Software solutions for high performance AO in the SOUL project

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ABSTRACT

The SOUL upgrade of the LBT SCAO systems allows closed loop operations running at 2kHz with up to 1200 sub-apertures, providing full telemetry of the computed slopes. To achieve such performances a number of optimizations of the software/firmware have been developed such as: the handling of the WFS camera data stream and higher throughput diagnostic, optimizations for the new slope computer and the mirror controllers. In this contribute we will focus on some of the most critical aspects as the slope computation in parallel to the frame readout and the diagnostic data download.

Keywords: Pyramid, SCAO, LBT, high contrast, AO Software

1. INTRODUCTION

The development of the software for the SOUL project has been carried out by the AO-group of INAF-Arcetri. For a complete description of the project refer to.[1] Here we will focus only on the software related aspects of it. As SOUL is an upgrade of the four existing AO systems, such developments consist in extensions and re-factoring of the existing FLAO/UAO software[2][3].[4]

The AO sub-system at LBT comprises a total four WFSs (Wave Front Sensors): two are paired with the two LUCI scientific cameras and two to the LBTI (LBT Interferometer). For each WFS there is a dedicated computer to handle its configuration and diagnostic data (WFS computers). Similar tasks are performed by two dedicated computers for each of the two adaptive secondary mirrors (ADSCEC computers). The realtime computations necessary at each step of the control loop are instead carried out by several BCUs (Basic Computing Units) developed by Microgate integrating and configuring DPS processors and FPGA logic. One BCU for each WFS has the role of Frame Grabber and Slope Computer, while the BCUs (6 computing units and one routing unit for each side) in the AsSec mirror controllers perform force computations while collecting and propagating the mirror diagnostic to the the rest of the AO system.

2. ADAPTIVE OPTICS SOFTWARE INFRASTRUCTURE AT LBT

As shown in fig.1 the SOUL WFS Software communicates with the TCS (Telescope Control Software) via remote connection as its predecessor FLAO/UAO. The TCS has access and means of communications with the AO software (SOUL in our case) only through an interface module called AOS (Adaptive Optics Subsystem, R=right in the picture). Other acronyms used in fig.1 are:

- PCS: Point Control Subsystem, pointing control
- PSF: Point Spread Function subsystem, collimation control
- OSS: Optics Subsystem, optical elements drive
- IIF: Instrument Interface.

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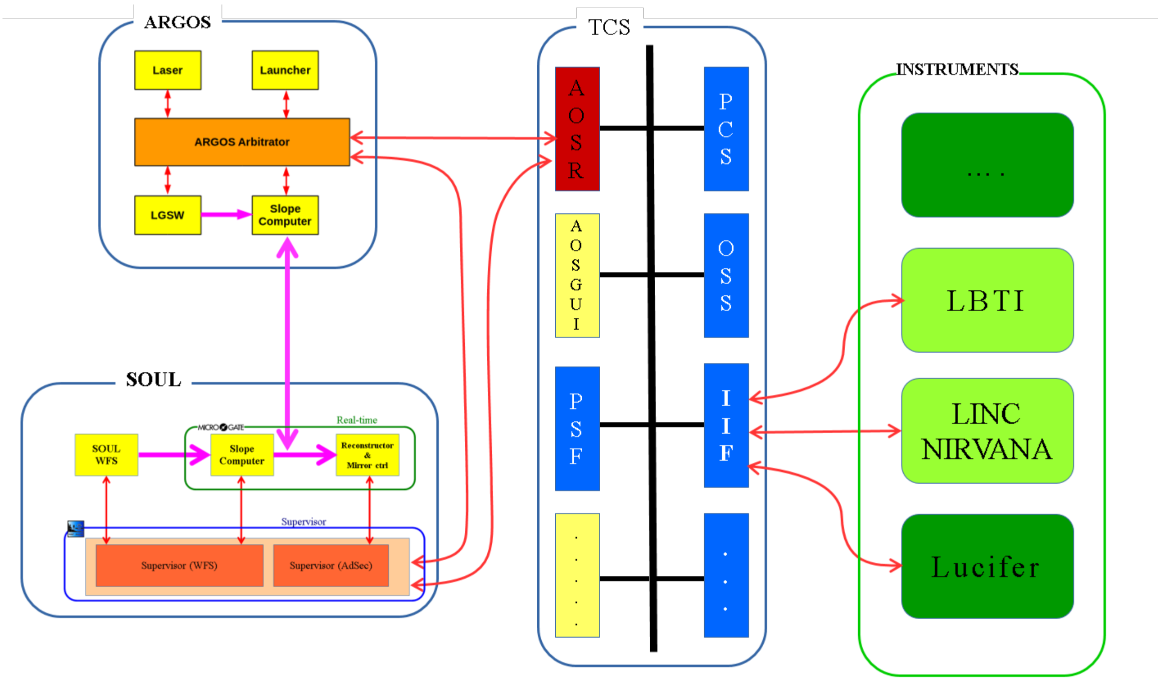


