Gemini North Adaptive Optics System

GNAO System Control
Architecture 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]	GNAO-SC-SPE-001	GNAO System Controller Subsystem Specification	TBC
[AD-02]			
[AD-03]			
[AD-04]			

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]	GNAO-SCI-002	GNAO Concept of Operations	TBC
[RD-02]	TBA	GNAO Control Software Core Architecture Design	TBC
[RD-03]	TBA	GNAO GFC Controller Architecture Design	TBC
[RD-04]	TBA	GNAO LGSF Controller Architecture Design	TBC
[RD-05]	TBA	GNAO AOS Architecture Design	TBC
[RD-06]	N/A	https://redis.io/	N/A
[RD-07]	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-07] 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-07] 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-06] 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 Control System Requirements and Architectural Design.

Scope

The scope of this document is limited to a high-level overview of the GNAO Control System architectural design and driving requirements. As the GNAO Control System encompasses all aspects of control for the entire GNAO system, the scope of this architectural design includes the GNAO Facility Controller, the LGSF System Controller, and the AOS System Controller.

Executive Summary

The GNAO System Controller (SyCo) is a collective name for all of the control software required to automate and operate the GNAO Facility. The SyCo is being developed as an independent work package, which relies on the LGSF, AOS, and RTC work packages to deliver the hardware to be controlled and the high-level functionality that needs to be implemented. As such, it includes the LGSF System Controller, the AOS System Controller (which includes control of the RTC), and the overall GNAO Facility Controller.

This document presents an Architectural Design for the GNAO System Controller. An architecture design is the first step in the control system design process. It defines the overall system framework, identifies and organizes the major software components, and shows how these components will work together to satisfy the system requirements.

This Architectural Design is presented first as a functional design, which identifies the functionality required to satisfy the SyCo system requirements, followed by a physical design which provides the required functionality. Following this, a series of Use Cases are presented that show how the architectural elements will work together to support operational usage.

Requirements

The full set of requirements for System Control can be found in the subsystem specification document [AD-01]. The top-level system requirements are summarized below:

- Must provide a Graphical User Interface which provides the command and status information necessary for human control of the system, including real-time AO performance and related displays.
- Must provide an EPICS interface that allows integration into the Gemini Observing Software system.
- Must provide a Maintenance Interface which provides unrestricted access to all high and low level system functions.
- Must provide a high level of automation to allow common tasks to be performed without requiring detailed knowledge of the steps involved.
- Must reject requests that are not safe or do not make sense in the current operating context of the facility.
- Must treat each subsystem as a separate entity which can be developed and tested independently.

Architecture Design

This section documents the GNAO System Control Architectural Design. The design is presented in two sections - a functional decomposition that identifies the functionality required to meet the system requirements, and an architecture design that illustrates how these functions will be implemented.

The proposed architecture is based on the concepts of Encapsulation and Abstraction. To the greatest extent possible, components at every level of the GNAO architecture operate independently, providing simple functional interfaces that allow control of these components without requiring detailed knowledge of how they operate.

GNAO System Functional Decomposition

A functional design for the control system architecture is presented below. Decomposition of the related function has been taken to the second level, which is deemed adequate for an architecture design. Further decomposition will take place during the preliminary design stage.

F0.0 - GNAO System

The GNAO Facility is functionally described at the highest level in Figure 1 below.

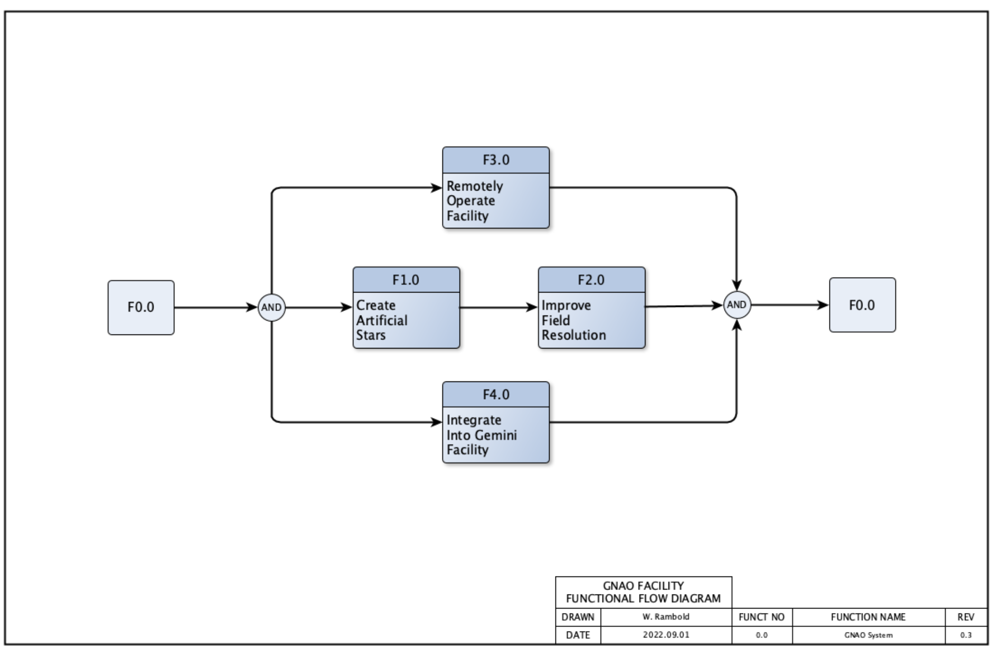

Figure 1: GNAO System Function Decomposition

F1.0 Create Artificial Stars
This includes all of the functionality required to project artificial stars on the Sodium Layer. The system functionality required to generate light, form it into an artificial star image, project the image on sky, and provide the means to maintain alignment of the star with the LGS Wavefront Sensors are included in this top-level function.

F2.0 Improve Field Resolution
This includes all of the functionality required to characterize the incoming wavefront and correct it before it reaches the science instrument. The system functionality required to accept an uncorrected image from the telescope, sample the wavefront to identify low and high order aberrations, use adaptive optics elements to correct the wavefront, deliver the corrected wavefront to the Science Instrument, and produce the real-time telemetry information required to record system performance are all covered in this function.

