Verification and Acceptance Test Results of the ERIS Adaptive Optics Module Mechatronics

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ABSTRACT

In this paper we will describe the tests performed to verify the requirements and performance of all the mechatronic devices related to the Adaptive Optics (AO) module of the VLT-ERIS project. The Enhanced Resolution Imager and Spectrograph (ERIS) project is a 1-5 m instrument for the Cassegrain focus of UT4 at the Very Large Telescope (VLT). The telescope is equipped with the Adaptive Optics Facility (AOF). ERIS will make use of the Deformable Secondary Mirror (DSM) and one Laser Guide Star (LGS). The ERIS instrument combines an imager (NIX) and an integral-field spectrograph (SPIFFIER) as well. INAF-Arcetri observatory is in charge of the Adaptive Optic (AO) sub-system of ERIS which is equipped with two Wave Front Sensors (WFSs). Specifically, the system is composed by one Natural Guide Star (NGS) and one LGS Shack-Hartmann sensors enabled with real-time computing capabilities and allowing for Single-Conjugate Adaptive Optics (SCAO) operations. In this work, we tested all the WFS mechatronic devices under gravity and thermal conditions to match the project requirement specifications, by replicating the operational status of the telescope Cassegrain focal station. In particular we will show all the achieved results and measured performance.

Keywords: Very Large Telescope, Adaptive Optics, Instrument Control, Beckhoff PLC, Instumentation Tests

1. INTRODUCTION

The Enhanced Resolution Imager and Spectrograph (ERIS)[1] is a 1 5 μm instrument for the Cassegrain focus of the Unit Telescope 4 (UT4) of the Very Large Telescope (VLT) at the Paranal Observatory, equipped with the Adaptive Optics Facility (AOF). ERIS is made of four main components: NIX, SPIFFIER, the Adaptive Optics Module (AOM),[2] and the Calibration Unit (CU[3]). The AOM is a Single-Conjugate Adaptive Optics (SCAO) system working either with a natural guide star to ensure high-contrast correction or an artificial guide star to maximize the instrument sky-coverage. The AO correction is provided by the AOF Deformable Secondary Mirror (DSM),[4] the artificial Laser Guide Star (LGS) is generated by the 4 Laser Guide Star Facility (4LGSF)[5] at UT4, the wavefront sensor camera detectors are identical to those used for GALACSI and GRAAL (the two GLAO systems of the AOF, the CCD220-based wavefront sensor cameras[6]) and the Real-Time Computer (RTC) is a modified version of SPARTA.[7] In addition, one of the scientific instruments (SPIFFIER,[8] an integral field spectrograph with a wavelength coverage of 1 - 2.5 μm and a spectral resolution R = 4000) is a modified version of SPIFFI, the 1 - 2.5 μm integral field unit used on-board SINFONI. Furthermore, another module of the ERIS instrument is NIX[9] is a replacement for NACO, and it provides an infrared imager working between 1 and 5 μm with coronographic capabilities. ERIS consists of the following modules:

- The **Calibration Unit** which provides facilities to calibrate the scientific instruments and perform troubleshooting and periodic maintenance tests of the AO modules (e.g., calibrate Non-Common Path (NCP) aberrations and flexure pointing models);
- The **Adaptive Optics module**, which will use the AOF DSM and one AOF laser, providing NGS and LGS visible wavefront sensing with real-time computing capabilities.

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- **Two science instruments**:
  - **NIX** (Near Infrared Camera System) which provides diffraction-limited imaging, Sparse-Aperture Masking (SAM) and pupil plane coronagraphy capabilities in the 1 - 5 μm (J to M) bands, either in standard observing mode or with pupil tracking and cu-be readout mode. NIX is a cryogenic instrument and is equipped with a 2048 x 2048 detector cooled at 40 °C by means of a Closed Cycle Cooler (CCC). The camera optics is able to provide a Field-of-View (FoV) of 27" x 27" in the J to Ks bands or 55" x 55" in the J to M bands.
  - **SPIFFIER**, which is a refurbished version of SPIFFI, modified in order to be integrated into ERIS. Its observing modes are identical to those of SINFONI. Both NIX and SPIFFIER are fed by a dichroic beam-splitter which reflects the visible light to the AO module.