Figure 1. SOUL WFS Software interactions with the TCS.

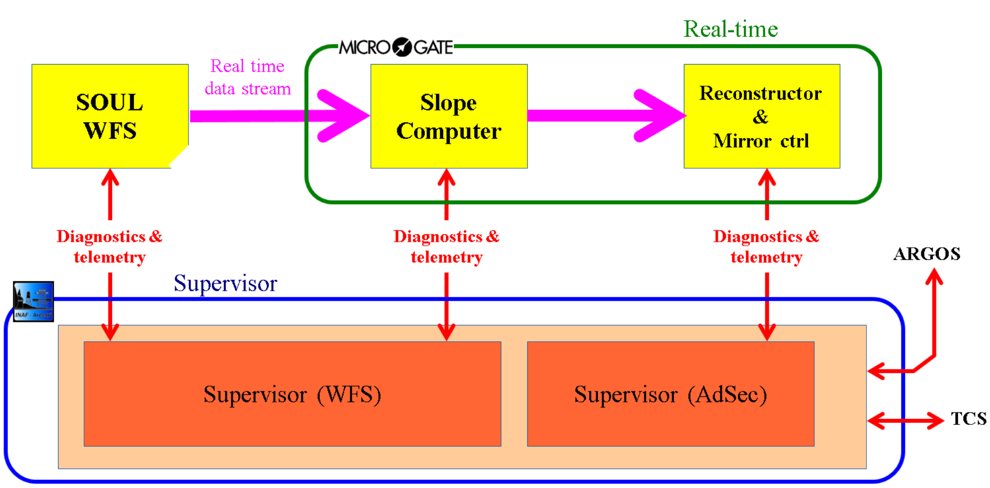


Figure 2. WFS and AdSec Hardware and Software mapping.