F3.0 Remotely Operate Facility
This includes all of the functionality required to allow GNAO to be operated remotely, without manual intervention. Remote operation encompasses everything from providing user interfaces to the physical manipulation of hardware devices. F3.0 is decomposed further in the sections that follow.

F4.0 Integrate Into Gemini Facility
This includes all of the functionality required to integrate GNAO into the larger Gemini Telescope environment.

Remotely Operate Facility Function Decomposition

The Enable Remote Operation function is decomposed into three major functional areas as shown in Figure 2 below: Controlling system functions (i.e. inserting an ADC or closing a servo loop); providing system status (i.e. laser propagation state, AO performance data); and enabling remote operation of the facility by external entities (i.e TCC, operator).

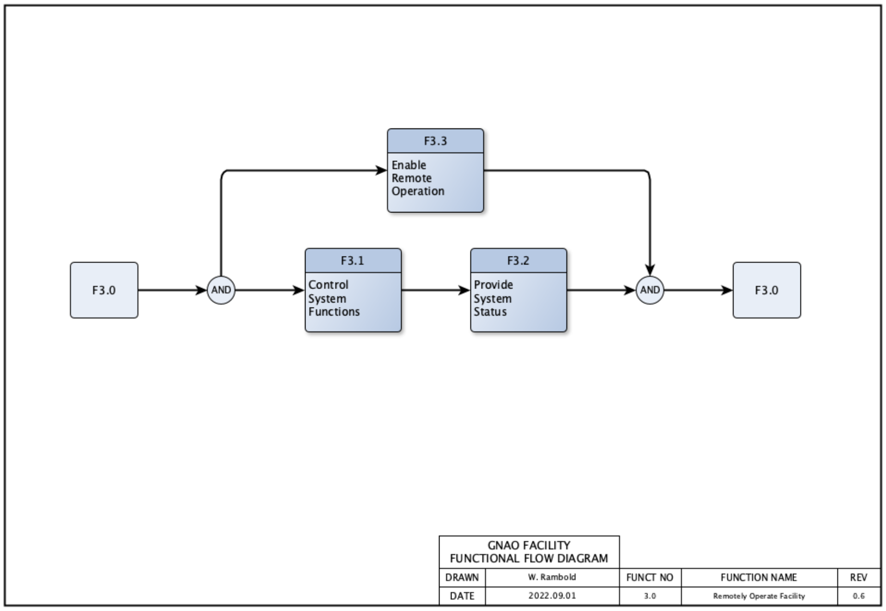

Figure 2: Remotely Operate Facility Function Decomposition

Each of these functional areas are decomposed one level further in the sections below:

F3.1 Control System Functions

This function provides the capabilities required to control all GNAO Facility components, as shown in Figure 3 below.

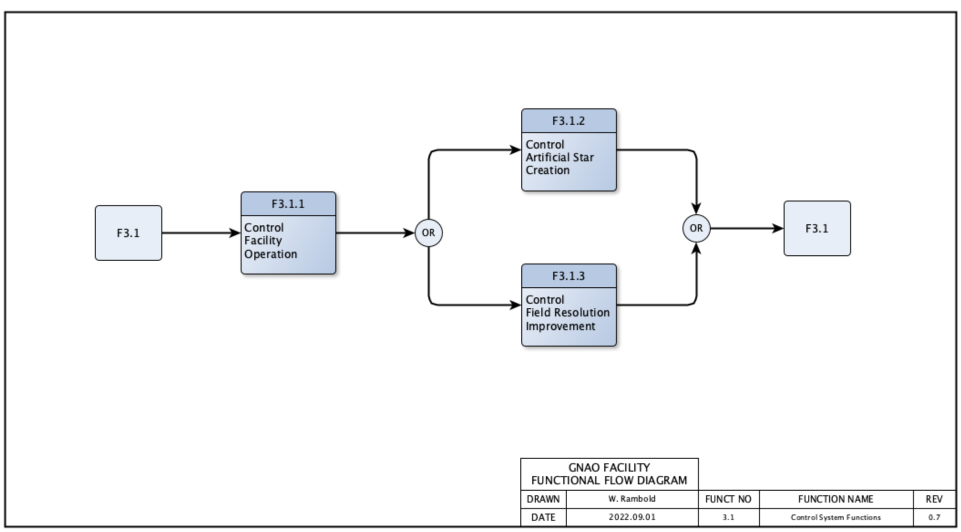

Figure 3: Control System Functions Function Decomposition

F3.1.1 - Control Facility Operation

This provides the functionality required to implement the main operating models, maintain and optimize the overall system state, and provide control and coordination of the two primary system functions. Further decomposition of this function can be found in the GFC Controller Architecture Design document [RD-03].

F3.1.2 - Control Artificial Star Creation

This provides the functionality required to control the safe projection of a laser guide star asterism and the maintenance of this asterism in the observed field. Further decomposition of this function can be found in the LGSF System Controller Architecture Design document [RD-04].

F3.1.3 - Control Field Resolution Improvement

This provides the functionality required to control the sensing and correction of atmospheric disturbances. Further decomposition of this function can be found in the AOS System Controller Architecture Design document [RD-05].

F3.2 Provide System Status

This function provides the capabilities required to monitor and report the status of all activities taking place in the GNAO Facility, as shown in Figure 4 below.

