THE INSTRUMENT CONTROL ELECTRONICS OF THE ESPRESSO SPECTROGRAPH @VLT

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Abstract

ESPRESSO, the Echelle SPectrograph for Rocky Exoplanet and Stable Spectroscopic Observations, is a super-stable Optical High Resolution Spectrograph for the Combined Coudé focus of the Very Large Telescope (VLT). It can be operated either as a single telescope instrument or as a multi-telescope facility, by collecting the light of up to four Unit Telescopes (UTs). From the Nasmyth focus of each UT the light is fed, through a set of optical elements (Coudé Train - CT), to the Front End Unit (FEU) which performs several functions, as image and pupil stabilization, inclusion of calibration light and refocusing. The light is then conveyed into the spectrograph fibers.

The whole process is handled by several electronically controlled devices. About 40 motorized stages, more than 90 sensors and several calibration lamps are controlled by the Instrument Control Electronics (ICE) and Software (ICS). The technology employed for the control of the ESPRESSO subsystems is PLC-based, with a distributed layout close to the functions to control. This paper illustrates the current status of the ESPRESSO ICE, showing the control architecture, the electrical cabinet's organization and the experiences gained during the development and assembly phase.

INTRODUCTION

ESPRESSO is the Echelle SPectrograph for Rocky Exoplanet and Stable Spectroscopic Observations that will be installed in the Combined Coudé Laboratory (CCL) of the ESO VLT. The main goals of ESPRESSO will be the measurement of high precision radial velocities of solar type stars for search for rocky planets, the measurement of the variation of the physical constants and the analysis of the chemical composition of stars in the nearby galaxies [1]. To reach these goals an extremely stable, accurate, efficient and high resolution spectrograph is required.

ESPRESSO will be able to operate either as a single telescope instrument or as a multi-telescope facility, collecting the light of up to four telescopes. In fact the light of each UT is fed from the Nasmyth focus, through a tunnel made up of optical elements (Coudé Train), to a Front End Unit (FEU) in the CCL of ESO VLT.

The ESPRESSO Instrument Control Electronics aims to control all moving parts that allow the light to follow that path and the lamps that calibrates the final spectrum, assuring also the safety of the instruments and people through a large number of sensors and alarms.

SYSTEM ARCHITECTURE

Each of the FEU four arms (see Figure 1) is composed by an Atmospheric Dispersion Corrector (ADC), a focus translational stage and a system that performs the field and pupil stabilization. The latter is composed by a set of piezo tip-tilt stages to modify the light path, two technical CCD (TCCD) and a neutral filter. The FEU provides, through a calibration slide, the means to inject the calibration light (white and spectral sources) into the spectrograph fiber when needed.
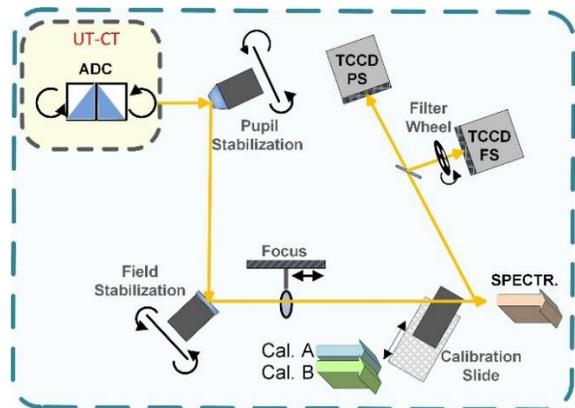

Figure 1: FEU functions in each of the four arms.

Moreover, the FEU provides a mode selector (see Figure 2) mounted on a rotary stage whose task is to feed the spectrograph fibers with the light coming from the selected telescopes and passing through the corresponding FEU arms in one of the specific instrument mode (single telescope High Resolution, single telescope Ultra High Resolution or multi telescope Medium Resolution).
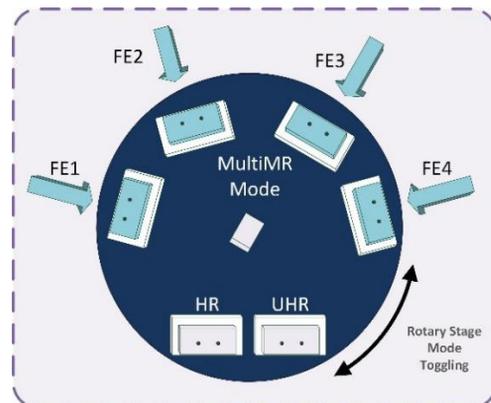

Figure 2: ESPRESSO mode selector.

