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AO Supervisor
Functional description

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ABSTRACT

The AO Supervisor is the comprehensive name given to the full set of software modules which control the First Light AO System. In this document we describe, by means of use cases, the functionalities of the AO Supervisor and its interactions with the LBT Telescope Control System.

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Glossary of terms and acronyms

ADC. Atmospheric Dispersion Corrector.

AdSec. The Adaptive Secondary Mirror. In this context usually refers to the software subsystem controlling the hardware devices related to the secondary mirror.

AO System. The components of the LBT first light Adaptive Optics System as a whole. It includes the Wavefront Sensor, the Adaptive Secondary Mirror, the AO Computer and some auxiliary devices (such as networking hardware).

AOS. A part (subsystem) of TCS dedicated to interaction with the AO Supervisor.

AO Supervisor. The software system which manages all the components of the AO System.

Camera lens. An adjustable lens used to control the positions of the four pupils on the WFS CCD.

`MsgD`. Message Dispatcher, the AO Supervisor message dispatching utility.

OSS. Optical Support System, the TCS subsystem which manages optical devices (Secondary mirror, Tertiary mirror).

PCS. Pointing Control Subsystem, the TCS subsystem which controls the telescope pointing.

PSF. Point Spread Function subsystem, the TCS subsystem which controls the image quality.

`RTDB`. AO Real Time Database, the AO Supervisor own variable repository.

TCS. Telescope Control System. The software dedicated to the management of the LBT telescope.

TCS Computer. The Computer (or farm of computers) running the TCS.

TT. Tip-Tilt mirror. A rotating mirror which provide pupil modulation in the pyramid sensor.

TV. Technical Viewer. An auxiliary CCD used by the Wavefront Sensor to acquire the reference star.

WFS. The Wavefront Sensor. In this context usually refers to the software subsystem controlling the hardware devices related to the wavefront sensor.

1 Introduction

The AO Supervisor is the comprehensive name given to the set of software modules which operate the LBT Adaptive Optics System.

After a brief introduction to the AO Supervisor architecture, we will describe its functionalities by means of operating scenarios or use cases covering most of the possible uses of the system.

A relevant part of the description is related to the interaction with the Telescope Control System and is strictly connected with the command description from the TCS point of view detailed in a dedicated document (see [5]). You might consider the quoted document as the client's vision of the AO Supervisor, while in this report we will detail the implementation aspects of the commands.

1.1 AO System Software Architecture

In figure 1 a block diagram illustrating the complete software architecture of the LBT First Light Adaptive Optics System is shown.

All the real-time operations of the system, i.e.: the implementation of the adaptive loop between the WFS and the AdSec, are performed by firmware hosted in the "Slope computer" and in the Adaptive Secondary boards, which essentially consist in various version of the AdOpt standard electronic board (usually known as BCU).

The supervision of the hardware/firmware components of the system is performed by a software system running in a Linux based workstation[1].

The set of software modules cooperating for the LBT AO System supervision is referred to as the "AO Supervisor".

Tasks of the AO Supervisor include: housekeeping operations on the AO System (start, stop, firmware upload, and the like), diagnostics, and interaction with the Telescope Control System.

In the following pages we provide a functional description of the AO Supervisor, illustrated by means of specific use cases related to common uses of the system (e.g. doing an observation in any of the available modes, performing calibrations, doing maintenance operations, and the like).

[1] Or on a few networked workstations: the AO Supervisor has been designed to operate on a workstation farm, if needed due to required computing power.

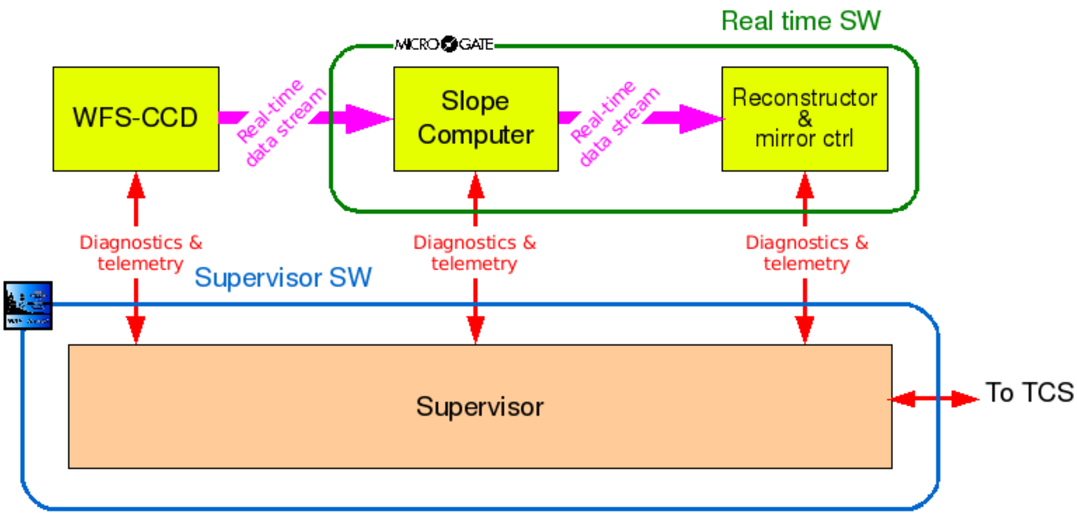

Figure 1: Complete LBT-AdOpt Software Architecture

1.2 AO Supervisor architecture

The AO Supervisor is a collection of processes, in the following pages referred to as *components*, loosely coupled via a message based protocol. The exchange of messages is performed via a central facility: the `MsgD-RTDB`. This facility provides also a number of accessory functions such as:

- Central repository for variables (the `RTDB` function).
- Shared memory buffer management (for data intensive exchanges).
- Logging

Figure 2 shows a diagram of all AO Supervisor components.

