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TELESCOPE CONTROL SYSTEM OF THE ASTRI SST-2M PROTOTYPE FOR THE CHERENKOV TELESCOPE ARRAY

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Abstract

The ASTRI SST-2M telescope is an end-to-end prototype [1], installed on Mount Etna (Italy), proposed for the Small Size class of Telescopes of the future Cherenkov Telescope Array (CTA) [2]. The ASTRI prototype adopts innovative solutions for the optical system [3], which poses stringent requirements in the design and development of the Telescope Control System (TCS), whose task is the coordination of the telescope devices, performing of the observational functionalities and the maintenance, test and calibration activities.

In this contribution we plan to highlight how the ASTRI approach for the design, development and implementation of the Telescope Control System has made the ASTRI SST-2M prototype a stand-alone, intelligent and active machine, able to efficiently perform all the required engineering and operative functionalities, to receive commands, transmit monitoring data and eventually recover errors.

Furthermore, the ASTRI approach provides for a Telescope Control Software that can easily be integrated in an array configuration: a first set of nine ASTRI telescopes is planned to be produced for early implementation on the southern CTA site.

INTRODUCTION

The ASTRI Software, named Mini-Array Software System (MASS) has the task of making it possible to operate the ASTRI telescopes under the constrains and requirements defined by CTA, even in the case of the ASTRI SST-2M prototype.

The MASS package provides a set of tools able to manage all on-site operations: perform the observations specified in the short-term schedule, analyse the resulting data, store/retrieve all the data products to/from the on-site repository, as well as perform engineering, maintenance and calibration activities. The general architecture of MASS software, grouped in a control hierarchy is sketched in Figure 1. Starting from the bottom, the Local Control group contains all the software components related to monitor and control the hardware on board the telescope and the auxiliary devices, together with the infrastructure and power assemblies. The hardware controllers are managed and coordinated at the higher level by the Device Control software group, through the Open Platform Communications Unified Architecture (OPC-UA) protocol [4], which supports rich data model while offering high compatibility with the Programmable Logic Controller (PLC) platform.

At the highest level the Operator Control System (OCS) provides all the services necessary for the observations and manages the data flow from the telescope control system to the data repositories.

TELESCOPE CONTROL SOFTWARE

The Telescope Control package (grey boxes in Figure 1) includes low and high-level software components dedicated to:

1. Monitoring and control of the hardware devices onboard the telescope and of the auxiliary assemblies (e.g. weather station, all sky camera, sky quality meters), together with the managing of safety standard functionalities.
2. Coordinated execution, based on the Use-Cases defined [5], of the functionalities provided by Local controllers in order to perform scientific observations, tests and engineering actions.
3. Error handling and fault conditions recovery.

Every software component of the ASTRI telescope is developed using the state machine approach: any telescope device is conceived as an abstract machine that can be in one of a finite number of states. A particular state machine is defined by the list of its states, and the triggering condition for each transition. In this way every telescope device can perform a predetermined sequence of actions autonomously. So, starting from the low-level and going to the higher levels, all the states are logically assembled together in order to form the final telescope state machine, as shown in Figure 2.

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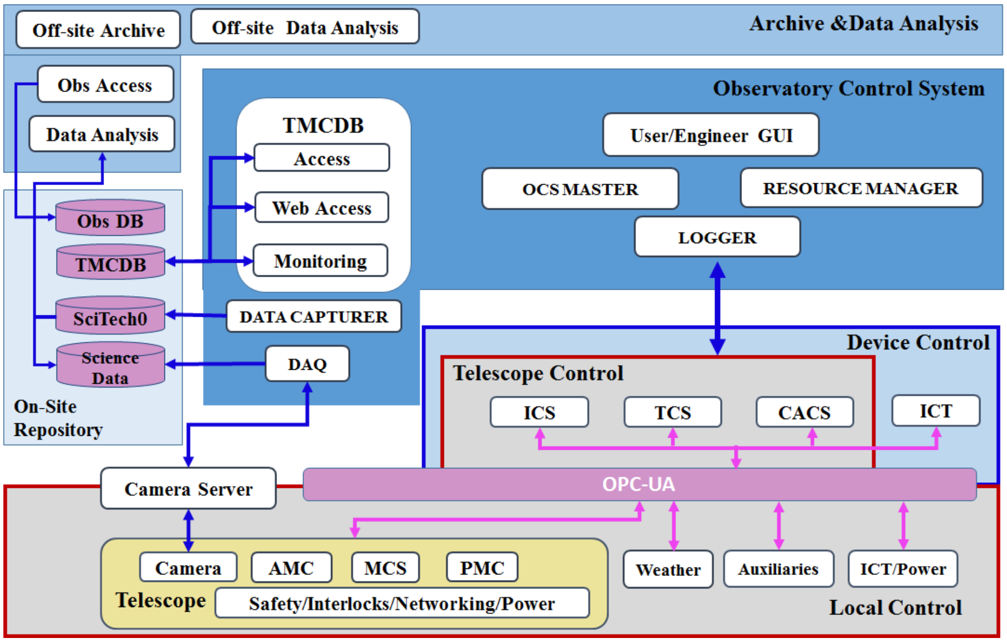

Figure 1: ASTRI SST-2M Control Software (MASS) architecture.