Figure 1 shows an overview of ERIS. Further details about instrument optical alignment can be found in[10] .

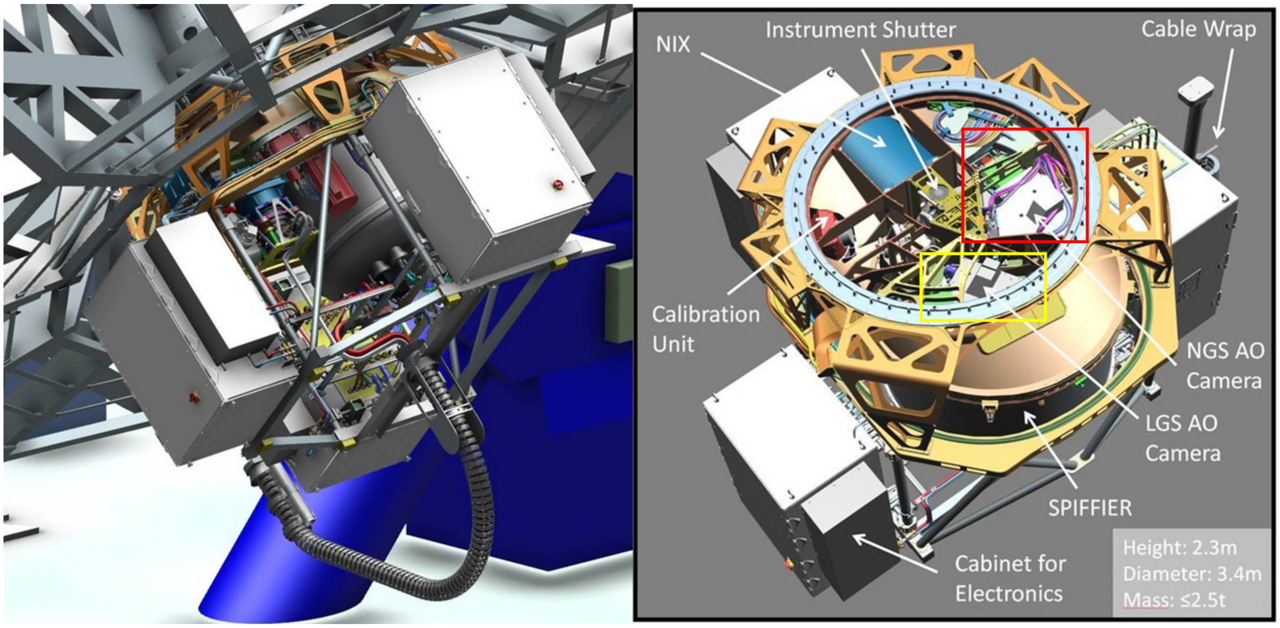


Figure 1: ERIS in a nutshell. Left: 3D model of ERIS munted at the Cassegrain focus of VLT-UT4. Right: detail view or ERIS as seen from the top of the AOM. The NGS and LGS WFSs are highlighted by the red and yellow boxes respectively. Images credits MPE.

Specifically, the AOM itself is made out of four main components:

- The *Warm Optics*: a set of optical components, that relay the telescope optical beam out from the Cassegrain Flange to the science instruments and to the two WFSs.
- The *LGS WFS*: an high-order Shack-Hartmann (SH) sensor with a pupil sampling of 40 x 40 sub-apertures, a FoV equivalent to 5" on-sky and 6 x 6 pixels per sub-aperture (0.8"/pixel scale). It operates only with an on-axis LGS, so it requires only an active compensation for the sodium layer height.
- The *NGS WFS*: it accomplishes both High-Order (HO) and Low-Order (LO) functionality for standard NGS operation and LGS operations respectively. In the first case configuration is similar to the LGS WFS: 40 x 40 sub-apertures, 6 x 6 pixels per sub-aperture, but it has a reduced FoV equivalent to 2.5" (so 0.4"/pixel scale). In low-order mode the WFS is configured to have 4 x 4 sub-apertures sampled with 12 x 12 pixels hence having a 0.2"/pixel scale). Moreover, to ensure an adequate sky-coverage, the NGS WFS has to patrol a 120" diameter circular-area on the telescope F13.4 focal plane to pickoff a reference star.