In the figure we can see that components can be grouped according to their type (controllers, GUIs, etc.), or according to their target (WFS components, AdSec components, Arbitrators).

WFS and AdSec components are, as their grouping suggests, directly related to the two main building blocks of the AO System: the Wavefront Sensor and the Adaptive Secondary.

Arbitrators are special components which are dedicated to perform the proper sequence of steps needed to accomplish a given complex task. They are crucial to understand the details of each operative scenario and thus they will be described in deeper details in the following section.

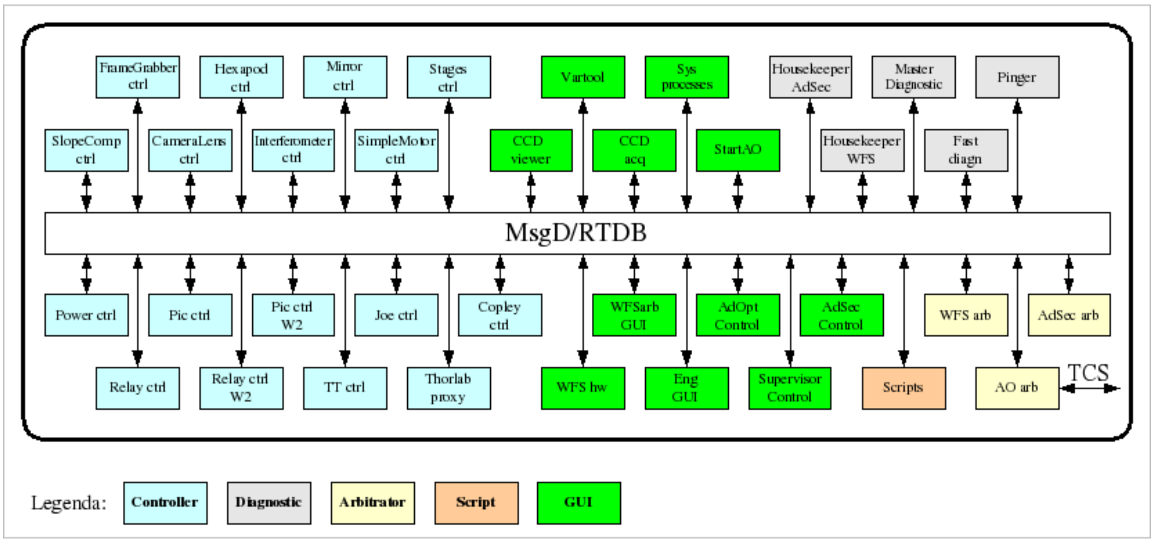

Figure 2: AO Supervisor Architecture

1.3 Arbitrators

In order to control the sequence of operations in an orderly manner, a few dedicated components, the arbitrators, have been designed. All arbitrators share the same software architecture based on a Finite State Machine (FSM) with some enhancements (for details see [6]).

AO Supervisor arbitrators come in a two level hierarchy, as shown in figure 3.

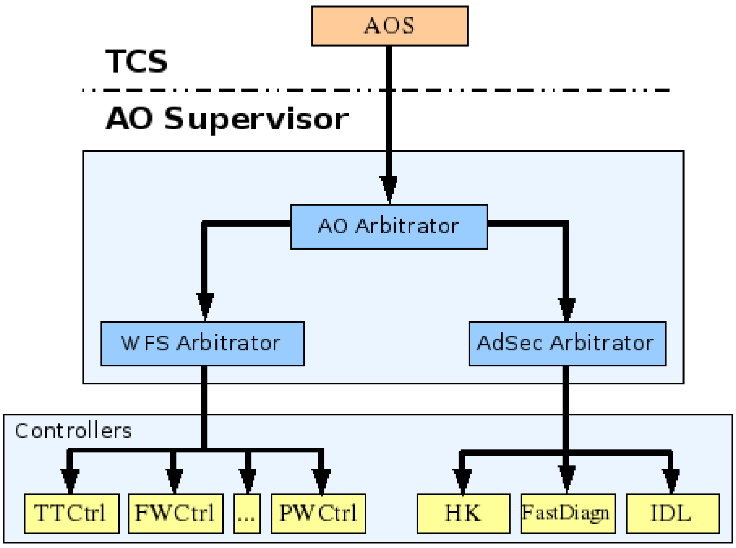

Figure 3: Arbitrators hierarchy

- the AO arbitrator - coordinates the operations between the two lower level arbitrators and communicates with the LBT-TCS through the dedicated subsystem (AOS).
- the **AdSec** arbitrator - controls the Adaptive Secondary

- the **WFS** arbitrator - controls the Wavefront Sensor

The hierarchical structure allows a greater flexibility of use: the **AdSec** and **WFS** modules can run independently, in operations that involve only their target subsystem; the AO arbitrator can run with only one of the two underlying modules below (for example, in seeing-limited operations when the **WFS** module is not needed); a lower module can be swapped out for a different one with an identical interface (for example, to support a different WFS focal station).

The **WFS** and **AdSec** modules do not have direct interaction with each other and rely on the AO arbitrator to synchronize their operation.

1.3.1 Finite State Machine Design

Figure 4 shows a diagram of the AO arbitrator FSM. Commands are implemented as transitions between states.