The OPC-UA is the interface protocol chosen between the high-level control software and all the hardware assemblies. The low-level functions of the telescope, together with the Safety logic chain, are implemented via PC-Based PLCs technology, using the Beckhoff TwinCAT 3 platform, which provides direct access via the OPC-UA protocol [6].

The Device Control and the OCS group components are implemented upon the same software frameworks chosen for the CTA high-level control functions [7]: the ALMA Common Software (ACS) middleware [8], which provides common ways to access the hardware, such as OPC-UA protocol, together with monitoring, alarm, and logging services support. Thus, the use of OPC-UA allows the decoupling of the access peculiarities of each assembly with the hardware control systems.

Each interface with a hardware component accessed via OPC-UA is described by an Interface Control Document (ICD). In ASTRI these ICDs take the form of tables in which each row is a command of four different types: monitoring points (GET), configuration points (SET), functional execution commands (CMD) and state transition commands (MODE).

For each control or monitoring point a complete description of the information required, e.g. data type, OPC-UA node, connected alarms, is provided.

We use the ICD format not only to document the interface, but also to help the developers in the task of producing all the support code that depends on non-device-specific logic, via a code generator. The ASTRI code generator is implemented in a few Python scripts and the output is depicted in Figure 3. Each high-level ACS assembly components is thus generated for hardware ICDs with a set of templates to control the assemblies together with simple simulators at the OPC-UA level and engineering user interfaces to test them.

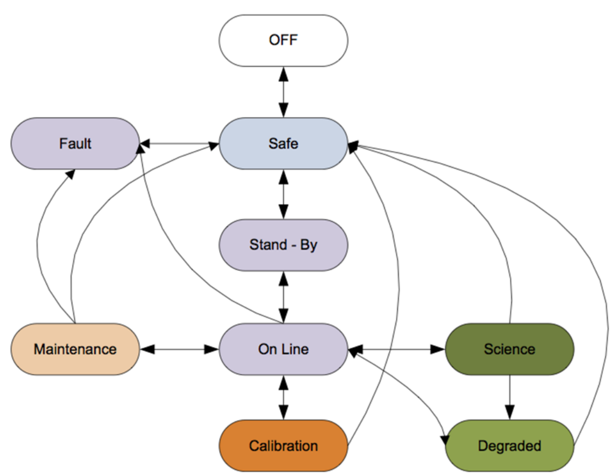

Figure 2: ASTRI SST-2M general State Machine.

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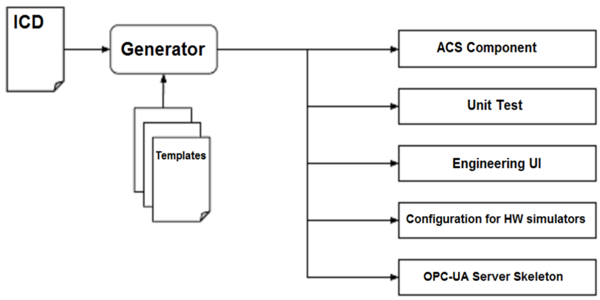

Figure 3: MASS code generation workflow.

Low-level Controllers

The ASTRI SST-2M prototype is composed of a complex set of devices and the Local Control systems are responsible to provide the functionalities needed for normal operations, testing, maintenance and calibration activities.

The controllers have to be able to execute commands received from external controllers (ACS components or Graphical User Interface) and providing access to the monitoring.

The Local Control components developed, associated to the related subsystems are:

- The Mount Control System (MCS), which is responsible for the motion of the Mechanical structure (including the kinematic chains and the drives), together with the start-up and shut down procedures [9].
- The Active Mirror Control (AMC), responsible for controlling of the position and tilt of the primary and secondary mirrors.
- The Cherenkov Camera detection [10].
- Interlocks logic chain and Safety functions, together with the health and telescope power consumption monitoring.
- The auxiliary instrumentation dedicated to the calibration purposes e.g. Pointing Monitor Camera (PMC), Sky Quality Meter (SQM) and weather station [11].