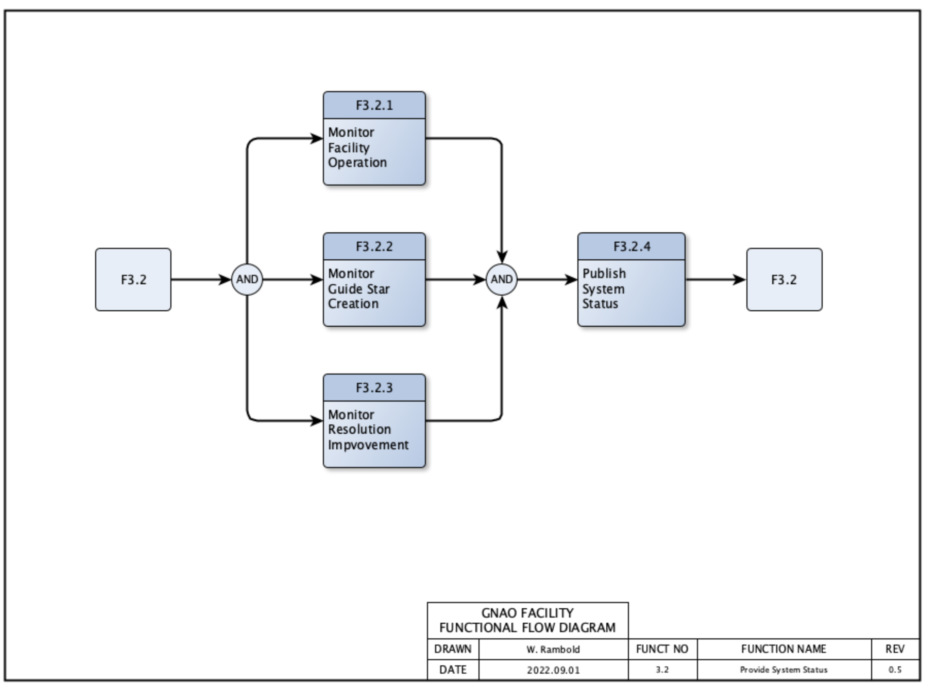

Figure 4: Provide System Status Function Decomposition

F3.2.1 - Monitor Facility Operation

This provides the functionality required to monitor and report on all system level activities. Further decomposition of this function can be found in the GFC Controller Architecture Design document [RD-03].

F3.2.2 - Monitor Guide Star Creation

This provides the functionality required to monitor and report on all guide star creation related devices and activities. Further decomposition of this function can be found in the LGSF Controller Architecture Design document [RD-04].

F3.2.3 - Monitor Field Resolution Improvement

This provides the functionality required to monitor and report on all field resolution improvement related devices and activities. This includes monitoring the embedded RTC and real-time telemetry information generated by the RTC. Further decomposition of this function can be found in the AOS Controller Architecture Design document [RD-05].

F3.3 - Enable Remote Operation

This function provides the capabilities required for human operators and other telescope software systems to remotely control the GNAO Facility, as shown in Figure 5 below.

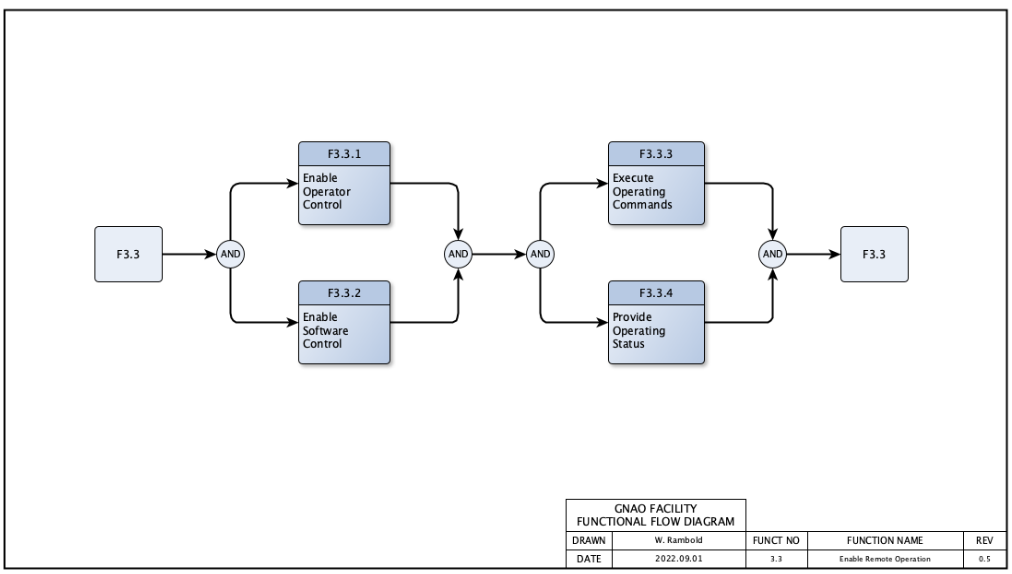

Figure 5: Enable Remote Operation Function Decomposition

F3.3.1 - Enable Operator Control

This provides the functionality required to enable full control of the GNAO Facility by a human operator in a remote location. All functions required for operation, including graphical user interfaces, must be available to the operator along with all status information required to make decisions and monitor performance.

F3.3.2 - Enable Software Control

This provides the functionality required to allow an automated software system to safely control the GNAO Facility without human intervention. All functions required for configuration and observation must be available, along with the status information required by these systems.

F3.3.3 - Execute Operating Commands

This provides the functionality required to accept operating commands from external control sources and execute them using the functionality provided in F3.1. Some operating commands will perform complex functions by invoking sequences of individual commands.

F3.3.4 - Provide Operating Status

This provides the functionality required to display or otherwise provide operating status information to external control sources using the functionality provided by F3.2.

Common Controller Architecture

A common controller architecture has been developed which provides all of the functionality required to implement controllers for the GNAO facility. Use of a common controller architecture reduces development time and simplifies ongoing maintenance and support. This common controller model is shown conceptually in Figure 6 below.

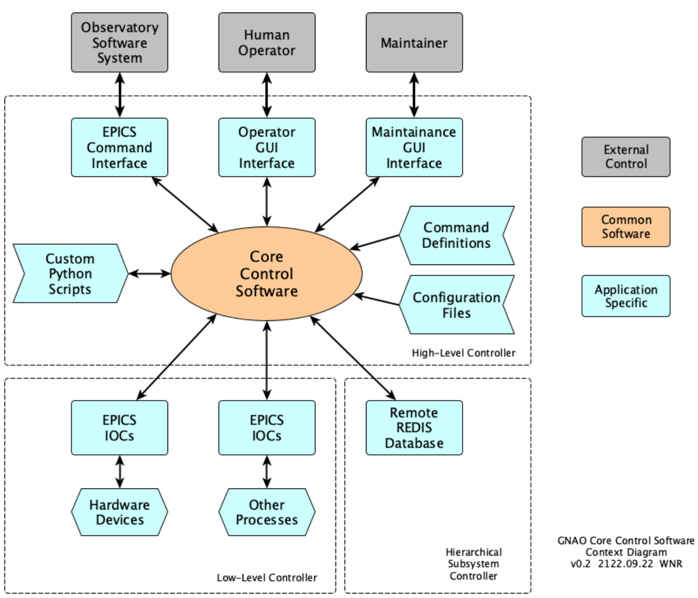

Figure 6: GNAO Common Controller Architecture

Controllers are split into two logical components: a high-level controller, which receives and executes operational requests from external systems; and a low-level controller, which facilitates control of individual hardware components. Each GNAO subsystem has one high-level controller and may have one or more low-level controllers, depending on the hardware used.