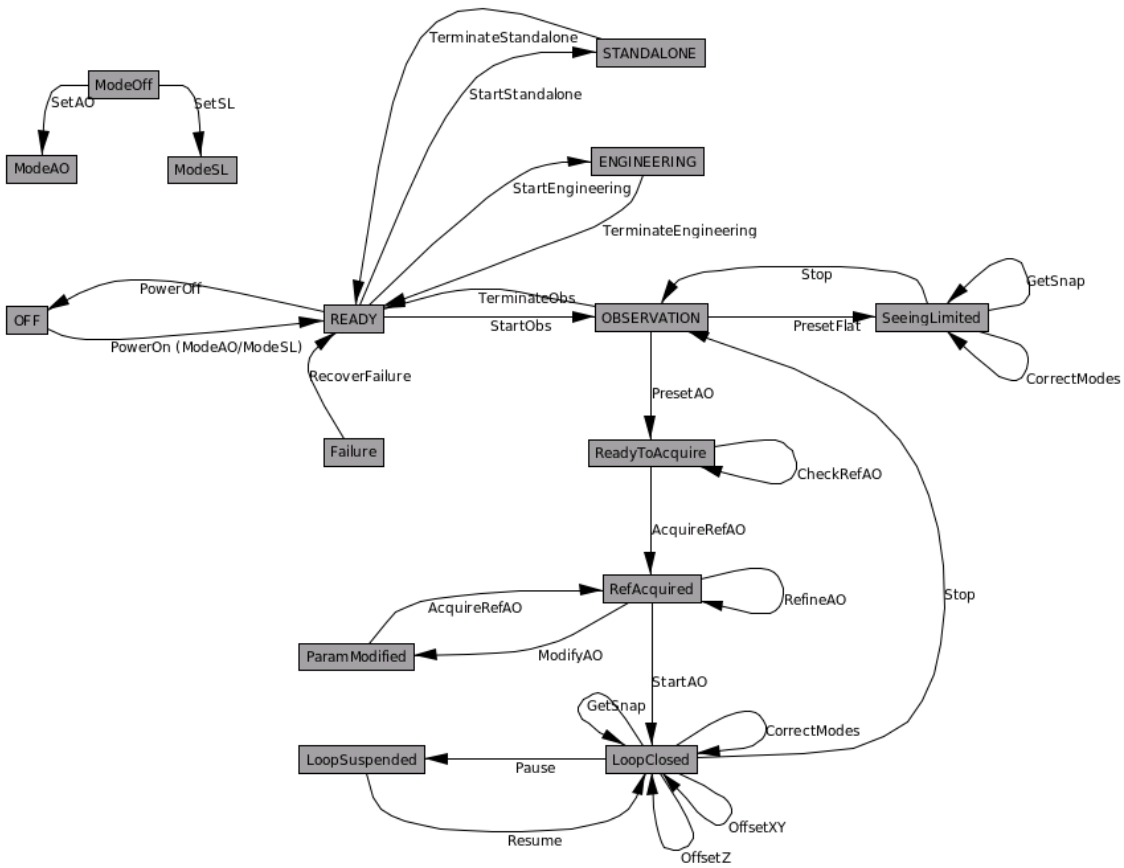

Figure 4: AO Arbitrator FSM Diagram

It must be noted that the FSM shown in Figure 4 is a simplified version where, for the sake of clarity, the branches needed to manage error conditions have been removed.

1.4 Software startup procedure

The AO Supervisor startup procedure[2], executed at system bootstrap drives the software system to Standalone mode, that is, with no interaction with any TCS subsystems.

In this mode no commands are accepted or issued through the AOS.

An operator GUI will be available on the AO workstation which will allow the telescope operator to choose whether to go into Engineering or Observation mode. Depending on the selected mode, the AO supervisor will be then ready to start calibration procedures or to service observation requests.

In order to support a correct rendez-vous, an intermediate Ready state is defined[3] between STANDALONE and OBSERVATION to allow the synchronization with the AOS. No commands are accepted in Ready state except for a request from AOS to proceed to OBSERVATION mode.

1.5 Internal supervision loops

During AO operation the AO supervisor activates a number of processes, whose purposes are to update the status of various hardware devices, according to variation of external conditions (such as: telescope elevation, rotator position, and the like) as shown in figure 5.

The fast optical loop (red line in figure 5) is managed by custom firmware on-board BCUs and the only task to be performed by the AO Supervisor is to configure it properly before the loop is started.

The other loops are, instead, controlled by AO Supervisor components.

- Force corrections[4] are computed by `FastDiagnostics` and corresponding offload commands are retrofitted to the AdSec.
- The `FastDiagnostics` also detects conditions which may endanger the deformable mirror. When this happens, the process alerts the AdSec controller so that it can perform proper actions.
- The ADC position[5] is updated according to telescope's current elevation. It has a very low rate.
- The Tip-Tilt mirror provides modulation of the beam on top of the pyramid of the WFS. The geometrical center of rotation may be adjusted to compensate for tip-tilt errors in the wavefront.
- The Rerotator loop updates the Rerotator position depending on telescope's current rotator position.
- The Camera Lens is updated to correct position error of the four pupils on the WFS CCD.
- Drift in modal errors are also computed by the `FastDiagnostics` and sent to the TCS to be offloaded by the Point Spread Function subsystem (PSF).

[2] In this section we describe the startup procedure from the point of view of interaction with the TCS. The complete startup sequence which includes the initialization of hardware subsystem, and so on, is detailed in section 4.

[3] This is needed to synchronize with the AOS status, in various cases; e.g.: AO Supervisor starting when AOS is not available, AO Supervisor starting when AOS is waiting for connection, AOS starting with no AO Supervisor available, etc.

[4] During Adaptive operation mirror actuators may develop local stresses due to deformations with zero resultant.

[5] The ADC is actually made up of two optical devices rotating in opposite directions.