2. SOFTWARE ARCHITECTURE

The ERIS architecture and the subdivision of functions among software subsystems is composed by standard components provided by ESO (such as DCS and RTC) and other components fully developed by the ERIS Consortium by building on the base software provided by ESO (template instrument software, base Instrument Control Software (ICS) and OS, panel editor, template library, configuration, start-up tools and libraries, etc.

Figure 2 shows a schematic of the ERIS software architecture. Further details can be found in[11] .

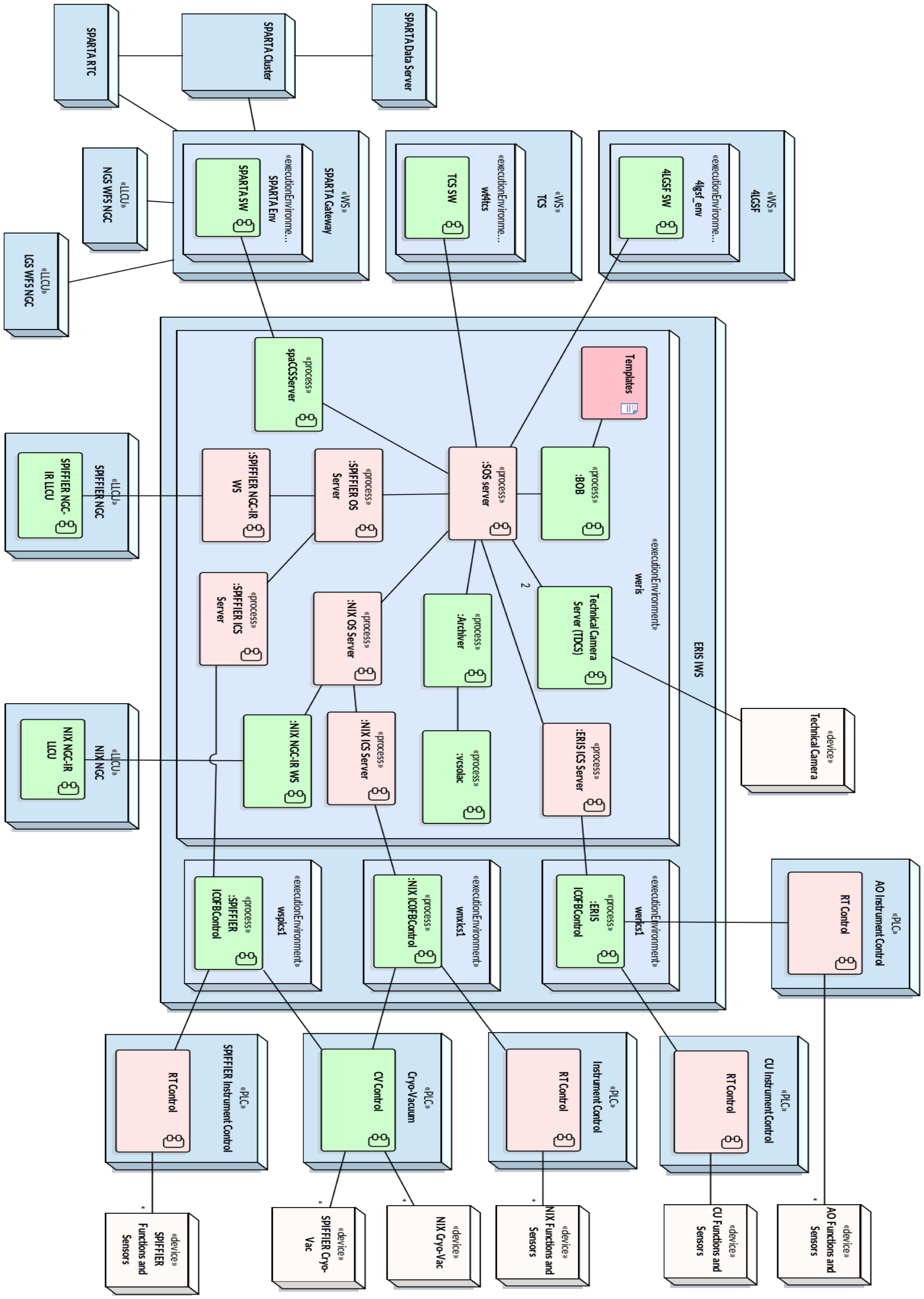


Figure 2: ERIS software module scheme.