The high-level control layer abstracts complex controller functions to a simple interface which allows external systems to operate the subsystem without needing to know how these operations are performed. It provides control of individual components, automates many common functions, and coordinates all subsystem-specific activities. The high-level control layer can autonomously react to changes in the internal subsystem state, or the external environment, as required to ensure safety and maintain performance. High level control is implemented using the Core Control Software package (see next section).

Hierarchical control architectures can be created by using direct communication between high-level controllers at each level to pass command and status information between them.

The low-level control layer implements the hardware abstraction layer of the control model. It hides device specific hardware control details and provides a standard interface that allows the high-level layer to manipulate hardware components as functional units. Low-level controllers communicate with dedicated ethernet-enabled hardware controllers, supplied by the associated component vendor, to move motors, read sensors, etc.. The use of EPICS as the hardware abstraction method allows the Gemini Engineering Archive to access and record all low level controller activity for operation and troubleshooting support.

Figure 7 illustrates this layered abstraction model. External control sources are represented in the first layer, system abstraction and high-level control functions in the second (system) and third (subsystem) layers, hardware abstraction in the fourth layer, contractor supplied hardware assemblies (i.e. LLT and AOB) provide the fifth and sixth layers.

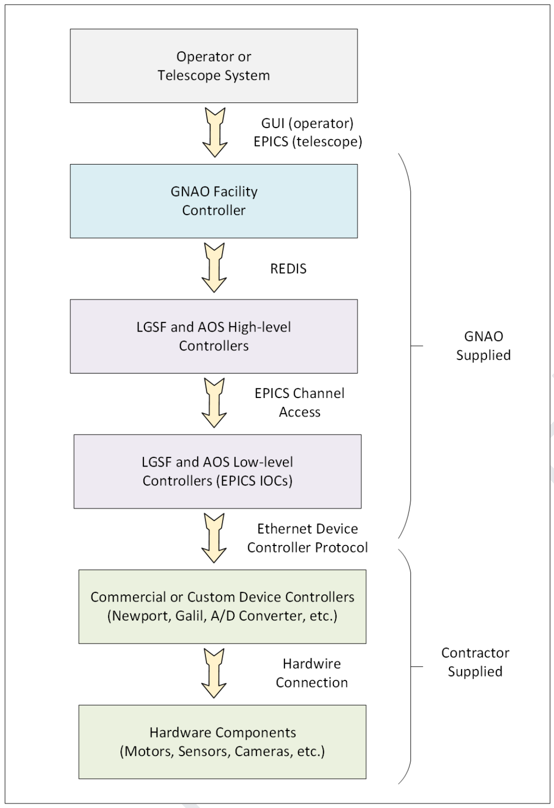

Figure 7: GNAO Device Control Flow

Use cases included in this document show how these GNAO system components interact during system operation.

Core Control Software

Control functions common to all controllers have been abstracted into the Control Software Core package. This package provides a standardized way for each controller to:

- validate and execute individual commands to perform simple functions.
- execute sequences of individual commands (sequentially and/or concurrently) to provide higher level functionality
- implement custom functionality in python scripts
- handle errors and exceptions during operation
- autonomously react to changes in the operating environment
- interact with low level controllers
- interact with hierarchical sub-systems

Figure 8 below shows the core architecture. This common software package is described in the GNAO Control Software Core Architecture Design document [RD-02].

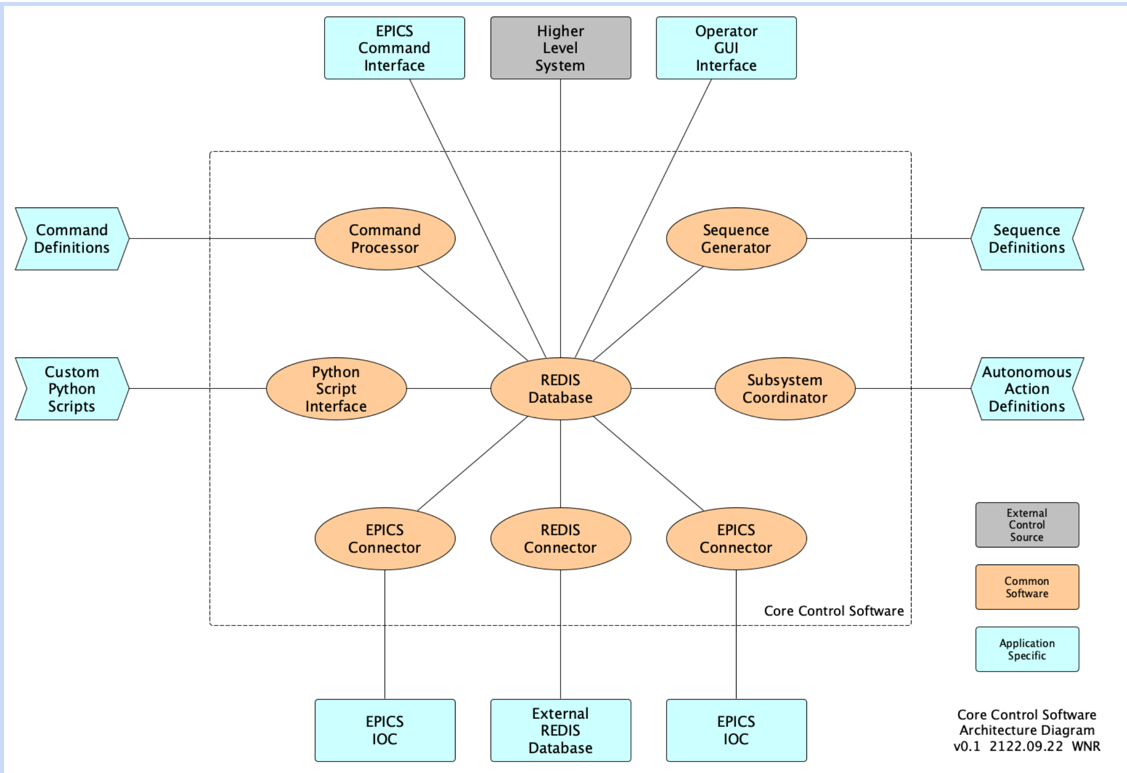

Figure 8: GNAO Control Software Core Architecture

The common controller software core is customized to create a specific application by adding the appropriate high level interfaces and/or low level controllers. Controller operation is customized by defining commands, sequences, scripts, and actions specific to that application. Not all components are needed for any given application (LGSF and AOS controllers do not need an operator or EPICS command interface, the GFC does not need a low-level controller).