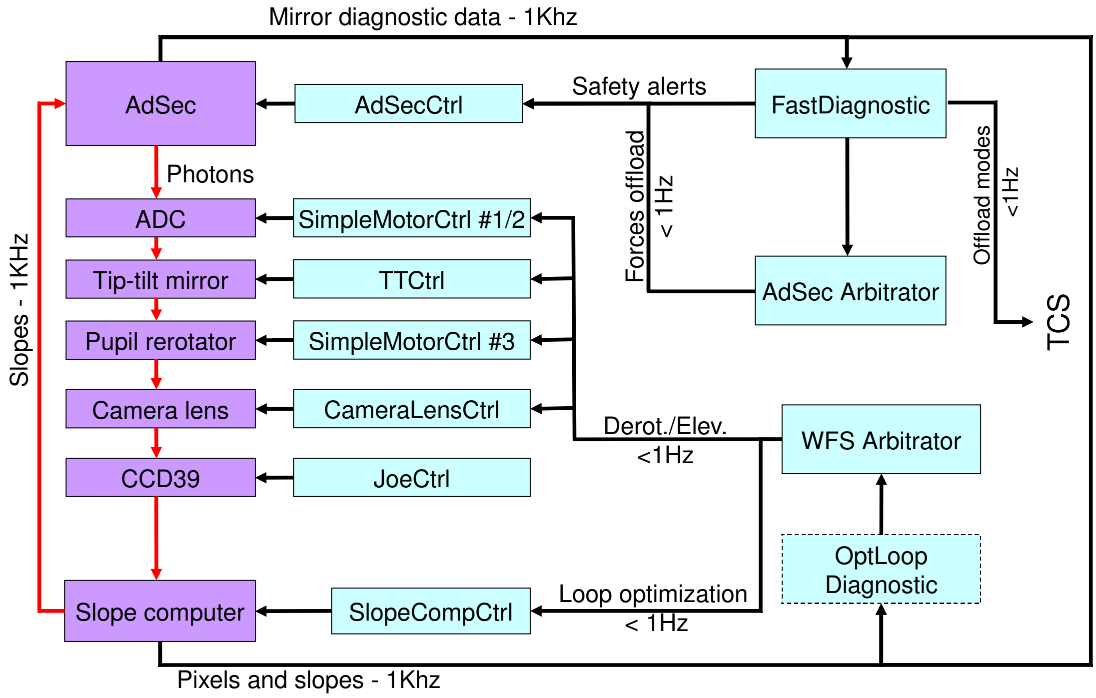

Figure 5: AO Supervisor Internal Control Loops

- The OptLoop Diagnostic is an process which uses data from both the deformable mirror and the slope computer in order to evaluate loop quality and, possibly, to optimize loop parameters. It is still considered at an experimental stage of development.

1.6 External commands

During the adaptive operation, the AO System will also possibly receive commands from the TCS. Figure 6 shows a diagram of command paths related to such external commands.

- Offset commands in both X,Y (field movement) and Z (defocus) can be requested by the instrument software through TCS/AOS. X,Y offset can be obtained either by adjusting the TT modulation (for small offsets, see path `OffsetXY`^{a} in figure 6) or by moving the stages (see path `OffsetXY`^{b} in figure 6). Z offset is performed always by moving the Z stage.

- Modes corrections in adaptive mode may be requested by instruments which are provided with means of detecting non common mode aberrations which are not detected by the WFS. The corrections are applied by modifying the "slope null" vector (see path `CorrectModes`^{a} in figure 6).

  In seeing-limited operation the modes correction can be used to allow active optics correction through the adaptive secondary. In this case corrections are applied by a "command offset" vector available in the adaptive secondary system (see path `CorrectModes`^{b} in figure 6).

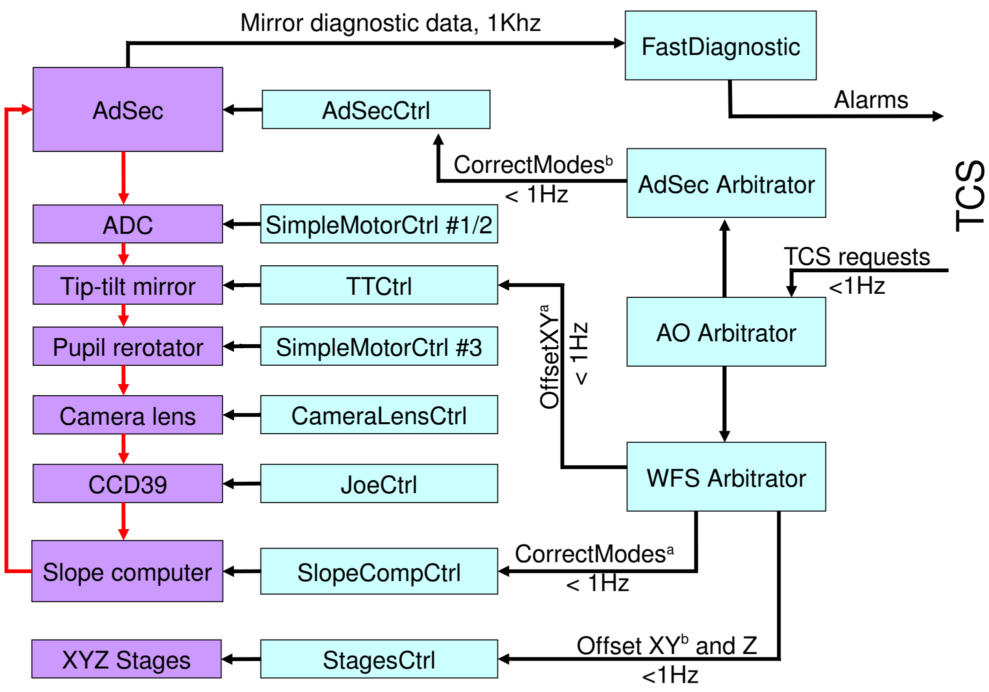

Figure 6: External commands

1.7 Diagnostics

The AO system generates a huge amount of real-time diagnostic data. The two main components are the mirror diagnostic data (actuator positions, amplifier voltage and current etc) and the optical loop data (CCD frames, slopes, mirror commands). Both of them generate one data frame per loop iteration, therefore up to 1KHz. Maximum data rate for both is around 20 MB/s sustained. The firmware supporting diagnostics operations provides the capability of decimating this data to ease network requirements, but it is advisable to keep the maximum data rate possible for better diagnostic of the system: 100 Hz data rate (2 MB/sec) is the lower limit compatible with the specifications.

