

# MAVIS: Conceptual architecture of the Instrument Control Software

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## ABSTRACT

In this paper, we describe the preliminary architecture of the Software for the Instrument Control System (ICSS) of MAVIS, the new MCAO Assisted Visible Imager and Spectrograph for ESO's Very Large Telescope. The instrument successfully passed its phase A in May 2020 and will start phase B in March 2021. ICSS is in charge of controlling all the motorized functions, managing the scientific exposures, monitoring the status of the system and coordinating the sequence of operations from the Observing Blocks receiving to the collection of the scientific data. A challenge from the SW point of view is that MAVIS, besides being an instrument for VLT, will use the ELT-SW framework, which is currently under development. A dedicated ELT/VLT gateway will provide the interfaces with the Observation Handling Subsystem (OHS), the Archive System, the Telescope Control System (TCS) and the AOF.

**Keywords:** Control software, instrument, VLT, ELT

## 1. INTRODUCTION

The MCAO Assisted Visible Imager and Spectrograph (MAVIS) is a new instrument for ESO's Very Large Telescope. It will operate at the Nasmyth focus of Yepun telescope (UT4) and will include an imager and a dual-resolution dual-band spectrograph. The instrument will operate in the visible band offering the opportunity to exploit in the 370-950 nm range the image quality obtained with the combination of the Adaptive Optics Facility (AOF) of UT4 and of an inner adaptive optics module, which includes two post-focal deformable mirrors. In this way the instrument can compensate the effects of the atmospheric turbulence in MCAO mode and delivers a corrected field of view to the post focal scientific channels, the imager (4Kx4K detector, 30x30 arcsec FoV) and the spectrograph (9Kx9K detector, 3x3 arcsec FoV). The instrument successfully passed phase A in May 2020 and will start phase B in March 2021. In this paper, we focus on the conceptual architecture of the Software for the Instrument Control System. The conceptual design of the instrument is given in another paper<sup>1</sup> of this conference.

## 2. INSTRUMENT FUNCTIONS

MAVIS has a modular design and the Consortium has adopted an architectural philosophy to reflect this modularity. Figure 1 shows a functional overview of the main MAVIS modules: adaptive optics module (AOM), imager, spectrograph and calibration unit.

The AOM module<sup>6</sup> is composed of the elements on the main optical bench from the entrance shutter to the science output ports and includes two wave-front sensors (WFS) for laser (LGS) and natural (NGS) guide stars. The light coming from the telescope enters the system through a shutter located at the Nasmyth focal plane. A field lens with active X/Y position control compensates for pupil motion.

An insertable mirror is located after the shutter and injects the output of the calibration unit into the optical train. Two Deformable Mirrors (DMs), conjugated to 6.0 and 13.5 km altitude, are set in the optical path to compensate for the effects of atmospheric turbulence, together with the UT4 Deformable Secondary Mirror (DSM). A dichroic, with a narrowband response near the 589nm sodium line, feeds then the LGS WFS sub-module in reflection. A linear stage allows focus adjustment for the effective range of the sodium layer.