GNAO Control Architecture

An overall GNAO control architecture has been developed, based on the common controller model, as an optimal solution to providing the required capabilities for GNAO. Figure 9 below shows this architecture in schematic form.

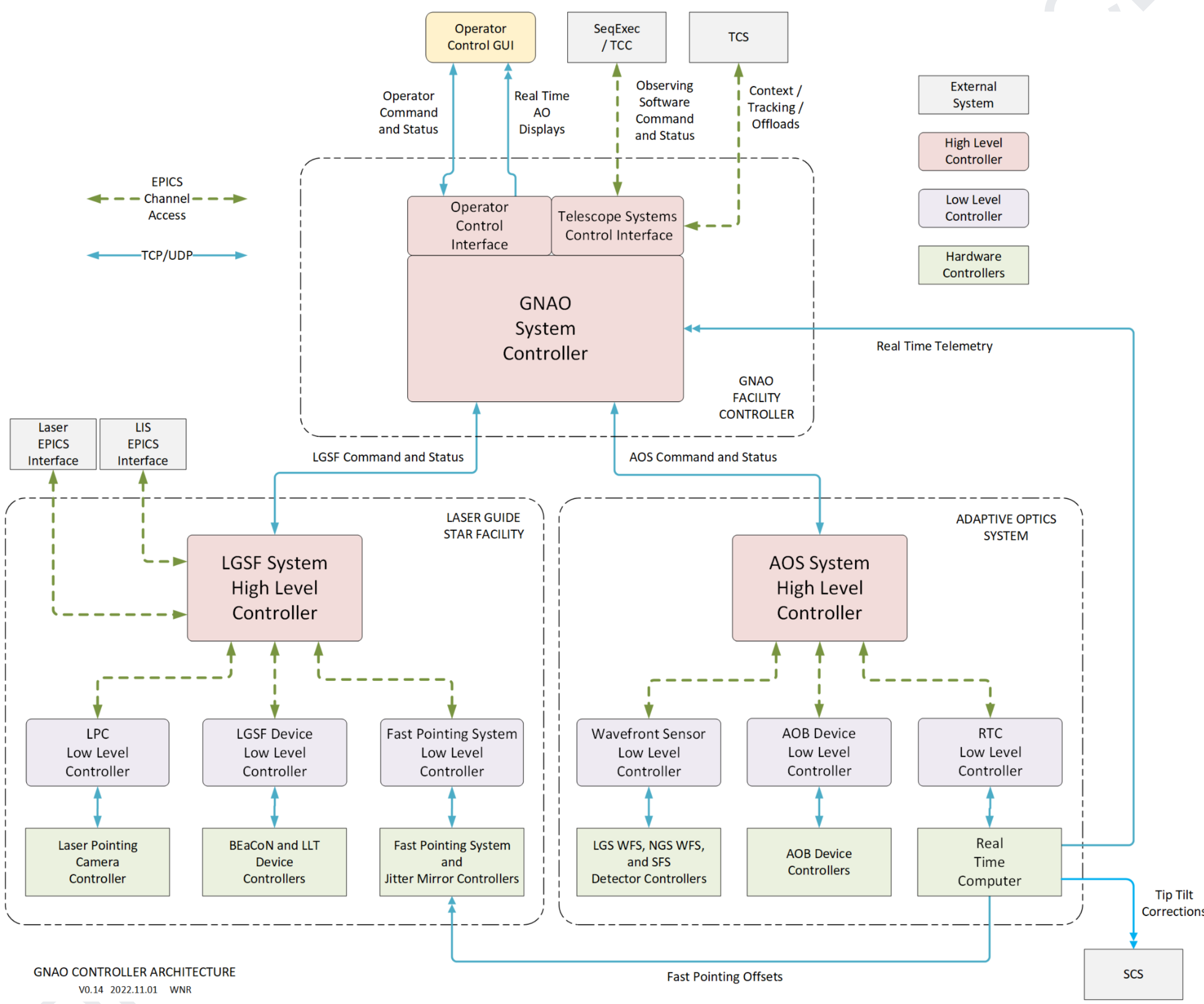

Figure 9: GNAO Control System Architecture Overview

The solution is built around two primary subsystems, the Laser Guide Star Facility and the Adaptive Optics System, controlled by a supervisory command and control subsystem, the GNAO Facility Controller. This architecture allows subsystems and their component assemblies to be developed, tested, and maintained independently.

Overall system control is provided by the GNAO Facility Controller which provides the external system interfaces, implements the operating sequences, and communicates with the subsystems via their functional interfaces.

The LGSF and AOS controllers manage all activities for their respective subsystems, allowing the supervisory level to concentrate on the high level functions required for effective system operation. Error and sanity checking is done at every level to ensure that requested operations are safe and make sense in the context of the current system state (i.e. not inserting the ADC when the AO loops are closed). These controllers handle any errors that may arise during command execution or subsequent system operation to ensure the system is left in a safe state.

Since the chosen hardware abstraction layer is EPICS, the low-level control layer for all subsystems is implemented using EPICS IOCs with community supplied or custom written device drivers. This architecture abstracts device specific control details to a common interface, hiding the details of how each dedicated device controller works. EPICS also allows direct access by the Gemini Engineering Archive and allows hardware components to be tested independently, using engineering screens that interact directly with the EPICS abstraction layer.

The three subsystem controllers are described below:

GNAO Facility Controller

The GNAO Facility Controller provides the high-level functionality required to fully integrate GNAO into the Gemini Queue Scheduled Observing process. It acts as a system coordinator and optimizer, relying on the LGSF System Controller to handle the specific details of artificial star projection and the AOS System Controller to handle the specific details of wavefront correction.