Diagnostic data are sent to the `FastDiagnostic` process which performs many safety checks as already mentioned above. The detection of dangerous conditions must be done within a delay of 10 ms from the onset of the dangerous condition, therefore the diagnostic program is run by the **AdSec** arbitrator whenever the mirror is turned on.

Optical loop data are also analyzed in real-time to monitor system performance, with less strict requirements about timing. A diagnostic process maintains a running mean of data over 10 seconds and can provide parameters to evaluate the loop efficiency.

Diagnostic data are saved on hard drive internal to the AO Workstation storage for post processing. A small subset, which may be of interest to the operator and the astronomer is also sent to the TCS data storage and telemetry, subsystem.

1.8 Engineering GUIs

Several engineering GUIs have been developed for the various modules and can be subdivided into two groups: the low-level GUIs which includes interfaces which operates directly on hardware subsystems and the arbitrator GUIs.

The low level GUIs are to be used for various tests in the lab and for troubleshooting tasks, under the control of properly trained personnel, at the telescope:

- low-level **AdSec** GUI to control mirror parameters.
- low-level **WFS** GUI to control wavefront sensor parameters.

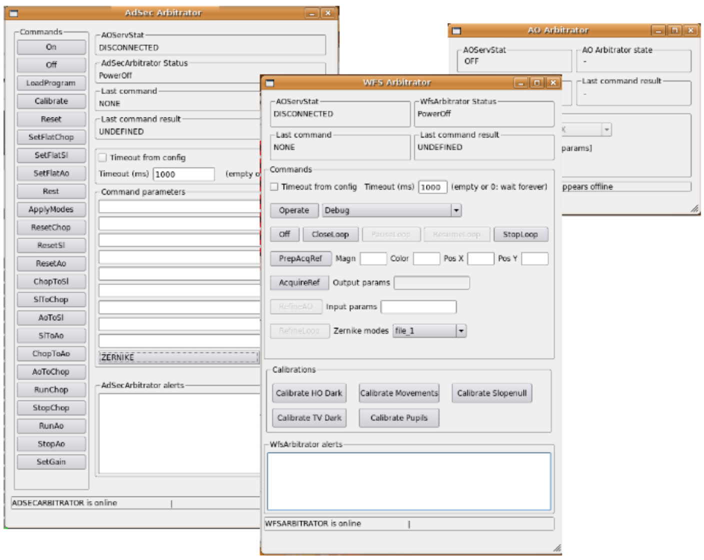

Figure 7: Arbitrator GUIs snapshot

The arbitrator GUIs, shown in figure 7, will be used for system calibrations and other maintenance tasks at the telescope (see sect. 3 for details on calibration procedures):

- **WFS** arbitrator GUI
- **AdSec** arbitrator GUI
- AO arbitrator GUI

1.9 The AOS

The Adaptive Optics Subsystem (AOS) is the subsystem of LBT TCS providing all the functionalities needed for interaction between the LBT AO System and the rest of the telescope, including instruments.

It is from any respect a standard subsystem of TCS, but includes the communication layer provided by the AO Supervisor to interact with AO Supervisor components. It can register as a client to the `MsgD` as any other component, and use all `MsgD` facilities.

The interactions are performed either by exchanging messages with the AO arbitrator or by setting the value of variables in the `RTDB`.

In order to perform its tasks, AOS provides a number of functionalities:

- Manages the communication rendez-vous with the `MsgD`.
- Provides mirroring of a small set of variables from the TCS `DD` to the `RTDB`.
- Provides mirroring of a small set of variables from the `RTDB` to the `DD`.
- Receives commands from other TCS subsystems (e.g.: the IIF) and dispatch them to the AO arbitrator, to support the OBSERVATION mode of operation.
- Receives commands from the AO arbitrator and executes them in the TCS environment to support the ENGINEERING mode of operation.
- Includes an AOS-GUI subsystem which provides the night time operator interface to the AO System.

2 AO Supervisor operating modes

Three main operating modes are defined for the AO Supervisor: STANDALONE, ENGINEERING and OBSERVATION.

The operating mode is enabled by the AO arbitrator. Therefore, manual intervention by the telescope operator is needed at the start of operations to set the AO system in either ENGINEERING or OBSERVATION state. Only when the system has been set in OBSERVATION state proper AO operation can start.

2.1 Standalone mode

In Standalone mode, the AO supervisor is independent from the telescope and does not send or receive commands[6]. This mode is used for internal calibrations and debugging. It is also the default state of the AO supervisor after a cold start.

2.2 Engineering

ENGINEERING mode is used to perform the AO system calibration and other maintenance operations. In this mode no commands from TCS are accepted, while the AO Supervisor can send (through the AOS) requests to various TCS subsystem (see figure 8). AOS will convert each AO Supervisor command in the proper sequence of TCS commands needed to perform the task.

[6] A low rate communication exchange is active even in STANDALONE mode to allow AOS to detect state changes.