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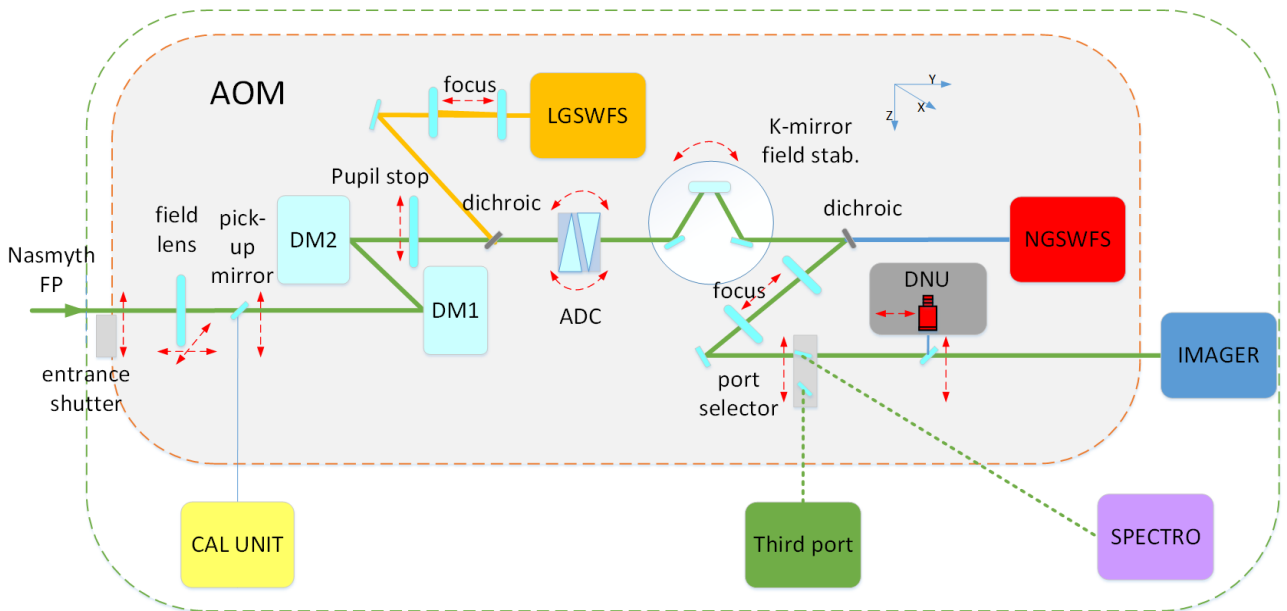


Figure 1. Illustration of the main modules and sub-modules of MAVIS: AOM, Imager, Spectrograph and Calibration Unit. The figure shows in red the detail of the functions under SW control in the post-focal relay sub-module.

The LGSWFS sub-module is composed of an assembly of eight WFS cameras (one for each LGS), mounted on a rotating carousel to compensate for the rotation of the laser asterism with the telescope elevation. Each camera has a 40x40 Shack Hartmann WFS.

Following the LGS dichroic, in transmission, a single Atmospheric Dispersion Corrector (ADC), corrects for atmospheric dispersion over the full wavelength range, including the NIR. De-rotation of the science field is necessary, as in all alt-azimuthal telescopes, since the pupil rotates differentially with respect to the science field. The AOM uses a K-mirror to optically de-rotate the field.

A dichroic then separates the optical train, feeding the NIR light, in transmission, to the NGS WFS sub-module.

The NGSWFS sub-module is composed of three WFS elements, as illustrated in Figure 2. Each NGSWFS element uses a pick-off mirror/probe and an XY translation stage to select a NGS from the 120" technical field of view. Moreover, each NGSWFS element uses a "1x1" WFS to provide low order turbulence information and can alternately be configured to provide truth sensing via a "2x2" Shack Hartmann WFS. The NGSWFS sub-module additionally incorporates a NIR acquisition camera.

The NIR dichroic has the visible science beam in reflection. A focus stage enables adjustment of the science focus independently of the NGS optical path. The light directs then to one of the scientific output ports: the imager and the spectrograph. The AOM includes a third science output port. This port affords access to the MAVIS AO capabilities for a possible future third ESO instrument, or for a visitor instrument.

Finally, an insertable mirror in the imager path can direct the light to a Diagnostics and Non Common-Path Aberrations Unit (DNU). The DNU provides pupil-imaging capabilities and an on-axis Shack-Hartmann WFS for NCPA determination.

