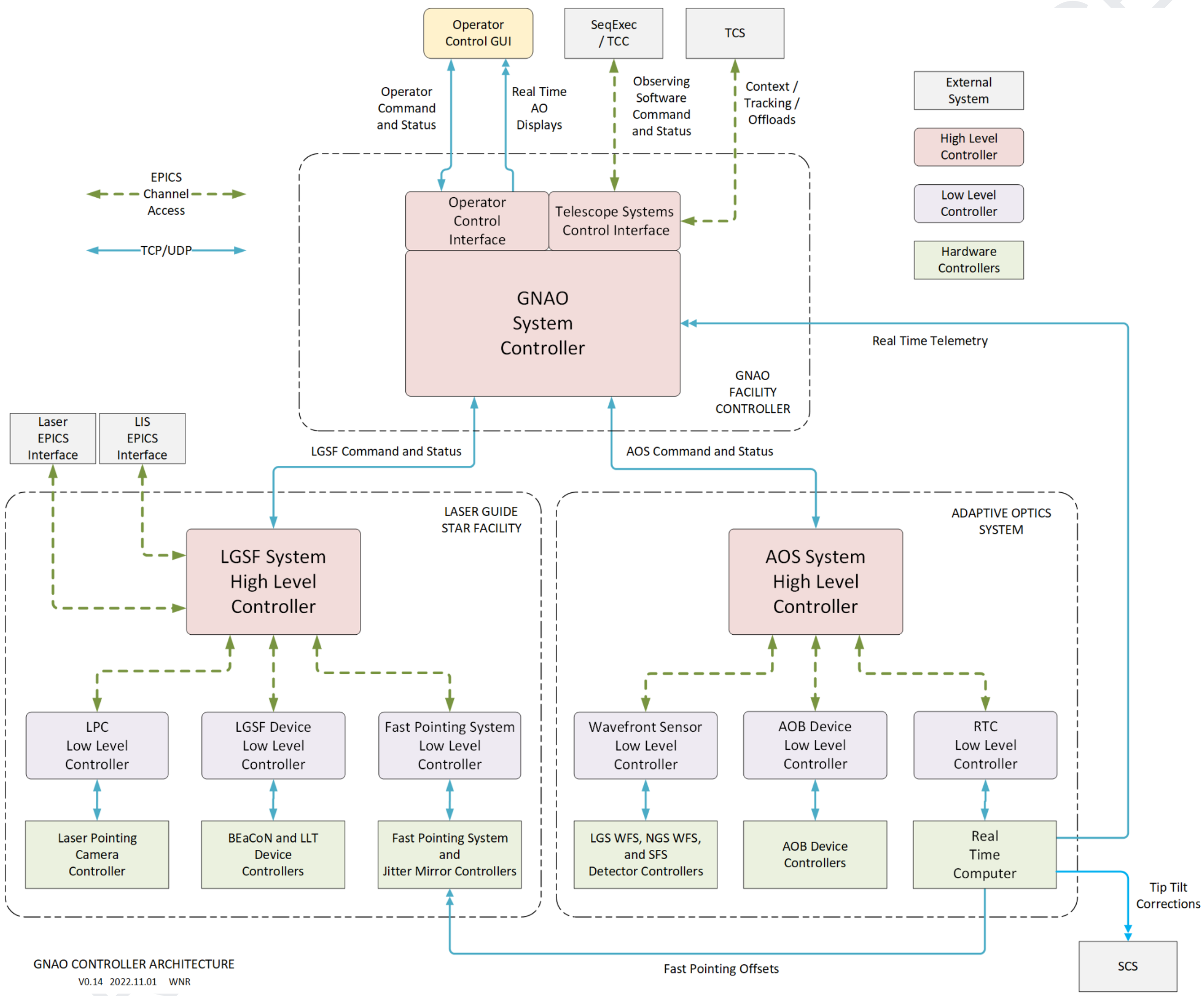

Figure 1: GNAO Control System Architecture

A complete description of the GNAO Control System Architecture can be found in the GNAO Control System Architecture Design document [RD-02]. The next section expands the Adaptive Optics System control section to provide details of its implementation.

AOS System Control Architecture

The AOS System Controller controls and coordinates all Adaptive Optics System activities. It consists of a high-level controller with dedicated low-level controllers to manipulate AOS hardware as required to improve the resolution of images delivered to the science instrument, as shown in Figure 2 below. Interactions between high and low level controllers can be recorded in the Gemini Engineering Archive for future use. This design is representative only, since the components for the delivered AOB have not been defined yet. The overall structure should be stable, specific device control details will change as the AOB design work progresses.