3. TESTS

In this section we are going to describe the architecture of the test setup. We are using a Linux workstation (i.e., Ubuntu 16.04 LTS) with installed the ERIS INS framework. This machine is able to run the ERIS INS GUI which has been already setup with all the devices composing the ERIS instrument. Then, we use a Windows 7 machine to run the Visual Studio Integrated Development Environment IDE). The used version (Ultimate 2013) already integrate the TwinCAT 3.1 framework. We used this machine to configure and develop the Programmable Logic Controller (PLC) software to be downloaded into the EtherCAT master (i.e., Beckhoff PLC).

The Beckhoff PLC is a Windows CE embedded machine with an already setup TwinCAT eXtended Automation Runtime (XAR) module to configure the PLC master. On the PLC side, all the I/O modules (to control both drive and encoder) must be configured for the specific motor controller as described in the respective datasheet.

Each device must be tested in two specific conditions: under gravity pressure (as it will be in the real operational mode) and at cold temperature (as it will be when mounted under the telescope dome). Indeed, to be compliant with the project specs, a bunch of measurements and tests had to be performed on all the devices the ERIS AO module is made up of. All the motorized axis have to be fast and precise enough under gravity, load, and cold conditions as they will be at the telescope. Furthermore repeatability of the measurement is essential as well to assure that their behavior will always be the same in time. Therefore, for each device we performed several movements (i.e., homing, fast/back-movement, fast/slow ramp, etc.) at cold temperature (down to -20 °C) to verify the compliance with project specs. We setup an in-house climatic cell and we developed the software to remotely control it and the devices, and to collect data to be analyzed. Also, as to perform gravity tests, we used an in-house rotating plate to replicate telescope working conditions.

3.1 Cold Tests

To permit the execution of different tests during the cooling and warming phase we decided to drive the devices through a python client which can be remotely controlled as required. We therefore started the development of a simple client to interface with the devices which have to perform several movements as required by the test such as homing procedure, fast movement/back-movement, fast/slow ramps (40/0.22 degree per second), and fast/slow steps (40/0.22 degree).

To remotely manage the in-house climate cell we used an Ethernet-controlled socket and we created on the laboratory PC a new virtual private LAN to communicate with it. This way, we could correctly access and control the socket via browser. To install and configure the device we followed the instructions on[12] . We then created a series of python scripts to perform the requested movements for each device as specified in the Final Design Review (FDR) ERIS requirement document, by sending commands to the device (which must be pre-configured in the PLC solution). Finally, we implemented a library tool script which contains some common functionalities (i.e. climatic cell and heater control, temperature control, etc.) which will be required by all the future tests to, for instance, set the desired temperatures (i.e. cold and environment) for the tests. These two temperature thresholds control the falling down and rising up thermal cycle, therefore we needed to set them as required by each single device tests. We exploited the TwinCAT 3.1 Scope Viewer framework to save the test output files and we implemented scripts to automatically start/stop the tool and to trigger the beginning/ending of every and each motor movement.