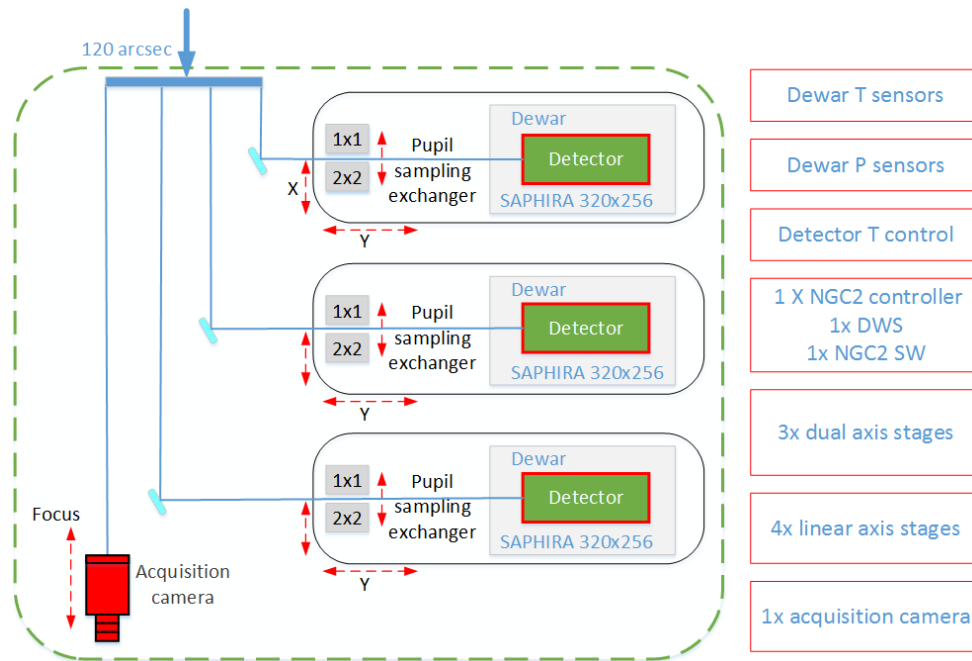


Figure 2. Schematic overview of the NGS WFS sub-module. The components under SW control are marked in red and summarized on the right.

The Imager is located at the focal plane produced by the AOM and uses a 4K detector to image a  $\sim 30'' \times 30''$  field. It includes two filter wheels for broad and narrow band observations.

The Spectrograph design, see Figure 3, is composed of two spectrographs and fore-optics, which spatially split the input field into two. The optics can switch between two spatial resolution modes (25/50 mas spaxels). Each spectrograph is single arm. Moreover, each arm can operate at four different spectral resolutions by changing the disperser element.

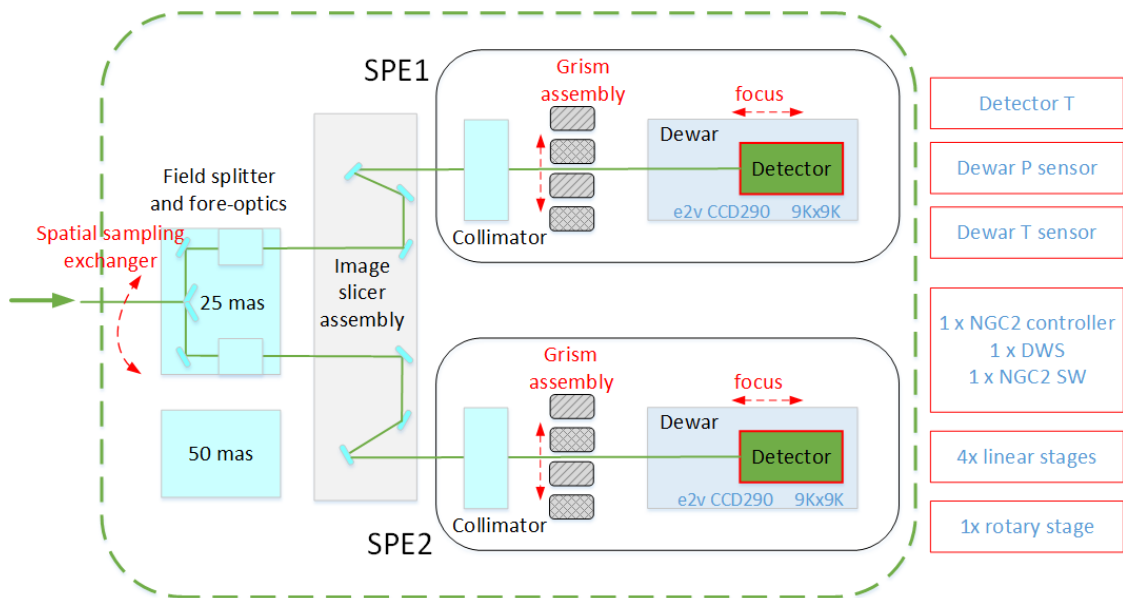


Figure 3. Schematic view of the spectrograph. Components under SW control are marked in red and summarized on the right.