The GNAO Facility Controller is based on the GNAO Control Software Core [RD-02]. The GFC is created by adding the following to the Common Controller architecture:

- Individual operating commands to control each basic LGSF function
- Definitions for command sequences to implement higher-level functionality
- Definitions for action to be taken by the GFC in response to internal and external events
- A graphical operator interface that communicates directly with the internal REDIS database
- An EPICS Command and Status interface that communicates directly with the EPICS based Gemini software systems, including the TCS.
- A specialized interface for reading, decoding, analyzing, and displaying telemetry information generated by the AOS RTC component.
- A REDIS/REDIS interface for communication with the LGSF System Controller
- A REDIS/REDIS interface for communication with the AOS System Controller

Each of the major architectural elements are described below, detailed information on the GNAO Facility Controller implementation can be found in the GNAO Facility Controller Architecture Design document [RD-03]

Operator Interface

The GFC is responsible for all communication with the operator during daytime setup and nighttime operations. A dedicated Graphical User Interface provides all of the control commands and status information required by the operator. Real-time interactive displays simplify the NGS acquisition process and monitoring of AO system operation. The Operator Interface interacts directly with the High-Level controller REDIS database, making it easier to add control or status features.

Telescope Systems Interface

The GFC is responsible for all low-bandwidth communication with Gemini Telescope Software systems. Since these systems are all EPICS based the Telescope Systems Interface provides an ICD 1b compliant set of CAD/CAR records, which allows other systems to command GNAO and monitor status provided by GNAO. GNAO is integrated into the Queue Scheduled observing process via the TCC, and all of the Telescope subsystems via the TCS.

GFC High Level Controller

The GFC High-level controller enables efficient operation of the GNAO system by non-AO expert users. To the greatest extent possible the GNAO Facility Controller automates routine setup, acquisition, and AO optimization procedures to reduce the time and expertise required from the operator to perform AO observations.

The GFC High-level controller manages all communications with external systems and internal subsystems. It also manages inter-subsystem interactions, like adjusting laser focus (LGSF) based on slow focus measurements (AOS) or sending M1 Figure Corrections (TCS) based on wavefront measurements (AOS). This allows the GFC to be aware of, and in control of, all aspects of GNAO operation, and enables it to validate all commands based on the current system state to maintain the safety and integrity of the facility.

The GFC High-level controller supports the integration of arbitrary python scripts provided by AO experts to facilitate performance optimization and testing of new AO correction algorithms. It uses these algorithms to optimize overall system performance based on status and telemetry information from the subsystems.

The GFC High-level controller subscribes to the Real-time Telemetry stream published by the RTC and uses this information to generate seeing statistics, populate user displays, and optimize system performance.

Communication between the GFC and LGSF/AOS controllers is implemented through REDIS/REDIS connectors, which emulate a shared database. This allows the GFC to trigger subsystem commands directly and access status information maintained in the subsystem database.

LGSF Subsystem Controller

The Laser Guide Star Facility is responsible for safely projecting an asterism of four laser guide stars onto the Atmospheric Sodium Layer. Because the science observed field delivered by the telescope rotates as the telescope tracks, the LGSF is also responsible for rotating the asterism to keep it aligned with the target field. The LGSF relies on the external Laser Interlock System to ensure that the asterism will only be projected when it is safe to do so.

The LGSF Controller is based on the GNAO Control Software Core [RD-02]. The LGSF Controller is created by adding the following to the Common Controller architecture:

- Atomic operating commands to control each basic LGSF function
- Definitions for command sequences to implement higher-level functionality
- Definitions for action to be taken by the LGSF in response to internal and external events
- Image processing routines for analyzing Laser Pointing Camera images to determine the position of laser guide stars in the observed field.
- One or more EPICS IOCs with the community and custom written drivers necessary to control the Beam Transfer and Laser Launch Telescope hardware devices via their associated device controllers.
- An EPICS IOC with custom written drivers for Laser Pointing Camera control and image recovery.
- A custom Fast Steering system processor to receive the real-time offset stream from the RTC, integrate offsets, and drive the Jitter Mirrors through the analog interface provided by each mirror controller.
- An EPICS IOC with custom written drivers to control the Fast Steering system.
- Direct EPICS channel access connections between the high-level controller, the Laser EPICS Interface, and Laser Interlock System EPICS Interface.

Each of the major architectural elements are described below, detailed information on the LGSF Subsystem Controller implementation can be found in the GNAO LGSF Controller Architecture Design document [RD-04]

LGSF High-level Controller

The LGSF High-level controller enables efficient operation of the Laser Guide Star Facility by providing a high-level command and status set which allows functional control of the facility. To the greatest extent possible, the LGSF High-level Controller automates configuration, propagation, safety, and field derotation operations to reduce the time and expertise required to project laser guide stars.

The LGSF High-level Controller will, for example, receive a command to configure the asterism (with projection mode, LLT assignments, and target sky coordinates) followed by a command to propagate this asterism to sky. On receiving the first command, the LGSF high-level controller will handle all the details of transforming sky to internal coordinates and positioning the mirrors to project stars in the desired locations on the sky using functions provided by the low-level controller. On receiving the second command, the LGSF High-level controller will handle all of the details of ensuring it is safe to propagate, propagating the stars to sky, and confirming that they have been propagated in the correct location. Once propagated, the high-level controller will automatically handle the details keeping the asterism aligned with the target field as the field rotates.

The LGSF High-level Controller receives the shape of the asterism to be projected, the assignment of launch telescopes to asterism points, the effective altitude of the sodium layer, and instructions regarding the projection of this asterism from the GFC.

The LGSF High-level Controller provides system component status, projection status, and any safety related information needed by the operator.

LPC Low-level Controller

The Laser Pointing Camera is used to confirm the location of projected laser stars. Since it only provides an ethernet socket interface an EPICS IOC with standard EPICS records will be used to integrate the LPC into the overall LGSF control infrastructure. Custom drivers will be written for the Area Detector and other EPICS records to make all camera functions and data available to external systems.