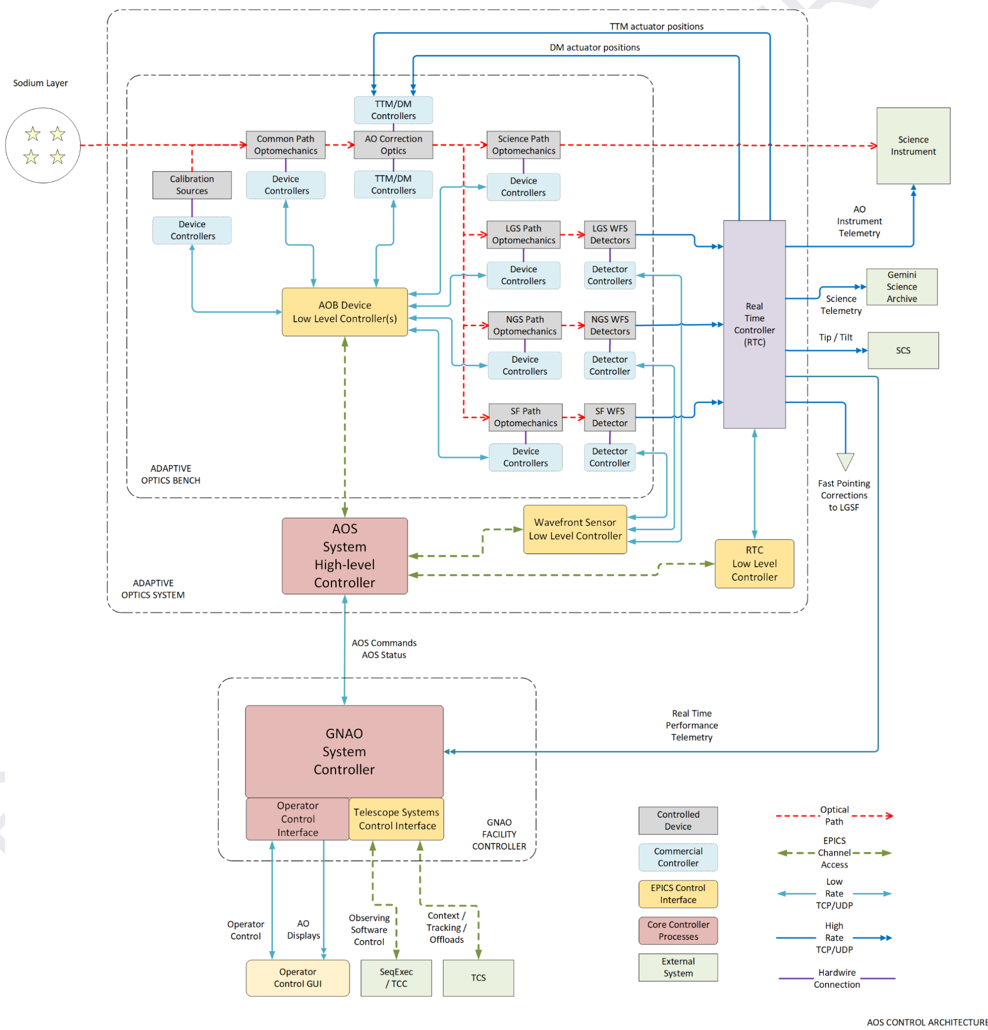

Figure 2: AOS Control System Architecture

The major architectural elements in this design are described in the following sections.

AOS High-Level Controller

The AOS High-level Controller implements the complex logic and sequences required to allow the AOS to be operated through a simple, functional command and status interface. This logic includes the processes that generate interaction matrices, support system calibration, and optimize correction performance. The AOS high-level controller is based on the GNAO Control Software Core [RD-03] with specific customizations that will be specified once the AOB has reached preliminary design stage.

The AOS High-level Controller also receives non-sidereal object tracking positions from the TCS (via the GFC) in telescope coordinates. It applies all coordinate transformations, position offsets, and distortion corrections required to convert these tracking streams to either NGS probe motions or NGS WFS Region of Interest locations (depending on NGS WFS design). It then uses the associated low-level controller to adjust the wavefront sensor positions to follow these non-sidereal objects.