### 3. CONTROL NETWORK

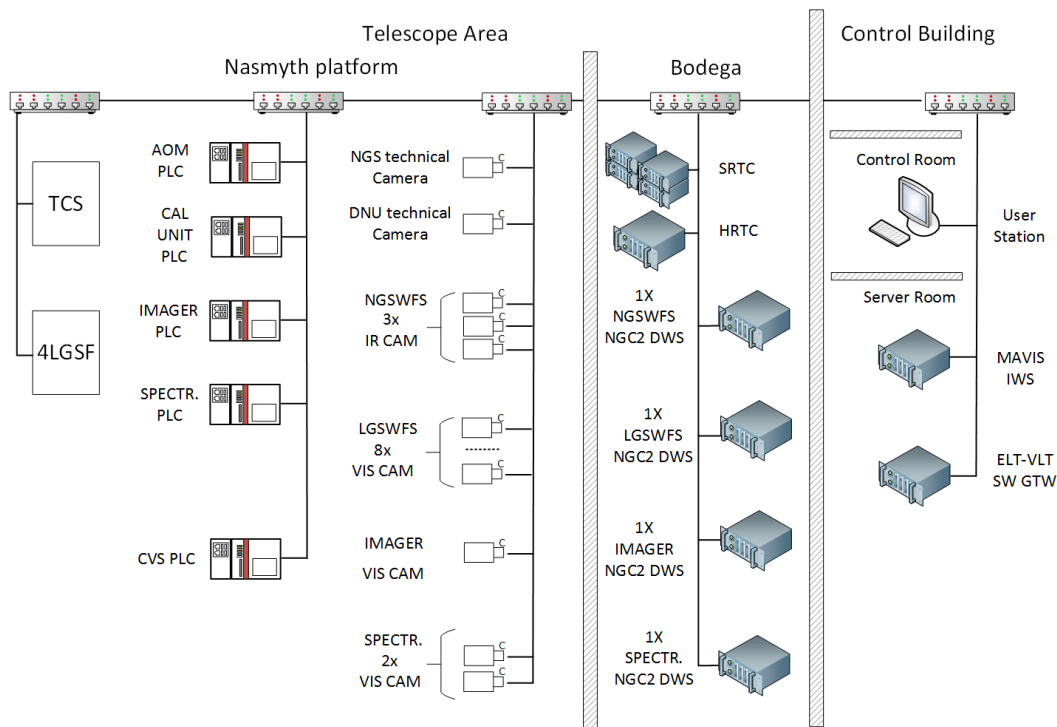


Figure 4. Control network architecture.

Figure 4 illustrates the control network architecture. MAVIS is controlled by one instrument workstation (MAVIS IWS) located in the Control Building. It will be connected via Ethernet to the Real-Time Control system<sup>5</sup> (RTC), depicted in the figure as a cluster of Soft-RTC servers and the Hard-RTC and, we guess, hosted in the basement of the telescope area, the so-called Bodega. The instrument workstation is connected to a dedicated server, which acts as ELT-VLT gateway (GTW) and we guess located in the control room.

The MAVIS IWS will communicate with the detector workstations (DWS) for the control of LGSWFS, NGSWFS, imager and spectrograph cameras. These Linux workstations are, at the moment, assumed to be located in the Bodega. Commands from IWS to DWSs and from DWSs to the cameras will be transferred via Ethernet. We expect to use ESO NGC2 controller to control the cameras.

During normal operations, no pixel/video data is expected to flow from the WFS cameras to the IWS. Pixel data will flow directly to RTC. In this case, RTC will send decimated pixel data to IWS for display purposes. If further analysis identifies a need, during maintenance operations a configuration change could allow pixel data to flow from the WFS cameras to the IWS.