Two fibers feed the spectrograph simultaneously: the target fiber and the sky/calibration fiber.

Finally, two ESO Next Generation Controllers (NGCs) control two scientific detectors: one for the red arm and one for the blue one.

ESPRESSO INSTRUMENT CONTROL SYSTEM

The control electronics of an instrument like ESPRESSO must satisfy a large number of requirements. It must be reliable, real time capable, accurate in motor positioning and must be easy to maintain on the long term. ESPRESSO ICE aims to satisfy these requirements using mainly COTS components and Beckhoff PLCs as control system [2].

In ESPRESSO the workload is divided between two Beckhoff CPUs (see Figure 3 and Figure 4). The first CPU purpose is to control all the FEU related functions while the second one manages the Thermal Control Systems, the Calibration Unit functions and the interface with the NGCs.

The Beckhoff CPUs used for ESPRESSO belong to the CX2030 series. An EK1100 bus coupler allows the EtherCAT fieldbus communication continuity among the different electronic sub-racks. The functional modules used for I/O and other tasks required by the instrument can be classified in four types:

- Digital I/O – for devices with discrete control signals and status output.
- Analog I/O – for devices with continuous control signals and status output and measurement devices.
- Communication Modules – for devices with high level interface (e.g. serial interface).
- Motion control modules – for the motorized functions.

ESPRESSO has 8 motorized functions for the ADCs, 14 stages in the FEU, and 8 in the calibration unit. All the motorized stages were chosen from the MICOS PI supplier and have a DC motor.

The Beckhoff modules selected for building the basic motion control block are:

- EL7342 - 2 channel DC motor output stage 50 V DC, 3.5 A.
- EL5101 - Incremental Encoder Interface.
- EL1084 - 4 Channel input, 24 VDC, switching to negative potential.
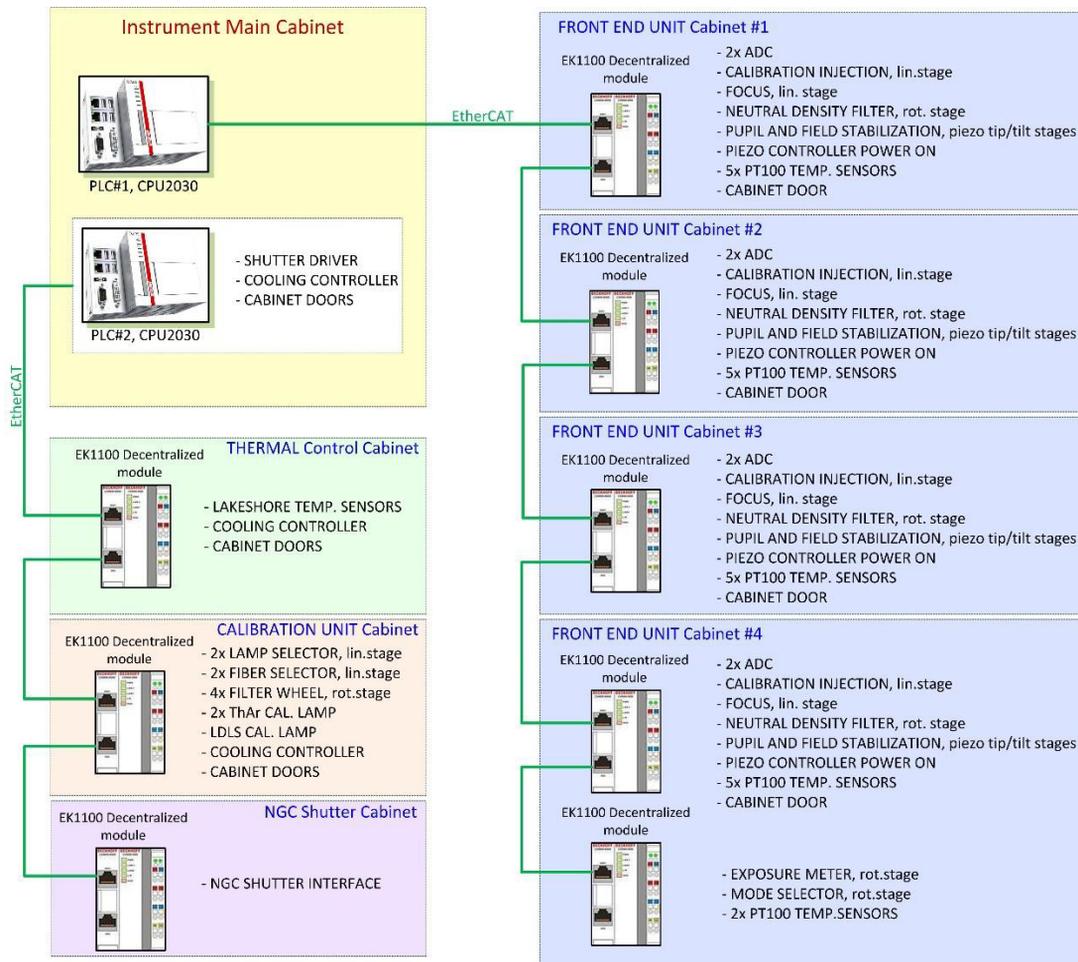