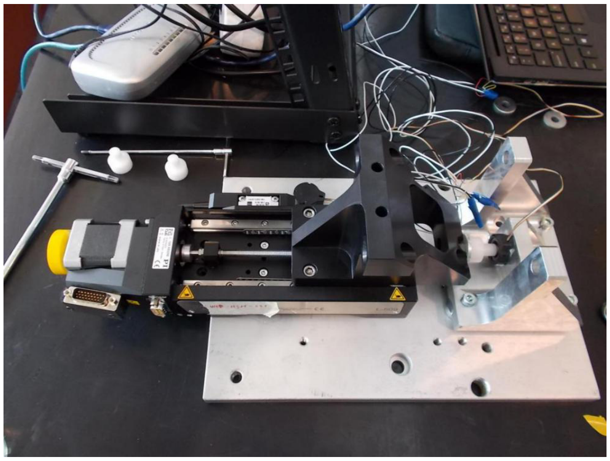
3.2 Gravity Tests

We performed measurements intended to characterize the stability of the motor central shaft against a pre-load on the rotator device to avoid step loss. For instance, both natural and laser guide star WFS subsystems have been installed on a tilting bench together with the alignment source. The motion control devices are powered on and connected to their control electronics. The cameras are powered on and connected to their control electronics, as well. An external F/13.4 source has been secured to the bench to guarantee that the beam direction is preserved during the slew. A dry run is done with a test camera to measure the amount of misalignment from the source during the slew. The test started with the tilting bench at 0 °C and the zero working point is taken (position of the stages and location of the alignment source spot on the cameras). The bench then has been moved at increasing elevation angle, with a defined step (e.g., 15 °C). At each step the working point is collected and stored. After reaching the maximum elevation the bench is tilted back by the same step to re-measure the working points.

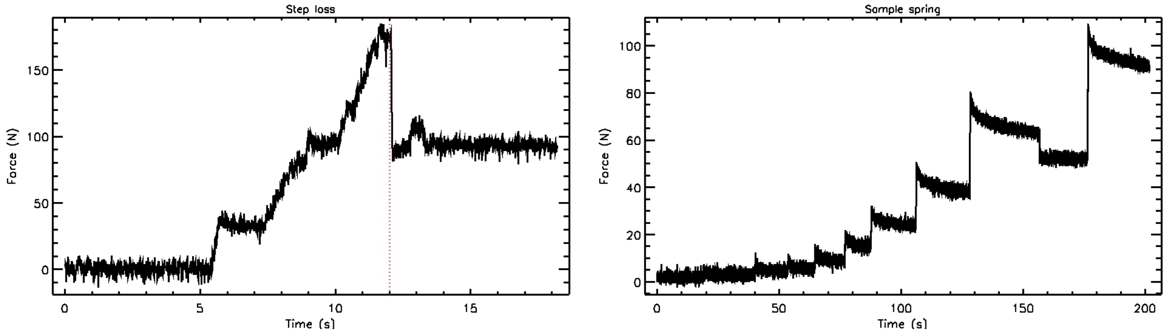
3.2.1 Test Results

We are going to show here some tests on the Nix Selector Mirror (NSM), shown in Figure 3a, and the XY motorized stage, shown in Figure 4a. The final NSM mount structure was bolted on the stage surface and we set up a fixed reference plane in which we applied a load cell to monitor the force (see Figure 3). The PI L509 device is demanded to position the NIX selector mirror in and out from the scientific beam in order to select between NIX and SPIFFIER. The measure was done with motor switched off. The movements have been done rotating by hand the shaft. The mirror has been chosen mainly for the speed and for the pushing capabilities to overcome to the earthquake oscillations. We identified the following specification applicable to the object:

- Homing: we set a reasonable time for homing of 60 sec.
- Max speed: the goal is to perform 100 mm in 20 sec.
- Max pushing force: to keep the NSM whole mount with holder and optics in place with the earthquake bound of 3.5 g, the motor has to push from design 1380 Kg by 3.5, that corresponds to about 50 N.



(a) Motorized NSM device.



(b) Step loss.

(c) Step loss.