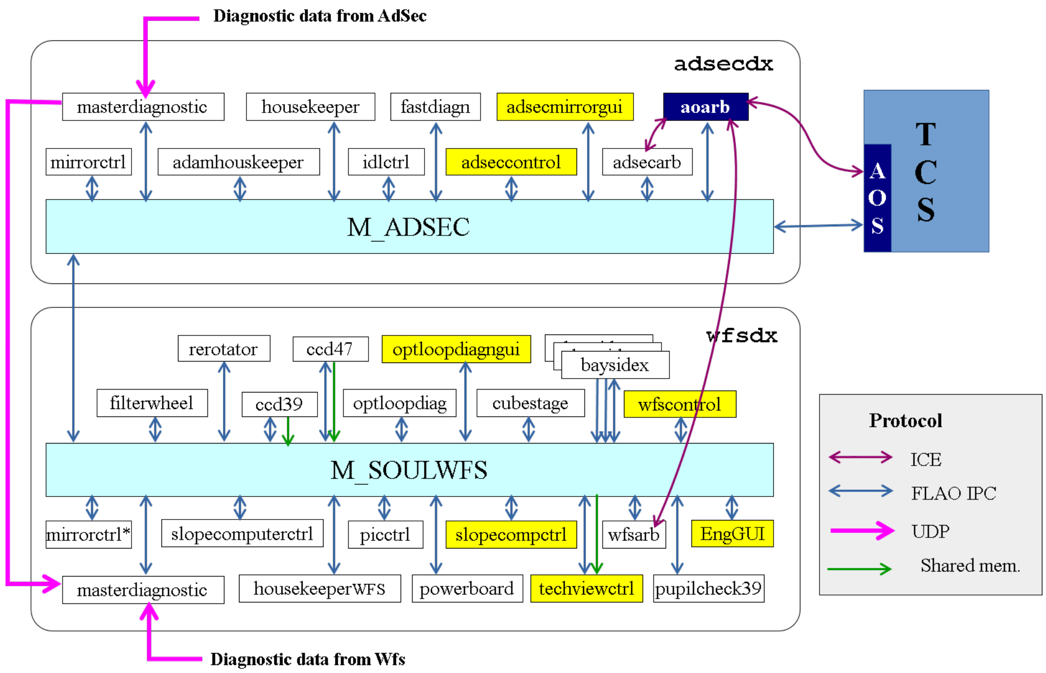


Figure 3. Detailed view of the two Supervisors

The WFS Supervisor and the AdSec Supervisor are the SW counterparts of the two hardware subsystems, running on two different host computers (WFS computer and AdSec computer). The interaction of the software modules with the related hardware is depicted in fig.2. This modules provide high level procedures and interfaces and communicate with lower level processes that are part of the software ecosystem, using several mechanisms, depending on the required performances and level of abstraction:

- shared memory
- UDP communication
- Inter Process Communication (IPC) mechanism developed in house and named Message Daemon which provides a shared variable mechanism.
- Remote Procedure Call (RPC), implemented in ICE (Internet Communication Engine see[5])

A detailed view of the two Supervisors is shown in fig.3. Each Supervisor is composed by several cooperating processes, each controlling a specific device (i.e. Pupil Re-rotator, Tip Tilt Mirror, CCD, Power Board etc) or absolving a specific task (i.e. Diagnostic Communication, several engineering GUIs, Control computations). Note the purple data stream which is the high bandwidth link used to collect and store telemetry data from both the Secondary Mirror (AdSec) and the Wave Front Sensor (WFS) implements a synchronized communication.

The implementation of SOUL software was made in C/C++ and Python languages, however some tasks are still performed by legacy routines which were developed for FLAO/UAO in IDL.

3. HANDLING THE NEW WFS CAMERA

The single most important new hardware component introduced in the SOUL upgrade is the new WFS camera, the Ocam2K produced by Firstlight. The new camera, in comparison with the previous (CCD39) allows for higher framerate, higher resolution, shorter readout time, lower readout noise. For a full specification and performance analysis of the Ocam2K please refer to.[6]

Table 1. Custom Read Out modes:.

Binning	Size [pix X pix]	Read Out Time [ms]
1x1	240x240	$< 0.50ms$
1x1	240x120*	$< 0.24ms$
2x2	120x120	$< 0.24ms$
3x3	80x80	$< 0.24ms$
4x4	60x60	$< 0.24ms$

*Cropped

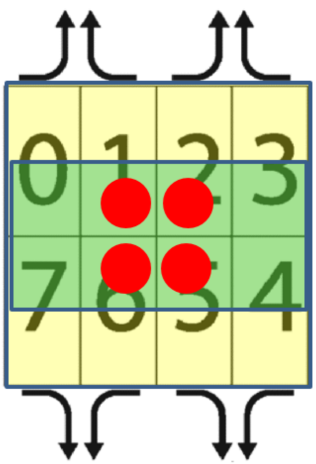


Figure 4. Cropped mode area shown in green, typical pupils in red.

The available Read Out modes are reported in Table 1. Besides the usual binnings, a custom 1x1 cropped binning was implemented in the camera firmware specifically for SOUL, to have the maximum resolution while lowering the readout time below one half of the minimum AO loop period (which is 0.5ms at 2kHz). This was possible because the pupils of the pyramid WFS occupy just a central window in the plane of the CCD, as shown in 4.