LGSF Device Low-level Controller

All devices in the BEaCoN (sensors and motorized stages) and LLT (sensors and hexapod) have dedicated hardware controllers with ethernet interfaces. An EPICS IOC with standard EPICS records will be used to integrate these devices into the overall LGSF control infrastructure. Most of the commercial controllers already have EPICS drivers, only a few devices will require custom drivers.

Fast Pointing System Low-level Controller

The LGSF receives a real-time stream of beam position offsets directly from the Real Time Controller (part the AOS) via an ethernet link. These offsets are integrated and used to adjust the position of the Jitter Mirrors and Field Selector Mirror to keep the projected stars centered on their associated wavefront sensors in the AOS. The RTC generates beam position offsets at the full high-order loop rate, typically 500 to 1000 Hz.

The high data rate, combined with the need for timing stability and minimal delay between receipt of the offsets and correction of the beam position, drives the decision to use a dedicated processing board for fast steering control. This processing board will have an integral EPICS IOC with standard EPICS records and custom drivers to integrate the controller into the overall LGSF control infrastructure.

AOS Subsystem Controller

The Adaptive Optics System is responsible for sensing and correcting distortion of the delivered telescope field caused by passage of light through the Earth's atmosphere. It uses light from natural guide stars and the artificial stars projected by the LGSF to sense the incoming wavefront, and active/adaptive optics to correct as many of the wavefront errors as possible. Within the AOS, the Real Time Computer component is responsible for determining the shape of the incoming wavefront and generating the required corrections. The AOS also has the capability of performing internal calibrations to maintain optimum performance.

The AOS controller is based on the GNAO Control Software Core [RD-02]. The AOS controller is created by adding the following to the Common Controller architecture:

- Atomic operating commands to control each basic AOS function
- Definitions for command sequences to implement higher-level functionality
- Definitions for action to be taken by the AOS in response to internal and external events
- Custom Python Scripts which support specialized AO functions and optimization.
- One or more EPICS IOCs with the community and custom written drivers necessary to control the Adaptive Optics Bench hardware devices via their associated device controllers.
- An EPICS IOC with custom written drivers for control of the LGS, NGS, and SFS wavefront sensors via their associated camera controllers.
- An EPICS IOC with custom written drivers for control of the Real Time Computer system via its embedded command and status servers.

Each of the major architectural elements are described below, detailed information on the AOS Subsystem Controller implementation can be found in the GNAO AOS Controller Architecture Design document [RD-05]

AOS High-level Controller

The AOS High-level controller enables efficient operation of the Adaptive Optics System by providing a high-level command and status set which allows functional control of the System. To the greatest extent possible the AOS High-level Controller automates routine setup, calibration, AO operation, and optimization procedures to reduce the time and expertise required to perform AO observations.

The AOS receives the observing mode and other information, such as the NGS guide star locations and magnitudes, it needs to configure itself to perform AO corrections or perform internal calibrations. It also receives loop, correction, and offload control instructions from the GFC as required during the acquisition and observation phases.

The AOS receives a Natural Guide Star tracking stream for each Natural Guide Star Sensor. The GFC receives these target position streams from the TCS and transfers them to the AOS when NGS tracking is enabled. The AOS handles all of the coordinate transformations and internal corrections needed to correctly position the physical NGS guide probes (or windows).

The AOS provides system component status, correction status, and any other information needed by the operator. It also provides low bandwidth offsets from the RTC, such as slow focus, M2 focus/coma and M1 figure correction. These are read by the GFC and transferred to the TCS or LGSF when the corresponding offload loops are closed.

The AOS System Controller supports the integration of arbitrary python scripts provided by AO experts to facilitate performance optimization and testing of new AO correction algorithms. It also automates many of the routine calibration procedures that use the AOS internal calibration source.

Wavefront Sensor Low-level Controller

Specialized detectors will be used for sensing the wavefront received from Laser and Natural stars. These detectors will have dedicated controllers to configure readout parameters and read pixel data from them. The detector controllers will have ethernet interfaces with open-source protocols that allow the low-level configuration and readout functions to be accessed remotely. One or more EPICS IOCs will be used to integrate these detectors into the overall AOS control infrastructure. This will most likely require custom drivers to be written to enable detector control via standard EPICS records (i.e. Area Detector).

High-bandwidth pixel data generated by the detector controllers will be sent directly to the RTC, this data will not go through the WFS Low-level Controller.

Detectors and detector controllers will be provided by the AOB vendor, all software required to interface these to the AOS controller will be provided by the GNAO project.

AOB Device Low-level Controller

All devices in the AOB (lamps, sensors, motorized stages, etc.) will have dedicated hardware controllers with ethernet interfaces. AO Optics devices (tip/tilt and deformable mirrors) will also have ethernet enabled controllers, these will be configured by the AOS Device Low-level Controller but accessed directly by the RTC to transfer high bandwidth actuator positions. An EPICS IOC with standard EPICS records will be used to integrate these devices into the overall LGSF control architecture. Most of the commercial controllers will have EPICS drivers, it is expected that a few devices (such as the AO optics) will require custom drivers.

Individual devices and device controllers will be provided by the AOB vendor. All software required to integrate these devices into the AOS control architecture will be provided by the GNAO project.

RTC Low-level Controller

The Real-Time Controller provides a custom socket interface for communication with its internal command and status servers. An EPICS IOC with standard EPICS records will be used to integrate the RTC into the overall AOS control infrastructure. Custom drivers will be written to allow RTC functions and status information (including low-bandwidth offloads) to be accessed by external systems through the EPICS interface.

The RTC component of the AOS generates real-time telemetry for use by the GFC, Science Instrument, and science data archive. The GFC uses this information to generate user displays and analyze/optimize AO correction performance.

The RTC provides real-time laser pointing offsets to the LGSF and tip/tilt offsets to the SCS. These will be transferred via direct connections, not through the RTC Low-level Controller.

The RTC component (including command, status, and telemetry servers) will be supplied by the RTC vendor. All software required to integrate this component into the AOS control infrastructure will be provided by Gemini.

Use Cases

Several Use Cases have been selected, based on expected Daytime and Nighttime Operations usage, that illustrate how the architectural components presented above work together during system operation. 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 to show how the components will interact in these scenarios. The "commands" and "parameters" used are not prescriptive, they are simply placeholders to indicate the type of commands that will be used.