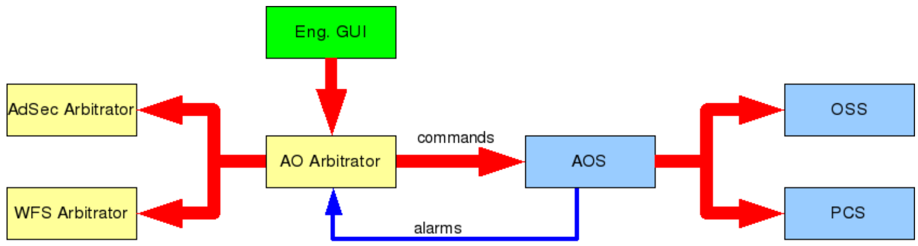

Figure 8: ENGINEERING mode command flow

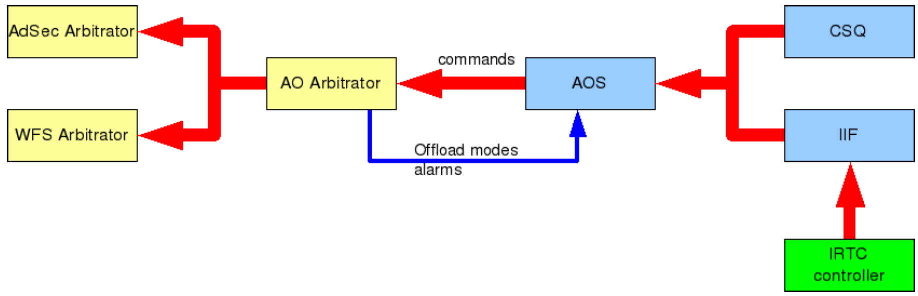

Figure 9: OBSERVATION mode command flow

2.3 Observation

In Observation mode, the AO Supervisor will service commands issued by any TCS subsystem[7] to support night observations. A diagram of the related command flow is shown in figure 9.

3 Calibrations

Three different kinds of calibrations can be performed:

- **AdSec**-only calibrations: flattening, internal feed-forward matrix, etc.
- **WFS**-only calibrations: mechanical displacements, reference source luminosity, etc.
- AO system calibrations: slopes null, interaction matrix.

The first two kinds of calibration can be executed by the two lower-level arbitrators autonomously, using their dedicated engineering GUIs. The latter needs coordination of both modules and are thus performed by the AO arbitrator while in Engineering or Standalone mode. Some operations, in particular the interaction matrix measurement, require the installation of the retro-reflector optics under the secondary mirror.

Note: Usually astronomers call "calibration" the operations to be performed just prior of an observation, such as dark frames, flat fields, etc. We,instead, used this term for system calibrations performed during engineering runs and stored on disk for later use.

[7]Practically speaking, most commands will come from the IIF subsystem.

4 Startup Sequence

4.1 Overview

The startup sequence will turn on the AdSec and WFS systems and properly initialize them for operation. This procedure is needed whenever the system is switched on. At the end the subsystems will be ready for operation and an operator GUI will allow to select the subsequent step (to proceed either to ENGINEERING mode or to the ready state which will allow AOS to request the OBSERVATION mode).

The procedure will allow an operator to specify which subsystem has to be started: the AO Supervisor will be able to run with only one of the two subsystems, e.g. with the AdSec only during FIX-AO operations, or with the WFS only, for WFS specific maintenance operations.

4.2 Procedure

- WFS: The following functions are executed in parallel whenever possible to reduce startup time.
  - Network communication with the WFS is checked
  - Motors and CCDs power supplies are turned on
  - Proper network communication with all devices is checked
  - Slope computer is configured for 1×1 binning and default pupil position
  - Movements are homed and limit switch functionality is checked
  - CCDs are configured for default frame rates and bias levels.
  - Tip-tilt mirror modulation is kept initially off
  - XYZ stages move to the center FoV position and default focus position.
- AdSec:
  - Main Power Supplies (MSPs) are switched on
  - the `lbt_load_program` function is executed:
    - Communications with DSPs is tested.
    - Firmware is uploaded to DSPs.
    - DSP memories are initialized.
    - The default configuration is loaded.
    - DSP program is started.
    - Communication with DSP program is tested again.
    - ASM FST is started.
    - The functionality of coils, current drives and capacitive sensor is checked.
    - Dust contamination is checked.

Execution time: Startup of WFS devices is executed in parallel whenever possible to reduce execution time. Total time is about 140 seconds.

5 FIX-AO mode of operation

5.1 Overview

The FIX-AO mode is the seeing limited mode of operation. The secondary mirror is set to a fixed shape. Different pre-calibrated shapes may be available for different instruments. At least a default shape will be available.

5.2 Preconditions

The AdSec mirror is in Operating state.

5.3 Procedure

Input parameters: Shape identifier

1. The TCS issues the request, specifying one of the available pre-calibrated shapes[8] (or the default).
2. The AO System sets the adaptive secondary to the requested shape.
3. The **WFS** is not used in this mode. The AO arbitrator will check the current **WFS** state and take the following action:
   - **WFS** in state Off or Operating: no change to current state
   - **WFS** in any other state: an Operate command is sent to **WFS** arbitrator to leave the **WFS** in a safe Operating state, but ready to restart quickly if needed.
   - No error is raised by the AO arbitrator if the **WFS** is not available.

5.4 Error conditions and recovery

- **Shape unavailable**. The request is simply rejected.

6 TTM-AO mode of operation

6.1 Overview

In TTM-AO mode the adaptive optics system provides Tip-Tilt corrections.

This case is a special case of ACE-AO with only 2 modes corrected (tip-tilt). All operations are identical to ACE-AO except for this limitation, so This mode is detailed in the next section.

[8]Different pre-calibrated shapes may be available for different instruments. The TCS will select the proper shape based on the instrument currently enabled.

7 ACE-AO mode of operation

The ACE-AO mode is the full adaptive operation mode. In the following section procedures to operate the AO System in adaptive mode are described in full details.

Note: In order to maintain a strict relationship with the command description for the AOS (see [5]), we use the command names defined in the quoted document.

7.1 Overview

In ACE-AO mode, the adaptive optics system provides full adaptive corrections. In order to increase the flexibility of use of the AO System, so that different ways of operation can be implemented, this mode has been subdivided into several elementary steps: `PresetAO`, `AcquireRef`, `StartAO`, `PauseAO`, `ResumeAO`, `StopAO`, `OffsetXY`, `OffsetZ`.

They must be performed in the following order:

1. `PresetAO`. To prepare for reference star acquisition.
2. `AcquireRef`. To acquire the reference star.
3. `StartAO`. To close the adaptive loop on the acquired reference star.

