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ABSTRACT

The ASTRI mini-array, composed of nine small-size dual-mirror (SST-2M) telescopes, has been proposed to be installed at the southern site of the Cherenkov Telescope Array (CTA), as a set of pre-production units of the CTA observatory. The ASTRI mini-array is a collaborative and international effort carried out by Italy, Brazil and South-Africa and led by the Italian National Institute of Astrophysics, INAF. We present the main features of the current implementation of the Mini-Array Software System (MASS) now in use for the activities of the ASTRI SST-2M telescope prototype located at the INAF observing station on Mt. Etna, Italy and the characteristics that make it a prototype for the CTA control software system. CTA Data Management (CTA-DATA) and CTA Array Control and Data Acquisition (CTA-ACTL) requirements and guidelines as well as the ASTRI use cases were considered in the MASS design, most of its features are derived from the Atacama Large Millimeter/sub-millimeter Array Control software. The MASS will provide a set of tools to manage all on-site

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operations of the ASTRI mini-array in order to perform the observations specified in the short-term schedule (including monitoring and controlling all the hardware components of each telescope and calibration device), to analyze the acquired data online and to store/retrieve all the data products to/from the on-site repository.

Keywords: Imaging Atmospheric Cherenkov Telescope, Telescope System Software, CTA, ASTRI, MASS

1. INTRODUCTION

The ASTRI mini-array is a collaborative and international effort carried out by Italy, Brazil and South-Africa and led by the Italian National Institute of Astrophysics, INAF. The goal of the project is to design, produce and propose to install nine ASTRI SST-2M telescopes at the southern site of the Cherenkov Telescope Array (CTA).[1] A first telescope prototype is now in operation at the INAF observing station in Serra La Nave on Mount Etna (Italy). The ASTRI SST-2M prototype is designed to be an end-to-end system compliant with the requirements and guidelines provided by CTA. To achieve this, industrial standards, proven technologies and best practices have been employed.

In the framework of the ASTRI mini-array project the task of the Mini-Array Software System (MASS) is to support 1) observations with the telescopes and analyzing the resulting data, as well as 2) engineering operations.[2]

2. MASS DESIGN

The main MASS components, which implement the required scenarios,[3] are depicted in Fig. 1. Telescope hardware is locally controlled, with each assembly responsible for its own safety. The assemblies are grouped in a control hierarchy, in which each parent relays the commands to its children. At the highest level the Operator Control System (OCS) provides all the common services necessary for observations and the Data Handling System (DHS) manages the data flow from the control system to the data repositories.

After the prototype phase for CTA the telescope teams are still expected to provide integration-ready local control devices and the low level control device components, while the CTA Array Control (ACTL) working group will provide the higher level control functions.[4]

3. MASS IMPLEMENTATION

MASS software is being developed upon the same software frameworks chosen for the whole of CTA: the ALMA Common Software (ACS) and the OPC Unified Architecture (OPC-UA). ACS middleware was developed for the Atacama Large Millimeter Array project; it features a distributed component model based on the Common Object Request Broker Architecture (CORBA)[5] and it is available under the GNU LGPL license. ACS provides common ways to access the hardware, together with monitoring, alarm, and logging services support. In the top-level design we have defined the ACS components and their interfaces.[6]

The OPC-UA protocol was chosen for the interface between the higher level control software and all the hardware assemblies. OPC-UA is a multi-vendor, platform independent, industrial interoperability standard.[7] The use of OPC-UA allows the decoupling of the access peculiarities of each assembly with the above control system. In the ASTRI SST-2M prototype the low-level functions of the Telescope Control Unit (TCU), the Telescope Health Control Unit (THCU) and the Active Mirror Control Unit (AMCU) are implemented via software Programmable Logic Controllers (PLCs) that use the Beckhoff Twincat platform to directly support access via the OPC-UA protocol. Access to the camera, weather station and other assemblies takes place instead via dedicated OPC-UA servers developed in-house, written in Java using the Prosys OPC UA SDK.

For control, each ASTRI assembly implements a finite state machine; Fig. 2 displays the Camera one.

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:

GET commands represent sensor monitoring points.