To deal with the higher data throughput of the Ocam2K and its data format (the industry standard "Camera Link:), a new Frame Grabber was implemented in the WFS BCU, also providing the functionality to assemble Jumbo Frames packets for high speed UDP communication. A simple but necessary re-configuration of telescope

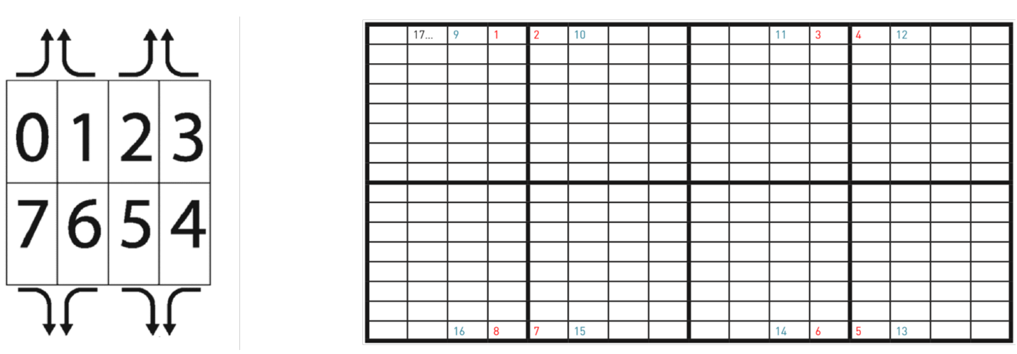
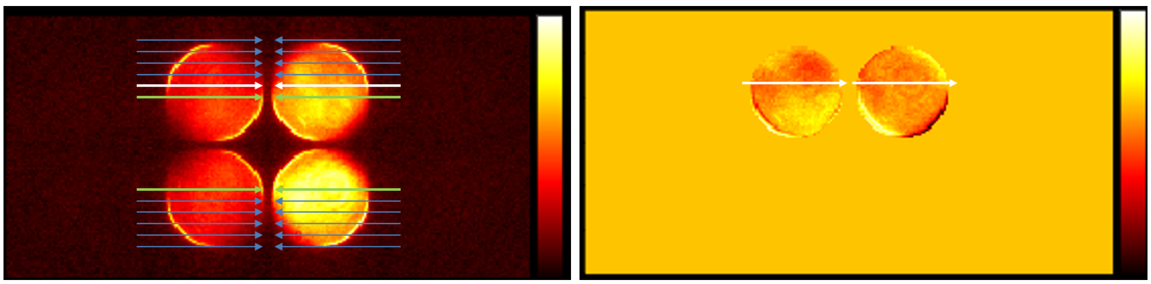


Figure 5. Ocam Pixels ordering.

ethernet network was made in order to allow such packets, by increasing the value of the MTU (Maximum Transmission Unit) of the network. Another update in the functionalities of the Frame Grabber has been made in order to deal with the peculiar pixels ordering of the camera, which reflects the CCD hardware structure, organized in 8 rectangular sections (or octants). The proper descrambling of the stream of pixel data was needed in order to correctly index the pixels, both for display and computation purposes. The pixels are emitted by the camera firmware in the order shown in fig. 5, where it is imagined to have just a few columns and rows for ease of display and explanation.

4. SLOPES COMPUTATION



(a) Pixels (b) Slopes

Figure 6. Pixels and Slopes correspondence.

The increased number of slopes (from 1660 in FLAO to current 2848 at bin1) and higher loop frequency (from 1kHz to up to 2kHz) required an improvement in the Slopes Computer performances, which was achieved exploiting the serial transmission of the pixels, by performing the needed computations in pipeline with their reception, as soon as the 4 four pixels involved in each slope computation are available. As an example consider the bin1 cropped mode: because of the placement of the pupils in the CCD area and the order of the rows Read Out, when one half of frame has been received it is possible to start computing the slopes relative to the central rows of the pupils. This happens after one half of the Read Out time from the beginning of the frame transmission. This process is depicted in In fig. 6: when the pixels in the green rows are read, the computation of the slopes relative to the white rows can begin. The total slope computation time for bin1 is 0.205ms.