After the successful completion of the three steps above, the system is operating in adaptive mode. The following steps can then be performed:

1. `OffsetXY`. To move the scientific camera field of view.
2. `OffsetZ`. To change the focus at scientific camera.
3. `PauseAO - ResumeAO`. To pause/resume the loop.
4. `StopAO`. To terminate the ACE-AO operation.

Here follows a detailed description of each elementary step.

7.2 PresetAO

The `PresetAO` command is issued at the start of an adaptive mode observation. This requests the AO System to preset the hardware devices so that they are ready to acquire the reference star.

The AO System will perform all the operations which do not require that the telescope is on target.

7.2.1 Preconditions

AdSec is in Operating state.

WFS is in Operating state.

7.2.2 Input parameters

- Requested mode: "TTM" or "ACE"
- WFS source: currently only "DEFAULT" accepted
- Scientific object coordinates (X,Y in millimeters) - with respect to the telescope FoV center
- Reference star coordinates (X,Y in millimeters) - with respect to the telescope FoV center
- Telescope elevation - target value of TCS pointing procedure
- Rotator angle - target value of TCS pointing procedure
- Gravity angle - target value of TCS pointing procedure
- Reference star magnitude
- Reference star color index
- Coherence length (R0)
- Sky brightness
- Wind speed
- Wind direction

7.2.3 Procedure

1. *Pointing*:
   (a) Check coordinate values.
   (b) Start moving stages to (X,Y).
2. *Configure devices*:
   (a) Set ADC (uses: elevation angle and rotator angle)
   (b) Set Pupil rerotator (uses: rotator angle)
   (c) Set Tip-tilt mirror and camera lens (uses: rotator angle)
   (d) Set CCD47 binning (uses: reference star magnitude) default: 16×16.
   (e) Set CCD47 integration time (uses: star magnitude)
   (f) Set CCD39 binning (uses: star magnitude, R0, wind speed)
   (g) Set CCD39 integration time (uses: star magnitude, R0, wind speed)
   (h) Set TT Mirror amplitude and frequency (uses: star magnitude, R0, wind speed)
   (i) Load Null Slopes Vector (uses: TT Mirror settings and CCD39 binning)
   (j) Load Reconstructor Matrix (uses: TT Mirror amplitude, CCD39 binning, number of modes).
   (k) Set overall loop gain.

3. *Completion*:
   (a) Wait for all movements to finish.
   (b) Start ADC tracking of telescope elevation and telescope rotator position.
   (c) Start Pupil rerotator tracking of telescope rotator position.
   (d) Start Camera lens and tip-tilt tracking.

7.2.4 Error conditions and recovery

No recoverable errors are expected during this commands.

7.2.5 Execution time

Execution time is variable depending on the target position and the CCD binning and integration time needed. Maximum time is 60 seconds. This command is designed to be execute in parallel with telescope slewing to the target, so that the AO system is ready to acquire the reference star immediately after tracking has resumed.

7.3 AcquireRef

7.3.1 Input parameters

None: parameters have been provided with the previous `AcquireRef` command.

7.3.2 Preconditions

Telescope is tracking or guiding on the object.
A previous `PresetAO` command has executed successfully.

7.3.3 Procedure

1. *Take darks*:
   (a) Set FW1 on 100% refl and FW2 on 0% transm.
   (b) Take CCD39 dark frames
   (c) Take CCD47 dark frames
2. *Check Pointing*:
   (a) Set Filter wheel 1 for ref. star acquisition (uses: star magnitude)
   (b) Set Filter wheel 2 for ref. star acquisition (uses: star magnitude)
   (c) Locate star on CCD47 → Possible error (star not found)
   (d) Check star flux → Possible error (flux too different from expected)

(e) Move XY stages to put the star on CCD47 hot spot- Iterate until error < threshold

(f) Set Filter wheel 1 to observing position (uses: star magnitude)

(g) Center star on pyramid moving Tip-tilt mirror and XY stages - Iterate until error < threshold

(h) Check star flux on CCD39 → Possible error (flux too different from expected)

(i) Command success.

7.3.4 Error conditions and recovery

A possible error is that the reference star is not found on the CCD47 field of view, or that a star is found but with a very different flux from the one expected. This can result from a variety of causes: wrong pointing, wrong reference star coordinates, bad sky conditions (clouds), etc. In this case the command will fail and an error reply to the TCS is sent. The reply contains in any case a snapshot of the CCD47 image, so that the star coordinates and/or sky conditions can be checked.

Resolution: another `AcquireRef` or `PresetAO` command must be reissued. `AcquireRef` must be reissued if the reference star parameters have changed. Otherwise, a `PresetAO` command will try again to acquire the same star as before.

7.3.5 Execution time

Execution time is variable depending on the CCD binning and integration time needed. Maximum time is 120 seconds.

7.4 StartAO

The `StartAO` command is expected to immediately follow the successful `AcquireRef`. Its only scope is to allow synchronization with operations of the scientific instrument.

7.4.1 Input parameters

None

7.4.2 Preconditions

The previous `AcquireRef` procedure successfully completed.

7.4.3 Procedure

1. *Close loop*:
   (a) Enable real time-loop
   (b) Enable mode offload procedure:

      A 10 sec running mean of the lower N modes is maintained. Those values are sent to the TCS. A threshold based algorithm computes the “offload hint”. If offload hint greater than 0, the TCS is notified.

   (c) The ADC and Pupil Rerotator continue to track.

7.4.4 Error conditions and recovery

Errors may arise if the delay from the previous `AcquireRef` command has been to great, so that telescope tracking errors have brought the reference star out of the 1 arcsec field of the pyramid sensor.

In this case the `AcquireRef` procedure must be repeated.

7.5 PauseAO

This command is used to temporarily open the adaptive loop for a short time, without changing the reference star. Because it is expected that a `ResumeAO` command will follow, during the pause the telescope must continue to track. Depending on the accuracy of open-loop tracking, it might be necessary to restart the guiding with the off-axis AG.