The AOS High-level controller has the capability of executing arbitrary Python scripts that can interact directly with the internal REDIS database used for interprocess communication. This allows algorithms for various Adaptive Optics functions to be refined and new algorithms/techniques tested by AO Scientists without affecting the formally released operating versions.

The AOS High-level Controller receives commands and publishes status via a direct REDIS database link with the GFC. It performs all hardware related actions through low-level controllers as described below.

AOB Device Low-Level Controller

The AOB Device Low-level controller provides a functional interface control to all AOB devices described in the following sections. Since the AOB has not been designed yet, the devices to be controlled are not defined and are described in general terms only. What is shown as a single low-level device controller may be implemented as multiple, specialized, device controllers when the devices to be controlled have been specified. All devices are controlled through standard EPICS records in a dedicated EPICS IOC, using standard hardware device support where available or custom device support for the remainder.

The AOB low-level device control conforms to the architecture described in the overall GNAO Control Architecture document [RD-02]. This low-level device control layer relies on a commercial ethernet-enabled device controller, provided by the hardware device manufacturer, to control each device. For the AOB, the AOB vendor will provide the individual hardware devices and their associated controllers. The GNAO project will provide all control layers above this. It is not yet known if the AO Correction Optics manufacturers will provide suitable detector controllers, or if custom controllers will be needed to talk to the Low Level Device Controller.

Calibration Sources

All devices relating to providing calibration fields as input to the AOB, including calibration sources, alignment sources, and atmospheric simulators.

Common Path Optomechanics

Any moveable or selectable components in the optical path between the AOB entrance port and the point where the wavefront sensing beam and science beam are separated. This would include components such as the entrance shutter, the mechanism that inserts/removes calibration sources from the entrance beam. It does not include the calibration sources themselves or the AO correction optics, which are described separately.

AO Correction Optics

The low and high order wavefront correction devices. This would include the Tip Tilt mirror (if used) and the Deformable Mirror. Note that the AO Correction Optics have two control paths - a low bandwidth path for configuring and controlling the operation of the device and a high bandwidth path for real-time actuator position streams.

Science Path Optomechanics

Any moveable or selectable components in the optical path between the point where the wavefront sensing beam and science beam are separated and the AOB exit shutter. This would include components such as the ADC prisms and the mechanism that inserts/removes the ADC from the exit beam.

LGS Path Optomechanics

Any moveable or selectable components in the optical path between the point where the LGS and NGS Wavefront Sensing beams are separated and the LGS wavefront sensor focal plane. This would include components such as focus/zoom stages and mechanisms that align the wavefront sensors with the projected laser guide stars. It does not include the wavefront sensors themselves.

NGS Path Optomechanics

Any moveable or selectable components in the optical path between the point where the Wavefront Sensing and Science beams are separated and the NGS wavefront sensor(s) focal plane(s). This would include components such as ADCs, focus stages, and mechanisms that align the wavefront sensors with the selected natural guide stars (if a focal plane array is not used). It does not include the wavefront sensors themselves.

SFS Path Optomechanics

Any moveable or selectable components in the optical path between the point where the Wavefront Sensing and Science beams are separated and the SFS wavefront sensor focal plane. This would include components such as mechanisms that align the wavefront sensor with the selected natural guide star. It does not include the wavefront sensor itself.

Wavefront Sensor Low Level Controller

The Wavefront Sensor Low-level Controller provides a simple “EPICS Wrapper” around the wavefront sensor detector controllers. This wrapper is necessary to integrate them into the overall AOS control architecture. The Wavefront Sensor Low Level Controller provides a functional interface to control all of the wavefront sensor detectors in the AOB.

EPICS records will provide low level access to each of the wavefront sensor detector functions and status items. This enables low-level control of the detectors, all higher-level control and coordination of detector activity is done by the AOS High-level controller. Examples of the functionality to be provided are provided in the following sections.

There will be two data paths associated with each wavefront sensor, a low bandwidth path to allow the Wavefront Sensor Low-level controller to configure and control the detector readout, and a high-bandwidth path to send pixel data directly to the Real Time Controller.

It is not yet known if the selected Wavefront Sensor detector manufacturers can provide suitable controllers, or if custom controllers will be needed to allow the Low Level Device Controller to configure and control detector readout.

LGS WFS Detector Controller

Provide low-level control of the four LGS Wavefront Sensor detectors. This includes functions such as setting the readout area, integration time, and readout rate, along with starting/stopping the detector readout. Pixel data from the LGS WFSs will be sent directly to the RTC over an ethernet link. The detectors to be used and method of synchronizing the detector readouts will be proposed by the AOB vendor.