Because the full pixel telemetry data at maximum framerate at bin1 would exceed the available bandwidth, different decimation levels for diagnostic data relative to Pixels and Slopes were implemented. Typically a high decimation rate for pixels is acceptable (i.e. only 1 frame every 16 can be transmitted) while full Slopes telemetry is desirable as it allows for the complete characterization of the AO Loop behavior. The slopes data can be used for PSF reconstruction or for the implementation of sophisticated control strategies as demonstrated in.[7] The diagnostic recording of slopes at full rate (2kHz) and the slopes re-scaling done in firmware, allows to compensate for the pyramid optical gain, making possible the implementation of complex gain optimization algorithms.

5. HIGH THROUGHPUT DIAGNOSTIC

As for the FLAO system, the communication path that allows realtime exchange of slopes and commands between the WFS and AdSec is called "fastlink" and implemented ad UDP packets over an optical fiber dedicated link. Such connection is represented in red in the diagram in fig. 7. Telemetry data is then sent to the using UDP with jumbo frames (blue arrows) to control workstations, where a process called "Master Diagnostic" is able to receive packets from multiple devices and align them into a single data frame using internal counters. The data is then made available on shared memory. In order to have an host where all the data is available an can be collected, the AdSec computer forwards the data to the WFS computer ("diagnostic tube"), with the same UDP protocol. From the WFS computer perspective, it appears like a single device is sending data together with the slope computer.