Figure 3: ESPRESSO functions overview.

The EL7342 is a full motor controller with included encoder interface but only its power output stage is being used because it is the one that better fits the requirements. The interface to the encoder is done with the ES5101, since it provides differential lines.

With this line-up of modules, both the velocity and position control loop must be implemented purely with software. The Beckhoff Motion Control (MC) subsystem provides all the necessary functions and it is already integrated in the programming environment. However there are some limitations. With this configuration only a P (Proportional) control loop for the position and a PI (with optional D (Derivative)) for the velocity control loop is possible. Tests have shown that if the velocity loop is well tuned, there are no problems with the position even if only the proportional term is used. Tests performed in the laboratory have also shown that some improvement can be gained by decreasing the cycle time of the motion control loop. It is set by default to a cycle time of 2 ms, but it can be easily changed to lower times. The counter-effect is an increase of the CPU load, but the proportional gain of the loops can then be increased providing a more responsive control without causing instability.

The tuning can be a tricky procedure, but the programing framework provides tools for monitoring and graphing the motor variables, including the current.

Figure 4: One of the main ESPRESSO PLC CPUs placed in a 19" sub-rack.

CONTROL ELECTRONICS HARDWARE LAYOUT

ESPRESSO CPUs will be hosted in the main ICE cabinet that will be placed in the CCL. In the same place the Thermal Control Cabinet, Calibration Unit Cabinet, Vacuum Cryo Control Cabinet and Fabry Pérot calibration light source will be hosted. These cabinets are 2000 mm high, 800 mm deep and 600 mm wide.

The cabinets are of Schroff Varistar LHX3 type. This variant includes a radial fan and heat exchanger and provides an optimum airflow for cooling of the equipment.

The four Front End Unit Cabinets are only 1200 mm high (see Figure 5) and will instead be placed near each FEU arm. They are equipped with a simpler cooling system. All the cabinets are mounted on a special custom made damper feet to reduce the effects of earthquakes.
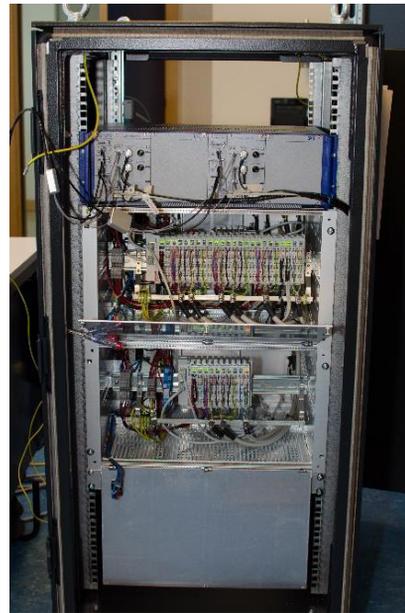

Figure 5: FEU #4 cabinet.