NGS WFS Detector Controller

Provide low-level control of the NGS Wavefront Sensor detector(s). This includes functions such as setting the readout area, integration time, and readout rate, along with starting/stopping the detector readout. Pixel data from the NGS WFS(s) will be sent directly to the RTC over an ethernet link. The detector(s) to be used and method of synchronizing the detector readouts will be proposed by the AOB vendor.

The AOB vendor will propose a solution involving either one focal plane array detector for all WFS or multiple detectors, one for each WFS. If a focal plane with multiple Region of Interest readout is selected the low-level detector controller will continuously update the location of the ROI (in the detector frame of reference) when performing non-sidereal tracking. The detector will have to follow this location stream without pausing the readout.

SFS WFS Detector Controller

Provide low-level control of the SFS Wavefront Sensor detector. This includes functions such as setting the readout area, integration time, and readout rate, along with starting/stopping the detector readout. Pixels data from the SFS WFS will be sent directly to the RTC over an ethernet link. The detector to be used will be proposed by the AOB vendor.

RTC Low Level Controller

The RTC Low-level Controller provides a simple “EPICS Wrapper” around the Real Time Controller itself. This wrapper is necessary to integrate it into the overall AOS control architecture.

An EPICS record is instantiated for each RTC command and status item. Custom device support is written for the standard EPICS records so they can communicate directly with the RTC command and status servers. This enables low-level control of the RTC, all higher-level control and coordination of RTC activity is done by the AOS High-level controller.

The RTC Low-level controller implements commands to control the production of telemetry data by the RTC but the real-time telemetry data produced does not flow through the RTC Low-level controller. Clients that want access to this data connect directly to the RTC telemetry server.

Real Time Computer

The Real Time Computer is a collection of software processes that analyze the incoming wavefront and generate the corrections necessary to correct distortions in this wavefront. Aside from the computer the processes run on there is no dedicated hardware for the RTC, all input and output data paths are ethernet based, all processes run on a multi-core PC.

The RTC reads pixel data directly from the LGS, NGS, and SFS wavefront sensor detectors. It sends wavefront correction signals directly to the Tip Tilt and Deformable Mirrors. It also offloads LGS position errors directly to the LGSF and telescope Tip Tilt errors directly to the Gemini Secondary Mirror. Low rate offloads, such as coma and mirror figure, are calculated and published by the RTC, these are transferred to the Gemini TCS via the AOS and GFC controllers.

The RTC provides a command server to allow external entities to control the internal processes, a status server to inform external entities of internal status and events, and a telemetry server to allow external entities to monitor correction performance.

Use Cases

Several Use Cases have been selected, based on expected Daytime and Nighttime Operations, that illustrate the basic capabilities of the AOS System Controller. More detailed use cases that build on these capabilities can be found in the GNAO Concept of Operations [RD-01]. These use cases are presented in ascending order of complexity, so that detailed operation can be shown in the initial cases to allow the more complex cases to focus on system operation.

Note that the use cases are rough outlines only, and will be refined during the preliminary design phase. The “commands” and “parameters” used are simply placeholders to indicate the sort of action taking place.

Use Case 1 - Manually Open the Entrance Shutter

Open entrance shutter. This is part of the startup procedure described in the GNAO Operational Concept document. This use case illustrates the execution of a command that results in a simple action by one device.

1. The operator opens the entrance shutter by pushing the appropriate button on the operator user interface, which sends the “openEntranceShutter” command to the GFC.
2. The GFC executes the “openEntrance Shutter” command, which validates the command by reading the system state (decides that it is appropriate and safe to execute it in the current system context - calibration not in progress, etc.) and indicates on the operator interface that the command has been accepted and is being executed. The GFC sends an “openEntranceShutter” command to the AOS controller.
3. AOS System Controller executes the AOS “openEntranceShutter” command, which validates the request (decides that it is appropriate and safe to execute in the current AOS context - shutter is healthy etc.) and sends the appropriate open position demand

to the entrance shutter motion controller via the associated EPICS motor record in the device control IOC.