The Nasmyth platform will host the NGS acquisition camera and the DNU camera. In these cases, pixel data flow from the cameras to the IWS. Moreover, the platform will host the detector front-end for scientific channels and for LGS/NGS WFS and the Local Control Units.

In the current design, the instrument devices are controlled by four PLCs, one per post-focal science instrument, one dedicated to AOM module and one to the Calibration Units elements.

Finally, scientific detectors and NGSWFS detectors will be set under cryogenic control. The Instrument Workstation will access the CVS PLC to monitor the sensors of the cryo-vacuum systems.

### 4. INSTRUMENT SOFTWARE ARCHITECTURE

The control software will be based on the Instrument Control Framework<sup>2</sup>, which is currently under development by ESO for the E-ELT.

Figure 5 illustrates the architecture of MAVIS ICSS, showing the main SW components and the different interfaces for control (orange), supervision (magenta), data acquisition (green), monitoring (blue) and data display (brown).

MAVIS ICSS is composed by a core of high-level components (Sequencer, Supervisor, OCS) that coordinate the observations and monitor and supervise the entire system; five subsystems will then interface with the instrument hardware: NGSWFS, LGSWFS, PFR-CU, IMAGER and SPECTROGRAPH. Calibration Unit, Post-Focal Relays devices and DNU assembly are seen here as one subsystem. Moreover, MAVIS ICSS interfaces with some VLT software components external to the instrument itself: the Observation Handling Subsystem (OHS), the Archive System, the Telescope Control System (TCS) and the UT4 laser guide-star facility (4LGSF).