All the PLC CPUs and modules are mounted in 19" sub-racks, similar to those used for the VME crates, as shown in Figure 4. A custom fixture was made to provide support for two standard DIN rails, one facing the front and one facing the back, on which the components were mounted. This is an unusual configuration for PLC, but it was chosen as the best compromise to make them fit in the 19" cabinets. The use of 19" cabinets is due to the presence of other equipment available only in this format. This solution offers some benefits, like the possibility to remove the whole crate from the system for easier maintenance, but the space occupation is not optimal.

Due to the same mechanical composition of each of the four FEU arms, the FEU electronics cabinets will be identical (containing, in addition to the PLC modules, also the piezo tip-tilt controllers) except for the fourth one. This cabinet will host also an additional 19" sub-rack with the PLC modules for the control of the exposure meter stage and sensors and the mode selector rotary stage (see Figure 5).

In the main cabinet, besides the CPU sub-racks, the shutters drivers, a 12" touch panel, a SELCO control alarm annunciator and the network switch will also be hosted.

SOFTWARE SUPPORT

ESPRESSO uses OPC-UA for the communication between the software components running on the PLC and the instrument control workstation [3][4]. During the development and testing phase the use of the OPC-UA protocol [5] proved to be useful since the process variables could be examined and set-up by using commercial OPC-UA clients like Unified Automation UAExpert or Softing OPC client [6]. In this way the PLC software components could be tested without the intervention of the instrument workstation, allowing for a better debugging.

Moreover, the Beckhoff programming environment provides the possibility to build Graphical User Interfaces that can run either on the programming system or on the target CPU. The former possibility was exploited during the initial debugging and testing phase while the latter will be used in the production environment for maintenance and troubleshooting by providing the touch panel connected to the CPU residing in the main instrument control cabinet.

The Beckhoff PLC runtime can runs both on PLCs, and standard desktop PCs which can be used if equipped with a specific network card that acts as an EtherCAT master. While this might not be the best choice in a production environment, it proved to be very useful since the ESPRESSO assembling phase is performed in different sites. The single subsystems could be driven and tested without the need to ship the CPUs at the remote sites and were instead driven by the PCs that were also serving as the programming system.

ASSEMBLING AND TESTING PROCEDURE

The mounting of all the electronics cabinets and sub-racks of ESPRESSO is being done at various sites of the institutes participating to the instrument. Once all the hardware is ready it is fully tested with the instrument control software. The first testing and acceptance procedure occurs at the site where the cabinets are mounted. The FEU electronics is sent to the observatory of Merate (Milano) to be tested also with the fully mounted and aligned optomechanical parts of the FEU subsystem. All the electronic cabinets will be then sent to Genève for the European integration and acceptance. After a successful test of the electrical cabinets and all the devices, all the equipment will be delivered to the Paranal Observatory in Chile for the final integration.

CONCLUSION

The sensors, calibration lamps and moving parts of an astronomical instrument like ESPRESSO for the ESO@VLT needs a flexible, precise in positioning and easy to maintain in the long term control electronics.

For ESPRESSO spectrograph COTS components with a Beckhoff PLC-based control electronics are used.

The Beckhoff PLC decentralization features are fully exploited thanks to the distribution of the electronics sub-racks in different electronics cabinets placed each near the FEU functions to control.

The PLC modules are placed in 19'' sub-racks, which may be a disadvantage in term of space occupation but it foresees very high maintainability features.

Schroff electrical cabinet supplier represented the best choice in term of wide selection of cabinet components, ensuring, in the water cooled Varistar LHX3 chosen for ESPRESSO, also a good air flow circulation inside the cabinet.

These cabinets are also earthquake resistant, an essential condition in a highly seismic territory like the Atacama desert.

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