4. Entrance shutter motion controller moves the entrance shutter to the open position and reports that the motion is complete in the associated EPICS motor record.
5. The AOS “openEntranceShutter” command is monitoring the EPICS motor record and sees that the shutter is now open and completes successfully.
6. The GFC “openEntranceShutter” command is monitoring the state of the AOS command it sent, sees that it has completed successfully, and completes successfully.
7. Operator interface is updated with the command completion status and current state of the entrance shutter.

If the command is not deemed valid it will be rejected and an error message returned to the operator to say why. If an error is encountered in the execution of the command an error message will be generated to indicate what happened. This error message will propagate up to the operator via the user interface.

Throughout this process all related status information (step position of the shutter motor, shutter moving state, etc.) is being continuously updated in real time as they change. The AOS System Controller publishes these status items, the GFC monitors them and relays the appropriate items to the operator interface.

Use Case 2 - Track Sodium Layer Altitude

Keep the projected stars focussed on the LGS Wavefront Sensors. Atmospheric conditions and the elevation of the telescope affect the apparent altitude of the sodium layer. When the apparent altitude changes, GNAO must refocus the wavefront sensors to minimize the size of the projected star. A separate Natural Guide Star and focus sensor are used to measure the telescope focus error. This use case illustrates the coordination of actions across a number of subsystems, execution of commands in parallel, and the ability of the controllers to perform autonomous actions.

1) Operator closes the Slow Focus loop by pressing the associated button on the Operator GUI, which sends the “closeSfsLoop” command to the GFC.
2) The GFC executes the “closeSfsLoop” command which checks to ensure the system is configured for slow focus correction (i.e. the AOS is reading the Slow Focus Sensor, the LGSF and AOS are tracking sodium layer changes, etc). If everything is not ready the command will fail with an error message. If everything is ready, the command sets the internal “sfsLoopState” variable in the GFC database.

3) The RTC has already started reading the slow focus sensor and calculating the focus error of the associated Natural Guide Star. The RTC updates the focus error in its internal status database.

4) The RTC Epics Interface IOC is monitoring the RTC focus error variable and updates the associated EPICS process variable.

5) The AOS System Controller is monitoring the associated EPICS process variable and updates the focus value in its internal database.

6) The GFC is monitoring the focus value in the AOS database and updates its internal focus value when the AOS focus changes.

7) The GFC System Controller has an autonomous action sequence defined to handle changes to the slow focus value. When the value changes the autonomous action sequence is triggered, which first triggers the GFC "updateSodiumLayerAltitude" command to adjust the sodium layer altitude based on the new focus value and save this value to its internal database. It then checks the "sfsLoopState" variable set in step 2 above to see if the SFS correction loop is closed. If not, the autonomous action sequence terminates at this point.

8) The operator has closed the loop, so the autonomous action sequence continues. It first checks to ensure that the LGSF and AOS are tracking sodium layer changes (based on their internal variables), then triggers GFC commands (in parallel) to send the new sodium layer altitude to the LGSF and AOS controllers by triggering the "sodiumLayerAltitude" command in each controller. The autonomous action sequence then waits for them to complete.

9) The LGSF Controller executes its "sodiumLayerAltitude" command, which first checks to see if the LGSF is tracking the sodium layer (an internal variable set by another command). If it is, the command calculates the appropriate Beam Expander stage position, then moves the stage to this position via the LGSF device low-level controller. When the stage is in position (or immediately if not tracking) the "updateSodiumLayerAltitude" command completes.

10) While this is happening, the AOS Controller executes its "sodiumLayerAltitude" command, which first checks to see if the AOS is tracking the sodium layer. If it is, the command then calculates the appropriate Zoom Optics stage position, then moves the stage to this position via the AOB device low-level controller. When the stage is in position (or immediately if the AOS is not tracking) the "updateSodiumLayerAltitude" command completes.

11) The GFC autonomous action sequence is monitoring the completion status of both the LGSF and AOS commands. When it sees that both commands have completed the autonomous action sequence is complete.

12) Steps 3 through 11 will repeat until something (either the operator of an internal event) clears the closeSfsLoop variable to open the SFS loop.

If the “closeSfsLoop” command is not deemed valid it will be rejected and an error message returned to the operator to say why. If any error is encountered in the execution of any command (including rejection) an appropriate “make safe” sequence will be executed before the sequence is considered complete and an error message will be generated to tell the operator what happened.

Throughout this process all related status information (focus error, new sodium layer altitude, position of beam expander and zoom stages, etc.) is being continuously updated in real time as they change. The LGSF System Controller publishes these status items, the GFC monitors them and relays the appropriate items to the operator interface.