7.5.1 Input parameters

None

7.5.2 Preconditions

The AO loop is currently running.

7.5.3 Procedure

1. *Open loop*:
   (a) Disable real-time loop (disables the fast fiber link).
   (b) Disable mode offload procedure.
   (c) The ADC and Pupil Rerotator continue to track.
   (d) Wait for Stop/Resume.

7.5.4 Execution time

No slow movements are necessary. Time is negligible.

7.5.5 Error conditions and recovery

None. If the pause lasts too long, it can cause an error on the following resume command.

7.6 ResumeAO

The `ResumeAO` command must follow a previous `PauseAO`.

7.6.1 Input parameters

None

7.6.2 Preconditions

The system has been paused.

7.6.3 Procedure

1. *Close loop*:
   (a) Check flux on CCD39 → possible error if flux is too low
   (b) Enable real time-loop (enables the fast fiber link)
   (c) Enable mode offload procedure
   (d) The ADC and Pupil Rerotator continue to track.

7.6.4 Error conditions and recovery

Errors may arise when for any reason (tracking errors, offset errors) the reference star is out of the 1 arcsec field of the pyramid sensor.

In this case the value of pointing error measured with the TV is sent back as part of the error reply. The TCS can use those values to adjust pointing and then repeat the `ResumeAO` command.

7.6.5 Execution time

No slow movements are necessary. Time is negligible.

7.7 StopAO

This command terminates the adaptive loops. After a Stop command, the loop cannot be closed again immediately. A new `PresetAO` and `AcquireRef` sequence must be performed.

7.7.1 Input parameters

None

7.7.2 Preconditions

The loop is currently running or is paused

7.7.3 Procedure

1. *Pause*:
   (a) If system is running: see sect. 7.5.
2. *Stop WFS devices*:
   (a) Stop CCD39 integration.
   (b) Stop CCD47 integration.
   (c) Stop ADC
   (d) Stop Pupil Rerotator
3. *Reset AdSec*

7.7.4 Execution time

No slow movements are necessary. Time is estimated in 5 s.

7.8 OffsetXY

This action will move the positioning of the pyramid in the field. While the AO loop is closed the net effect will be offsetting the field in the scientific camera.

According to current knowledge of telescope behaviour we espect that "close loop" offset larger than 1 arcsec would require times larger than useful, due to the need to rely on mode offload to avoid to reach limit positions of the mirror shell.

Larger offsets are to be implemented by a sequence:

1. `PauseAO`
2. *telescope offset*

3. *telescope point back*
4. `ResumeAO`

which is OK whenever there is no need to be diffraction limited during the offset.

7.8.1 Input parameters

(ofsX, ofsY) (in millimeters)

7.8.2 Preconditions

The system is operating in Adaptive mode. The requested offset is within a few arcsec. Movements larger than the **AdSec** stroke need to be offloaded to the telescope pointing system and will therefore be slower.

7.8.3 Procedure

1. *Displace stages*:
   (a) Compare displacements with offset limits.
   (b) If outside limits: notify error.
   (c) Compute speed[9].
   (d) Move stages to (X,Y).

7.8.4 Error conditions and recovery

Any request which will drive the system out of the allowed range is ignored (and an error message is returned).

7.9 OffsetZ

This command will move the stages along Z axis. While the AO loop is closed the net effect will be changing the focus on scientific camera.

7.9.1 Input parameters

ofsZ.

[9]Because telescope pointing in this mode depends on mode offload, the speed of movement is limited by the capability to transmit mode offload requests to TCS and by its capability to adjust telescope pointing.

7.9.2 Preconditions

The system is operating in Adaptive mode. The requested offset is within the acceptable range.

7.9.3 Procedure

1. *Displace stages*:
   (a) Compute Z displacement from ofsZ.
   (b) Compare Z with offset limit.
   (c) If outside limit: notify error.
   (d) Compute speed[10].
   (e) Move stage to Z.

7.9.4 Error conditions and recovery

Any request which will drive the system out of the allowed range is ignored (and an error message is returned).

8 Slopes Null Computation

8.1 Overview

Slopes null is the reference frame measured with the **AdSec** in flat position. The slopes null may be different for different instruments or for different configuration of the same instrument.

A different slopes null set must be acquired for each combination of CCD39 binning and tip-tilt modulation.

Slopes null may be taken with either the internal **WFS** reference source (if the retro-reflector mirror is mounted) or using light from a star pointed to by the telescope.

This procedure is started from the AO Arbitrator engineering GUI.

8.2 Preconditions

- **AdSec** is in Operating state with a chosen flat position.
- **WFS** is in Operating state.
- the required source (either reference or starlight) is selected.

[10]See previous note

8.3 Procedure

1. the **WFS** arbitrator steps through the various combinations of CCD binning and tip-tilt modulation and saves a slopes null set for each combination.

8.4 Execution time

Fixed time of about 5 minutes.

9 Interaction Matrix Computation

9.1 Overview

The interaction matrix must be taken using the internal **WFS** reference source and the optical retro-reflector installed on the **AdSec**. A different interaction matrix must be taken for each combination of CCD39 binning and tip-tilt modulation. Since this operation is quite time consuming, the system will not step through the different parameter combinations but only use one.

This procedure is started from the AO Arbitrator engineering GUI.

9.2 Preconditions

- **AdSec** is in Operating state
- **WFS** is in Operating state and a certain CCD39 binning and tip-tilt modulation has been set using its engineering GUI.

9.3 Procedure

1. the **AdSec** arbitrator sends the first modal shape to the mirror
2. the **WFS** arbitrator acquires a set of slopes and saves them on disk.
3. The two steps above are iterated for all modal shapes (up to 672)
4. When all measures are collected, the resulting matrix is inverted and saved on disk.

9.4 Execution time

Strongly dependent on the averaging done during slopes acquisition. Up to 1 hour.

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