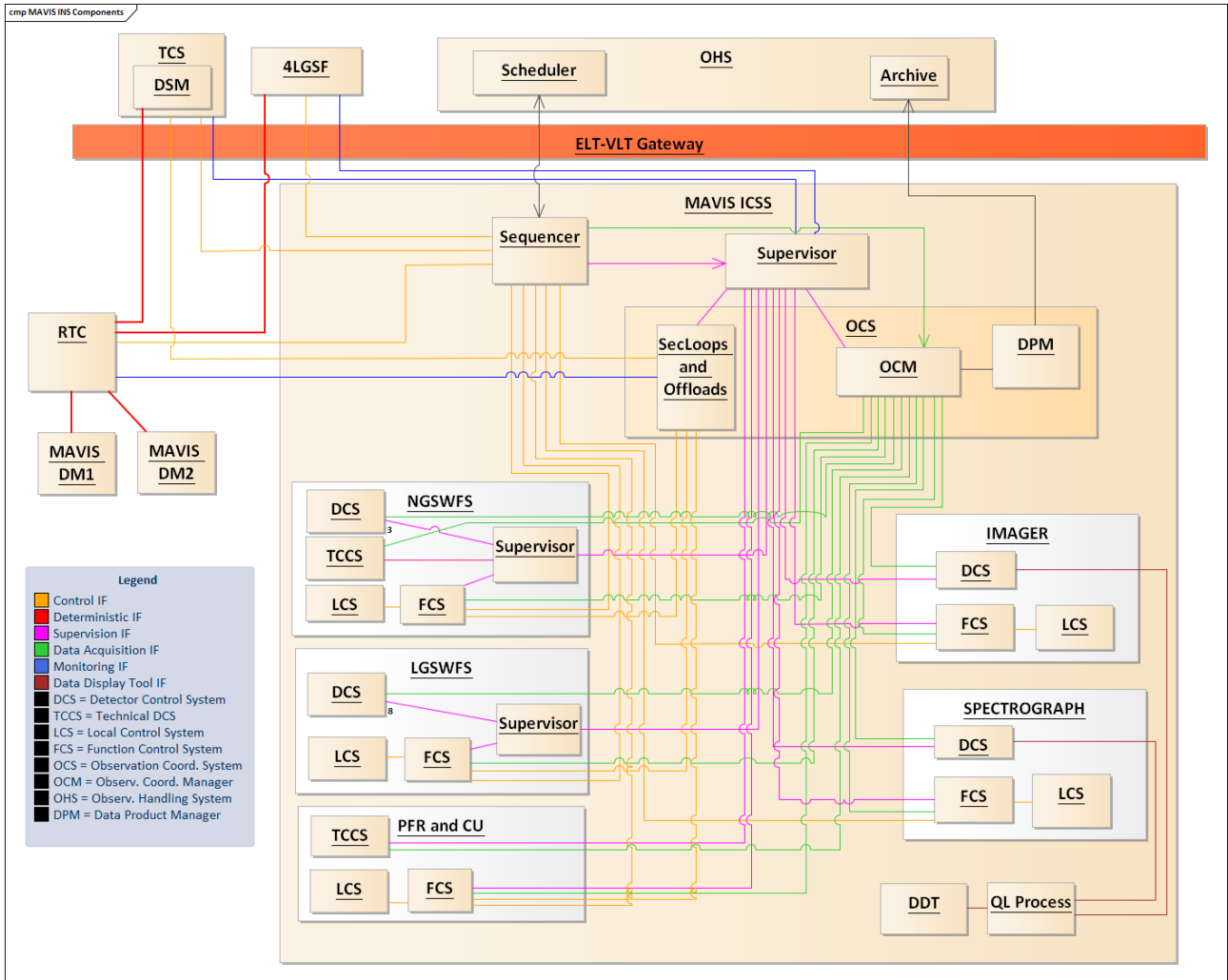


Figure 5. MAVIS Instrument Control Software architecture overview.

#### 4.1 Coordination software

The coordination software is composed of three main components, according to the current design of the ELT Observation Coordination Framework<sup>3</sup>: the Sequencer, the Supervisor and the Observation Coordination System (OCS).

The Sequencer is in charge of receiving the observing blocks from the Observation Handling subsystem (OHS) of the VLT Data Flow System. It orchestrates the observations by sending control commands in sequence to external (TCS and 4LGSF) and internal components (RTC, FCSs). The Sequencer interfaces with the Supervisor, the OCS and each device through the Function Control System<sup>4</sup> (FCS). All scripts interpreted by the Sequencer will be implemented in Python. The Supervisor is in charge to supervise the state of each component and of each sub-system.

The Observation Coordination System includes three components: the Observation Coordination Manager (OCM), the Data Product Manager (DPM) and the “SecLoops and Offloads” component. The coordination manager OCM coordinates the execution of the exposures, interfacing with each Detector Control System (DCS) and informing each FCS of the start/end of an exposure. OCM interfaces with the data providers and the Data Product Manager, which combines image files, produced by each DCS, with the metadata delivered by each subsystem and returns the produced output, in FITS format, to the Data Flow System. Finally, the “Secondary loops and offloads” process, based on the Guiding Manager of ESO Framework, receives periodically from RTC the corrections to be applied to a subset of actuators. It interfaces with the telescope and the NGSWFS probes (offloads) and with the PFR de-rotator and the LGS WFS focus device (secondary loops).

#### **4.2 Sub-system software**

The architecture of the five subsystems is similar. They include a FCS, which interfaces with the Local Control Units, and one or more DCS, which interface with WFSs and scientific cameras. The Local Control Units include the low-level software, which runs on Beckhoff PLCs.

In NGSWFS and “PFR and CU” a technical DCS will be present to control, respectively, an acquisition camera and a multi-purpose technical camera.

In the case of NGSWFS and LGSWFS a local Supervisor will supervise their state. This choice is motivated by the fact that these subsystems include more than one DCS, as there are three cameras in NGSWFS and eight LGSWFS.

#### **4.3 ELT-VLT Gateway**

MAVIS is a VLT instrument but MAVIS ICSS will be based on the SW framework for ELT. MAVIS ICSS will interface with external components (OHS, TCS, 4LGSF) which are running under VLTSW. A dedicated ELT-VLT gateway, provided by ESO, will enable the communication between the ELT communication layer (MAL) and the VLT one (CCS), allowing interoperation with the telescope and the AO facilities at Paranal. High-speed control (connections in red in Figure 5) will flow directly from the RTC to DSM/4LGSF.

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