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 device control IOC.
4. Entrance shutter motion controller moves the entrance shutter to the open position and reports that the motion is complete.
5. The AOS "openEntranceShutter" command 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 - Measure Laser Power and Position

Propagate the lasers to the Beam Dump Mirrors in the BEaCoN and measure the laser power and position. This is likely to be part of daily LGSF checks and may also be a step during the startup sequence. This use case illustrates a command that requires the coordination of actions within a single subsystem.

1. Operator requests a measurement of beam power and position on one of the Beam Transfer units by pressing the appropriate button on the operator interface, which sends the “+YMeasureBeamPower” command to the GFC.
2. GFC executes the “+YMeasureBeamPower” command, which validates the command and decides that it is appropriate and safe to execute it in the current system context (observation not in progress, etc.) and indicates on the operator interface that the command has been accepted and is being executed. The GFC sends an “+YMeasureBeamPower” command to the LGSF controller..
3. LGSF System Controller receives the command and validates it, deciding that it is appropriate and safe to execute in the current LGSF context (good health, not propagating to sky, etc.), and then executes a sequence of individual LGSF system commands to:
    a. request the two +Y BDMs be inserted via the LIS EPICS Interface
    b. request the +Y Laser System to produce a beam at reduced power via the LEI
    c. request the laser and safety shutters be opened via the LIS EPICS Interface
    d. read the two power meters to ensure that light is reaching the power meters
    e. if either meter does not see the beam, request that the laser shutter be closed via the LIS (make safe) and complete the command with an error and error message

f. request the +Y Laser System to produce a beam at full power via the LEI

g. read the two power meters to determine the beam power and position

h. update the associated status variables in the LGSF

4. The LGSF "+YMeasureBeamPower" command completes successfully
5. The GFC "+YMeasureBeamPower" command is monitoring the state of the LGSF command it sent, sees that it has completed successfully, and completes successfully.
6. Operator interface is updated with the command completion status and beam power and position for each of the two output beams.

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 any command 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 (position of BDM and shutters, power meter readings, 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.

Use Case 3 - Track Sodium Layer Altitude

Keep the projected stars focussed on the atmospheric sodium layer. 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 projected beam 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.

Use Case 4 - Aircraft Detection

During an observation the LIS* will block propagation of the beam and send an interlock if the Transponder Based Aircraft Detection system (TBAD) signals that an aircraft is getting too close to the propagation zone. GNAO must respond by pausing all loops and preparing the system to resume operations once the aircraft is outside the exclusion zone (the interlock is cleared). This use case illustrates automatic response to an external fault condition.

*Note - This use case assumes that the LIS maintains two EPICS variables, a minor alarm condition (pause propagation and resume when the alarm is cleared) and a major alarm condition (shutdown and prevent startup when this is active). The LIS controls the safety shutter and beam dump mirror directly so the EPICS variables are only there to tell the LGSF controller which type of interlock has occurred. This has not been confirmed, but it would be better if the LIS could signal aircraft detection via EPICS at least one second before closing the shutters so the appropriate loops can be opened beforehand.

1) An aircraft enters the exclusion zone, this is detected by TBAD.

2) TBAD sends an interlock signal to the Laser Interlock System (LIS)

3) The LIS sends a minor alarm signal to GNAO via its EPICS interface

4) The LGSF System Controller is monitoring the LIS minor alarm signal and sets its internal “minorLisInterlock” variable, which triggers the LGSF autonomous action sequence that responds to minor interlocks.

5) Since this is a minor interlock, the LGSF autonomous action sequence does not disable field rotation and sodium layer altitude tracking so the beams will be pointing in the correct place when propagation is resumed. The autonomous action sequence triggers LGSF commands to stop the fast correction updates to the jitter mirrors, center the jitter mirrors, and disable the alarms that come when the LPC loses the guide stars. When these commands have completed the autonomous action sequence terminates.

6) The GFC is monitoring the LGSF “minorLisInterlock” variable and sets its internal “minorLisInterlock” variable, which triggers the autonomous action sequence that responds to minor LIS interlocks.

7) The GFC autonomous action sequence sends the “pauseAoLoops” command to the AOS and waits for it to complete.

8) The AOS executes the “pauseAoLoops” command, which sends the “pauseHighOrderLoop” to the RTC via the RTC low-level EPICS interface.

9) The RTC pauses the coma and M1 figure offsets, then pauses the high-order loop and stops reading the LGS WFS. The RTC continues to read the NGS WFSs and keeps the low order and SFS loops closed, since these do not rely on laser guide stars.

10) The RTC signals completion of the “pauseHighOrderLoop” command, which is seen by the AOS controller, which completes the AOS “pauseAoLoops” command.

11) The GFC sees that the AOS command has completed and terminates the autonomous sequence.

12) A short while later, the LIS closes the Beam Dump Mirrors, which blocks propagation of the laser guide stars.

13) The GFC signals the Operator and Telescope Software systems that a minor interlock has been received and AO operation has been paused via the operator user interface. The Telescope Software may automatically pause an observation based on this information.

14) After a period of time the Aircraft passes and it is safe to resume operation

15) TBAD signals the LIS that there is no aircraft detection

16) LIS removes the minor alarm interlock to GNAO

17) The LGSF sees that the minor interlock has been cleared and clears its internal interloc variable.

18) The GFC sees that the minor interlock has been cleared and triggers an autonomous action sequence which requests permission from the Operator to resume operation via the Operator GUI.

19) The Operator determines that it is safe to continue resumes AO operation by pushing the appropriate button, which sends the “resumeAo” command to the GFC.

20) The GFC commands the LGSF System Controller to propagate to sky using the same sequence as an initial propagation. This ensures that all internal steps and checks are performed before actually propagating, and that the spots will be projected to the correct location

21) The GFC waits for the LGSF to confirm that the lasers have been propagated correctly and then commands the AOS System Controller to reacquire the Laser Guide Star in the same manner as an initial acquisition. This will ensure that the spots are correctly centered on the LGS WFS and the relevant loops and offloads have been enabled successfully before sending signals to the DMs.

22) The GFC waits for the RTC to confirm that the AO loop has been closed and is stable, then informs the Operator and Telescope Software systems that the observation can be resumed.