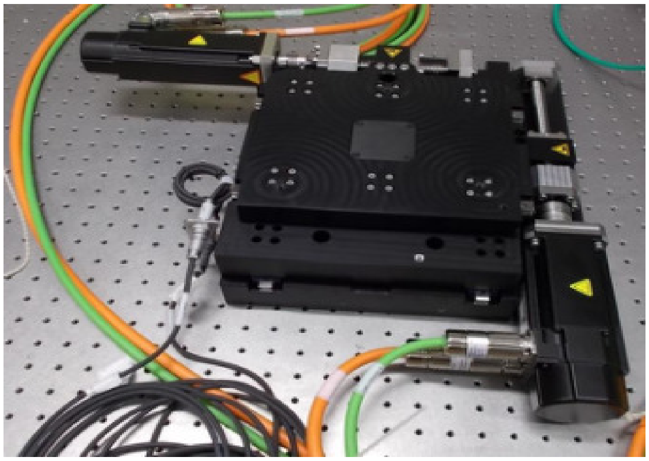
Figure 3: Measurements to characterize the stability of the motor shaft against a pre-load to avoid step loss.

In the plot in Figure 3b we see the force read by the load cell against the time while we were rotating the shaft to pre-load the load cell. The red line marks the instant where the motor lost steps and get back in position. As check the second lost of steps is the little bump just after. The limit value of pushing force is therefore about 90 N. Then we asked to the motor to perform steps of the order of fraction of mm ahead and we monitored the pushing force (see Figure 3c). By comparing the two plots, we note that the position error is usually below the micron after a while so we can substantially state that the motor can keep constant force up to about 90 N. The small decaying effect, as effective movement of the stage, are due to the setup deformations.

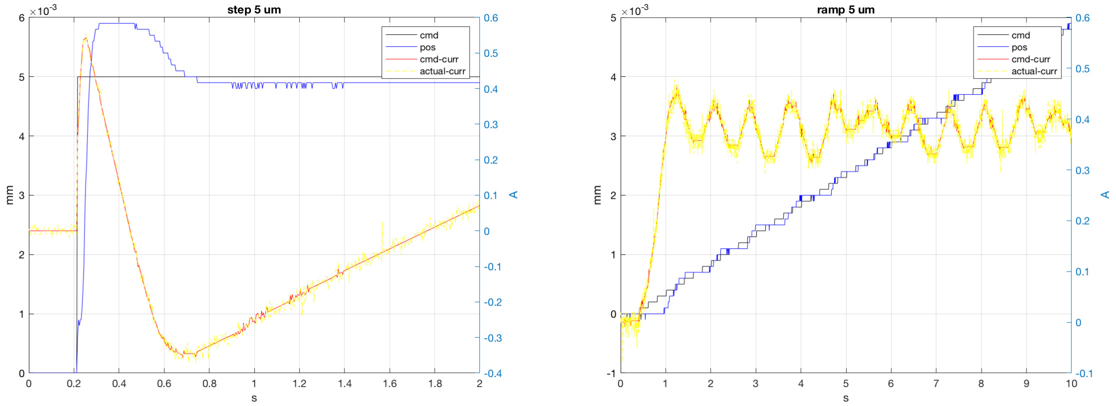
The Steinmeyer dual stage XY has to take care about the positioning and the focus of the NGS module in the patrol field. Hereafter we are considering the X-axis movements (Dual Stage X, see the following Figure 4a) part, corresponding to the positioning along X-axis. In the definition of the technical requirement we used the design scale of about 500 um/arcsec relation between stage movements and on-sky. The device has to match the following specs:

- Accuracy of 8 mas at stage level, which is split according the budget and therefore is set to 1μm.
- The stage has to perform movements of 100 arcsec/h. We tested its precision by using small ramps. The validation measurement is the following error on a ramp of 150 μm in 10 sec.
- The baseline is a movement of 1 arcsec with 1 sec period update. We can imagine the offset as a set of steps of 10 μm. Here we tested step of 10 μm, settling time of 0.1 sec as worst case.
- The offset on the field has to be of at least 1 arcmin, corresponding to 30 mm. The movement speed has been set to a reasonable value for test (i.e., 5 mm/sec).

All the measurements were done with the stage simply placed on a optical bench, with gravity normal to the stage and with a load of about 40 Kg (see Figure 4). We tested the behavior of the system even on large movements (in which is not required any particular overshoot constrain but an high speed is requested) up to very small movements (1μm with 1μm overshoot constrain).



(a) Motorized XY stage.



(b) Steps.

(c) Ramps.

Figure 4: Small movements with a load of about 40 Kg, G vector normal to stage.

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