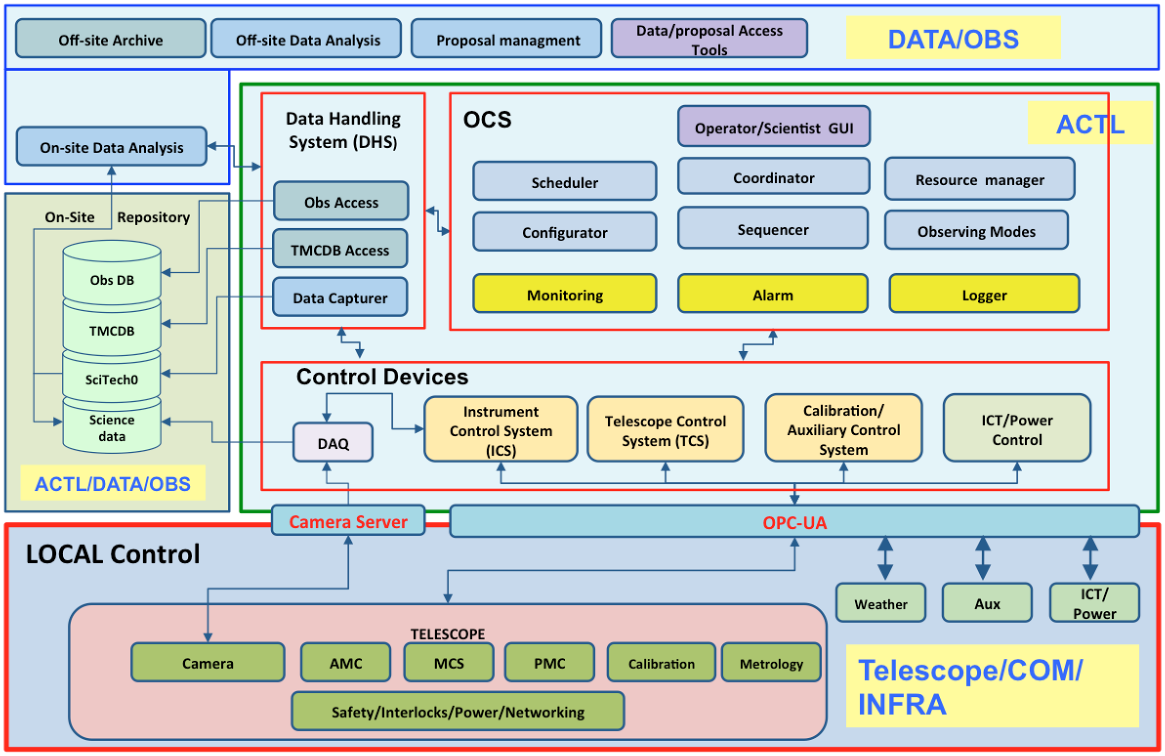

Figure 1. The main components of MASS: in the local control group we have the local control of the hardware assemblies, in the control devices group the main subsystems that implements the logic for control and monitoring, the OCS includes all the high level control functions, and the DHS manages of all the data produced. Also the archives and off-site facilities are depicted.

SET commands are read/write variables for configuration and parameters.

CMD commands are proper commands.

MODE commands are used to request state transitions.

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 leverage code generation to help the developers in the repetitive task of producing all the support code that depends on non-device-specific logic. As depicted in Fig. 3, for MASS we are generating the low level ACS assembly components with their own complete engineering UIs and configurations for hardware simulators at the OPC-UA level.

3.1 MASS CONTROL SUBSYSTEMS

3.1.1 Instrument control software system

The ASTRI Instrument Control Software (ICS) oversees all monitoring and control operations of the ASTRI camera (configuration, command, housekeeping).[8] As described in Fig. 4, the ICS is split internally into several independent functional blocks that communicate with each other, and provide an interface to interact with the other systems.[9] On the monitoring side, the software continuously analyzes the internal environmental parameters such as 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. In order to meet all these requirements, an appropriate command set for the camera system was