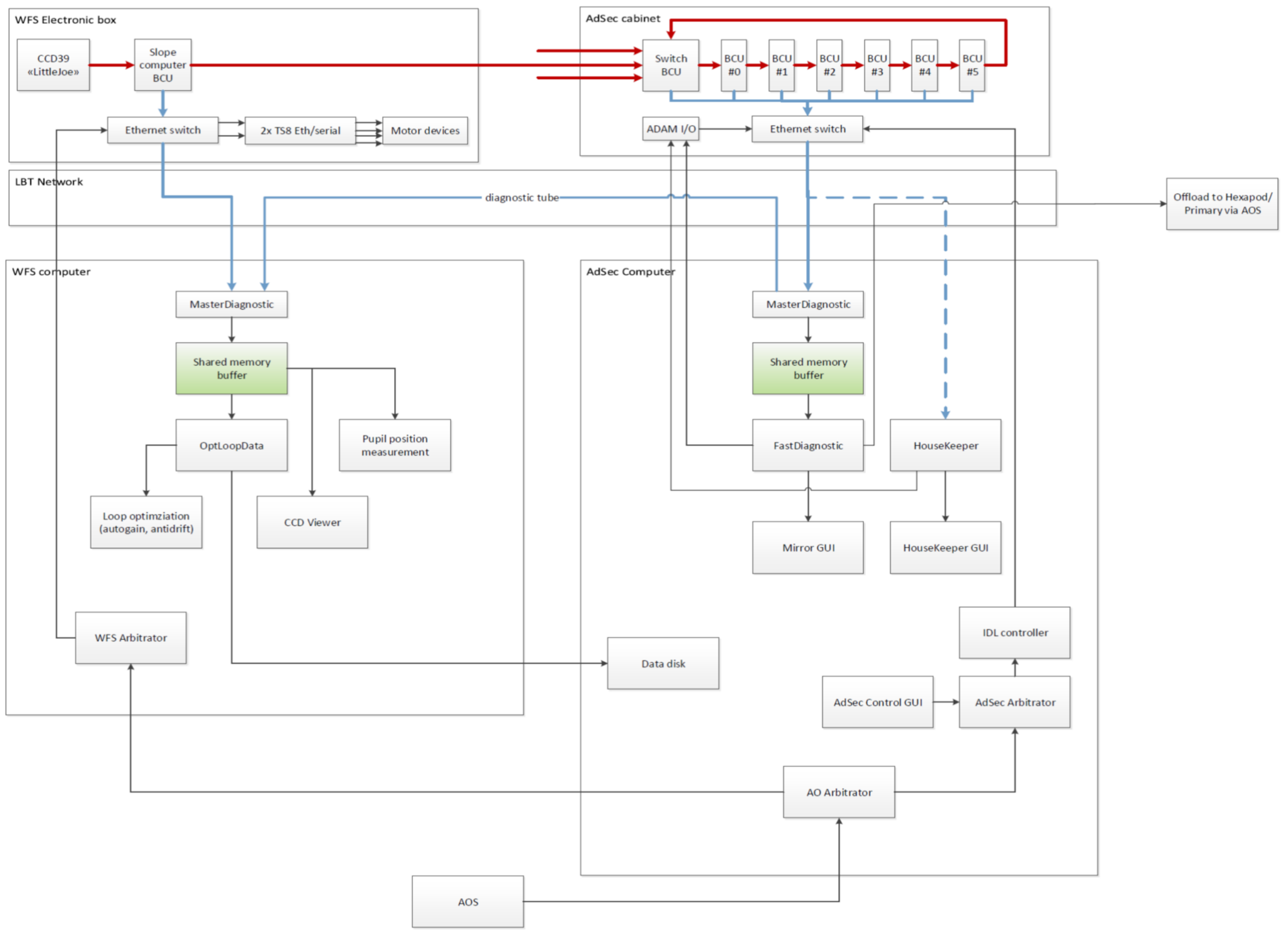


Figure 7. Optical Loop Diagnostic data transmission scheme.

6. ADSEC FIRMWARE TUNING

The key point on ASM set-up is the configuration of the dynamics. While the control loop is taking care of the fine positioning, the modal deformation driven by the SC is demanded to the feed-forward contribution. The relevant parameters for this active positioning are:

- Time of the pre-shaper shape for command contribution (Pre-shaper CMD)
- Time of the pre-shaper shaper for current contribution (Pre-shaper CURR)
- Delay in the position reading (Acc DELAY)
- Length of the position reading accumulation for noise rejection (Acc LEN)
- Settling time (St) for low/mid/high stiffness modes
- Maximum overshoot reached

The pre-shaper time reduction has been obtained by decimating a full 'cos-arccos' original shape using a firmware feature while the "Acc" parameters are quantized into ticks of about 1/70kHz. The figure 8 shows the final parameter set. While the low order modes dynamics is slightly affected by the feed-forward contribution due to the low stiffness, the high order modes, corresponding to high stiffness modes, take full advantage of the increased feed-forward speed. These parameters are therefore pushing the ASM to the maximum allowed performances without significant changes in the system control law.

Case	Pre-shaper CMD (ms)	Pre-shaper CURR (ms)	Acc DELAY (ms-len)	Acc LEN (ms-len)	St - Low (ms)	St- Mid (ms)	Rt – High (ms)	Max Overshoot	Max FREQ (Hz)
Base	0.1	0.8	0.6 (43)	0.056 (4)	1.05-1.11	0.75-0.8	0.7	10.5%	1000
1	0.1	0.65	0.6 (43)	0.056 (4)	0.9-1.10	0.65-0.70	0.58	10.5%	1300
2	0.1	0.55	0.5 (36)	0.056 (4)	0.9-1.10	0.57-0.65	0.49	12.6%	1500
3	0.1	0.45	0.4 (28)	0.056 (4)	0.9-1.10	0.5-0.7	0.4	15.3 %	1800
4	0.1	0.35	0.4 (21)	0.056 (4)	0.9-1.10	0.4-0.6	0.31	20%	2100

Figure 8. AdSec Control Parameters

7. CONCLUSIONS

The introduction of new WFS cameras with different logic and increased performances triggered the software updates described in this paper. Several parts of the existing FLAO/UAO software were updated, refactored and some had to be rewritten, particularly those related to the camera pixels handling and to the slopes calculation.

With the SOUL project progress in advanced status, having upgraded 3 over 4 systems, the software infrastructure described here has been extensively tested and has proven to work. Before completion of the commissioning of all the 4 systems (which is ongoing as we write) and its release for science there is still room for improvements, especially in terms of user experience and extensions to provide additional diagnostic data display.

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