The optical assembly and the MCS are managed by a PC-based PLC technology, whose electronics of control, based on EtherCAT[1] communication protocol, have been chosen in order to maximize the homogeneity and the real-time performance of the system. Both the electronics and software PLC are provided by Beckhoff automation company, which provides the TwinCAT 3 development environment with an OPC-UA compatible server/client functionality.

The other assemblies of the telescope are controlled directly through dedicated OPC-UA servers developed in-house, written in Java using the Prosys OPC-UA SDK.

Thanks to the architecture, design and technology chosen, all devices on-board the telescope are managed independently by the related controllers and all the control software packages can be easily integrated into the high-level controllers in a consistent, future-proof and straight-forward way through the OPC-UA protocol.

High-level Controllers

The ASTRI approach is to conceive the telescope as a stand-alone system able to manage all the primary functions needed to acquire a celestial source starting from a minimal set of input parameters (e.g. coordinates of the target). In this way the high level software should be concerned only with the business logic and not with the details of the hardware operations. Thus, any of the components of the Control Device or OCS does not include direct control of any ASTRI hardware, and is not responsible for any time-critical operations [12]. All real time functions are performed at the PLC or Local Control level.

The software components related to the Telescope control are briefly described below.

Telescope Control System (TCS) Coordinates the motion of the Telescope (MCS) and the active optic system (AMC) in order to perform a pointing or tracking and to obtain a stable image for the Camera. It is also in charge of monitoring and controlling thermal loads, the Health and Safety status of the prototype, triggering the power on/off of the devices and performing the procedures based on the failure/alarm situations of the devices.

Instrument Control System (ICS) Will oversee all monitoring and control operations of the ASTRI camera (configuration, command, housekeeping). On the monitoring side, the software continuously analyses the internal environmental parameters (temperatures, humidity, voltages, currents) and automatically takes suitable steps to ensure that we continue to operate in safe conditions. On the control side, it allows the user to manage all the camera functions.

Calibration Auxiliaries Control System (CACS) The calibration subsystem includes all the components dedicated to the monitoring of site conditions, both for safety and calibration. It comprises a weather station, an all sky camera, a sky quality monitor, and other sensors.

Information and Communication Technology (ICT) The MASS control system runs over a plethora of servers and network appliances [13]. We plan to integrate ICT monitoring together with the general monitoring and alarm systems to provide the operator with a view of the telescope array that includes the ICT hardware.

Graphical User Interface

The full access to the capabilities of the ASTRI SST-2M prototype is provided by a dedicated Graphical User Interface (GUI), contained in the OCS block of Figure 1.

The ASTRI GUI exploits directly the ACS components in order to operate the Telescope. As shown in Figure 3 for each assembly the code generator creates a specific engineering UI, that gives access to all the functions described in the related ICD. The GUI uses JavaFX in a usual Model-View-Controller pattern. The View is defined in FXML, an XML-based language that provides the structure of the user interface. The Controller is a Java class implementing the necessary logic while the Model is a local

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stub for the remote ACS component. The generated GUI is a complete way to access all the hardware functions, locally or remote.

The GUI provides to an ASTRI user the possibility to perform scientific operations and also represents an easy interface for the engineering tests, calibration and maintenance activities.

The Main panel of the ASTRI GUI, reported in Figure 4, allows the monitoring and control of the whole telescope at glance. From the monitoring point of view the Main panel shows the time and site related quantities, provides