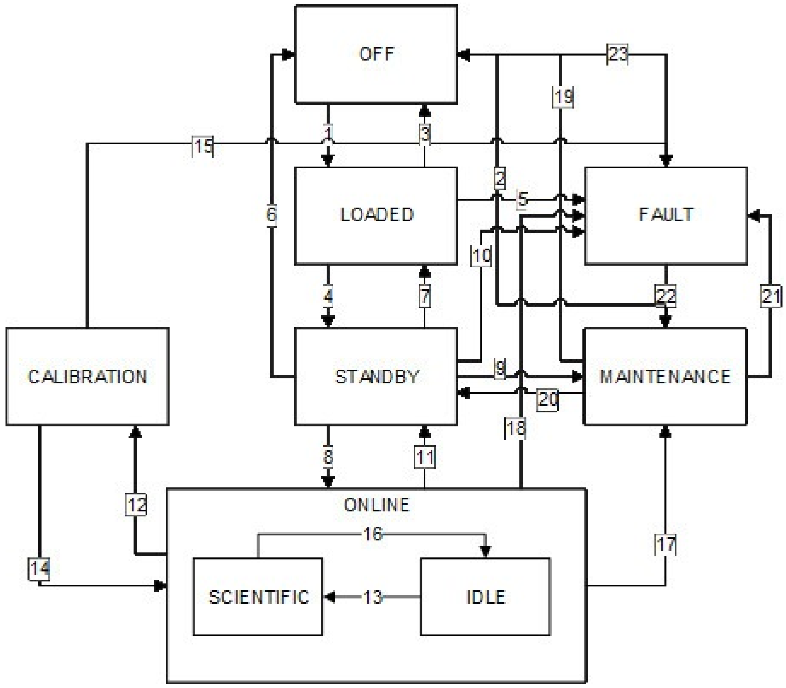

Figure 2. ASTRI camera finite state machine. Each number in the figure identifies a transition from a defined state to another, e.g. (1) Power on, (4) Init, (8) Start.

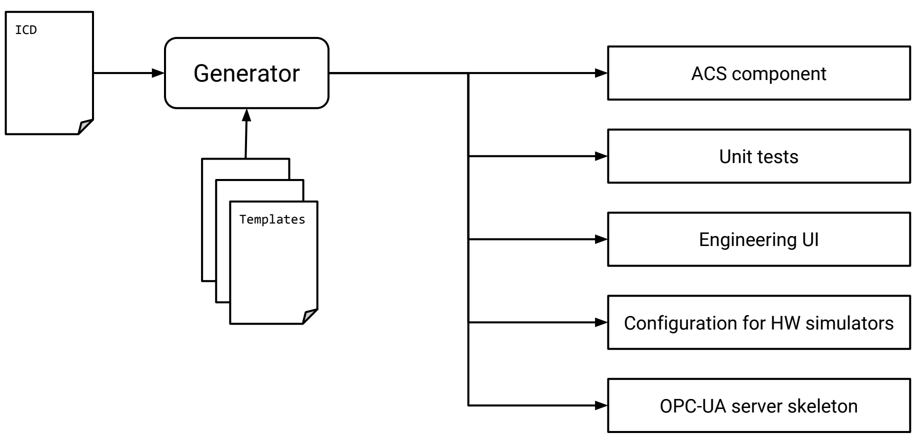

Figure 3. MASS code generation workflow. The code generator generates from hardware ICDs and a set of templates the ACS components for control of the assemblies together with simple simulators and engineering user interfaces to test them.

defined in the ICD. As for other subsystems during the course of operations the camera can switch from one state to another according to well-defined sequences, as per Fig. 2.

3.1.2 Telescope control system

The Telescope Control System (TCS) coordinates both the Mount Control System (MCS) and the Active Mirror Control system (AMC) in the task of pointing and obtaining a stable image for the Camera.[10] The command and monitoring are implemented as ACS components, while the real time functions are delegated to the Telescope Control Unit (TCU)[11] and the Active Mirror Control Unit (AMCU),[12] which are implemented as software PLCs.

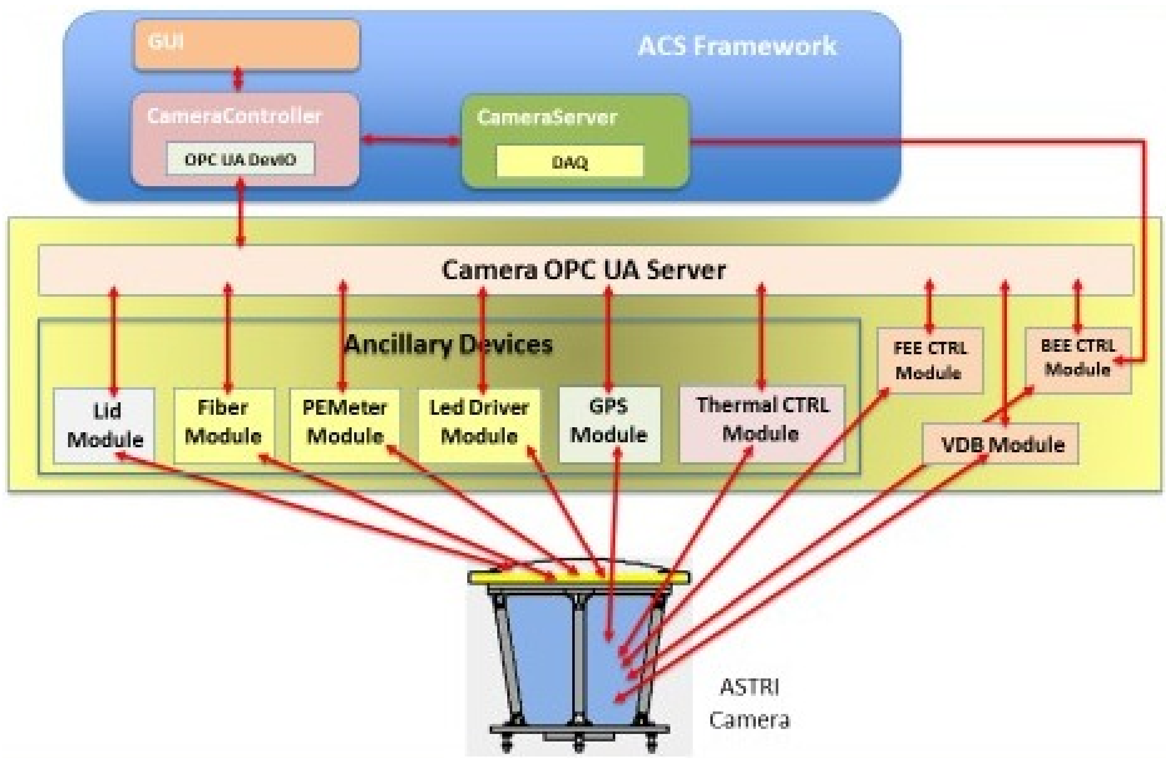

Figure 4. A view of the ASTRI camera system showing its internal components and the separate control and data links.

3.1.3 Data acquisition system

The Data Acquisition (DAQ) system, installed in the camera server for the ASTRI SST-2M, acquires, stores and displays camera data[13] either for the Assembly, Integration and Verification/Test or operation phases. The camera server design has been updated for the specific mini-array requirements: data acquisition, buffering, timestamping, mono-muons and stereo-trigger event preselection. If needed, other pre-processing components will be taken into account.[14]

3.1.4 Data handling system

The Data Handling System (DHS) is responsible for on-site processing of all the data produced and the delivery of data to the off-site archive, procedures that in the CTA project are under responsability of the CTA-DATA working group.[15–17] While the standard ACS services are used to give access to a configuration database and collect monitoring data for engineering purposes, a new component was developed to serve as the connection point with the science-oriented output data. Inspired by a similar component in ALMA, this Data Capturer component acquires all the metadata of interest such as the telescope pointing or the weather information that are necessary for the scientific analysis together with scientific data from the camera that pass through the DAQ system.

3.1.5 Calibration and auxiliary system

The calibration subsystem includes all the components dedicated to the monitoring of site conditions, both for safety and calibration.[18] It comprises a weather station, an all sky camera, a sky quality monitor, and other sensors. They provide essential monitoring and input for MASS and are integrated in the MASS work flow via their own OPC-UA servers and ACS components.

3.1.6 ICT monitoring system

The MASS control system runs over a plethora of servers and network appliances.[19] 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. We are using the ASTRI prototype as a test bed, leveraging our experience with OPC-UA to integrate within MASS the Internet Control Message Protocol (ICMP) and Simple Network Management Protocol (SNMP) monitoring support for all the deployed hardware at Serra La Nave.[20]

3.1.7 User interface

It is possible and desirable to directly command each ACS assembly component via Python scripting, but we also developed engineering graphical interfaces for the hardware engineer and the telescope operator at Serra La Nave. As described in Section 3, for each assembly we are generating a specific engineering UI that gives access to all the functions described in the ICD for test and maintenance. As the use of these complete engineering UIs could be too cumbersome for the day-to-day operations we designed an integrated GUI as well, from which the operator can access the main functions necessary for ordinary telescope operations. In this integrated version of the GUI we have worked to make the management and monitoring of data and commands to the telescope operators efficient and intuitive, following SCADA (Supervisory Control And Data Acquisition) standards for the electronic instrumentation.[21] The interface has been divided into several views. The main one, visible in Fig. 5, allows a general monitoring and control of the most important functions of the telescope, while in others, each specific to each individual component, the operator can act on the particular functions of the single device. Using the GUI an operator in Serra La Nave can point the ASTRI SST-2M prototype, monitor its operations and keep track of system alarms and faults.

Figure 5. ASTRI Engineering GUI main view. This view allows the operator the control and monitoring of the most important functions of the telescope.

4. CONCLUSIONS

The MASS software leverages industrial standards, existing project experience and open source software to meet ASTRI and CTA requirements. Now deployed at Serra La Nave for the ASTRI SST-2M prototype operations, it will also be a convenient testbed for all the updates necessary to support the ASTRI mini-array definition and development.

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