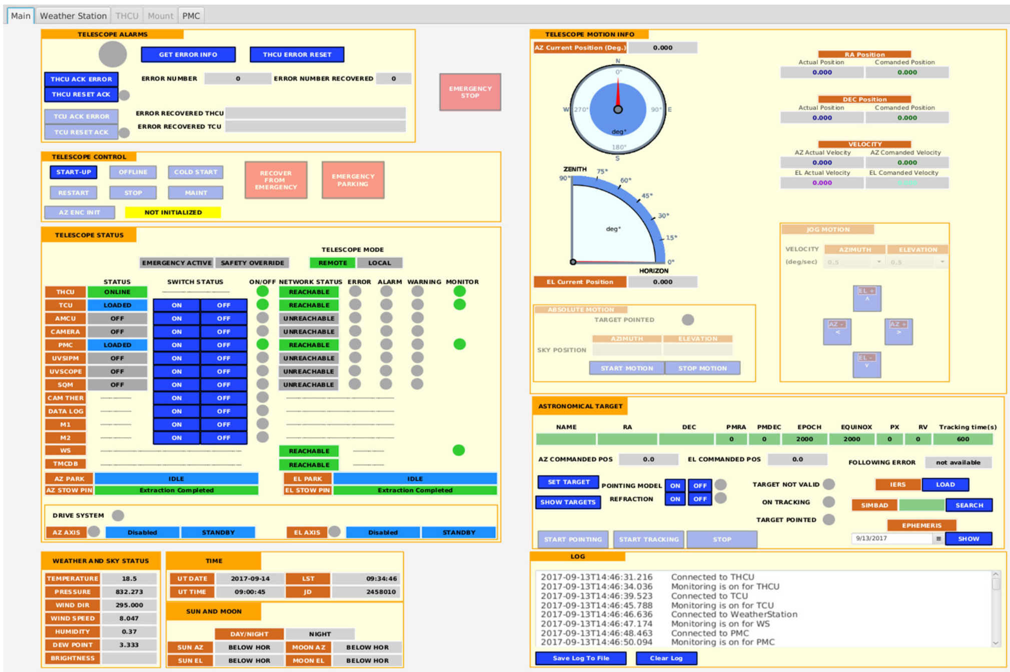

Figure 4: ASTRI SST-2M User/Engineering GUI. Main Panel.

motion information (axes positions, velocities, accelerations), shows the states of sub-devices, and alerts the user for emergency or alarm/warning situations.

From the control side it provides access for automatics start-up and shut-down procedures and to commands for the point to point or velocity motion of the axes. The Main tab allows for easy pointing and tracking of a source simply inserting the coordinates or by selecting a target from a list of objects.Targets can also be selected with an online research in the SIMBAD Astronomical Database and checked for time visibility at the site with a call to the Staralt web site in the SIMBAD panel.

In addition to the Main Panel, several dedicated panels (secure locked) give access to other functionalities specifically available for the maintenance and engineering purposes.

STORAGE AND DATA REDUCTION

The storage of the ASTRI scientific and engineering data is managed by some of the ACS components contained in the OCS block.

The engineering data, defined in the ICDs of the hardware sub-devices as "*to be archived*", are retrieved by the Telescope Monitoring Configuration Data Base (TMCDB) -Monitoring component from the TCS and stored in a dedicated on-site repository (TMCDB). The engineering information contained in the TMCDB can be accessed by the Access-ACS component or through a dedicated Web application.

The Scientific data sets made available by the Camera operations, are managed by the Data Acquisition (DAQ) system, installed in the camera server. The DAQ component is able to acquire the camera data, store them in a dedicated on-site repository and display them either for the Assembly, Integration and Verification/Test or operation phases [14].

While the standard ACS services are used to give access to a configuration database and collect monitoring data for engineering purposes, a new component, the so called Data Capturer, was developed to serve as the connection point with the science-oriented output data. This component acquires and stores, in a specific on-site repository, all the metadata of interest such as the telescope pointing or the weather information that are necessary for the off-site scientific analysis together with scientific data from the Camera that pass through the DAQ system.

Since the on-site archive is expected to be responsible only for buffering data, an off-site scientific archive is provided for later analysis and validation. The off-site archive system allows the data access at different user-levels and for different use-cases, each one with a customized data organization [15].

As an end-to-end prototype, besides all hardware and control software systems, the ASTRI project includes a

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software package (ASTRI data reconstruction and scientific analysis software) for the data processing chain. The data handling systems provides a series of tools, developed using C++/python languages, to perform the complete data reduction, from the raw data detected by the Camera to the final scientific product.

CURRENT STATUS AND SUMMARY

The MASS software components presented in this paper, which provide for the scientific/engineering operation of the telescope, have been successfully integrated and the package is currently installed at the telescope site (version V.0.2.0 has been released on July 2017) [16].

The ASTRI SST-2M has already passed the mechanical commissioning and optical validation stages [17] and it is currently undergoing the scientific verification stage. The first Cherenkov events have been successfully acquired in May 2017 [18] and another run for data taking is foreseen starting from fall 2017.

All of these results were obtained by using the MASS software package implemented up to now and thus represent a good validation of the whole software architecture designed and developed.

In the ASTRI approach the Telescope Control System is the component in charge of the complete coordination and management of the telescope for scientific and engineering functionalities developed at low level for the specific subdevices, while the OCS is the software group dedicated to the user operation of the telescope (GUI), data storage and schedule management. In this paper we showed how the ASTRI architecture provides for the TCS to be completely independent from the OCS, making the low-level hardware controllers completely transparent to the GUI.

In this way the Telescope, from a software point of view, can be seen as a robotic and stand-alone machine, able to be fully operated by any other high-level controller which is ACS/OPC-UA compatible, simply excluding the OCS part of the MASS and defining a specific interface.

This separation provides an easy and efficient way for the integration of the prototype in the high-level control software system of the ASTRI telescopes, under array configuration as proposed for CTA.

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