The Software Quality Assurance programme of the ASTRI Mini-Array project

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Abstract. The ASTRI Mini-Array is a gamma-ray project led by Istituto Nazionale di Astrofisica with the partnership of the Instituto de Astrofisica de Canarias, Fundacion Galileo Galilei, Universidade de Sao Paulo (Brazil), North-West University (South Africa) and the University of Geneve. The ASTRI Mini-Array consists of nine innovative Imaging Atmospheric Cherenkov Telescopes that are being installed at the Teide Astronomical Observatory (~2400 m a.s.l.) in Tenerife (Canary Islands, Spain). The ASTRI Mini-Array software will cover the entire life cycle of the project, including scheduling, operations and data dissemination. The on-site control software will allow the operator to communicate remotely to the array (including automated reaction to critical environmental conditions). Due to the high-speed (10 Gbit/s) networking connection available between Canary Islands and Italy, all data will be delivered every night to the ASTRI Data Centre in Rome for their processing and dissemination. The ASTRI team made experience with ASTRI-Horn, the first Italian dual-mirror Cherenkov telescope, prototype of the ASTRI Mini-Array project. Exploiting lessons learned from ASTRI-Horn, we decided to adopt an iterative incremental model for the software development in order to provide more software releases according to the project schedule. We have implemented a Quality Assurance (QA) programme specific for the software, which defines the strategy and the organization for the management of the quality control. In this contribution we present the layout and the contents of the ASTRI Mini-Array QA software programme, describing the organization adopted for its management and reporting some examples of how it has been applied so far.

1. Introduction

The ASTRI Mini-Array is a project led by the Italian National Institute for Astrophysics (INAF) aiming at constructing and operating an array of nine innovative Imaging Atmospheric Cherenkov Telescopes (IACTs), to study very high energy astronomical sources emitting in the TeV spectral band [1]. The ASTRI telescopes are characterized by innovative technological solutions, such as the dual-mirror Schwarzschild-Couder optical configuration [2], a modular, light and compact focal-plane camera consisting of an array of multi-pixel silicon photo-multiplier sensors [3], and an efficient and fast front-end electronics, specifically designed for ASTRI [4]. The telescopes of the ASTRI Mini-Array are an evolution of the dual-mirror ASTRI-Horn telescope [5], installed on the slopes of Mount Etna, Italy, at the INAF "M.C. Fracastoro" observing station [6]. After the optical validation [7] and the first detection of the Cherenkov light in May 2017 [8], ASTRI-Horn successful observed the Crab Nebula in December 2018 [9]. With respect to ASTRI-Horn, the telescopes of ASTRI Mini-Array implement a larger field of view, are equipped with the updated version of the compact Cherenkov camera and its read-out electronics, and include an optical photon detection module for performing intensity interferometry observations. The nine telescopes are being installed at the Teide Astronomical Observatory, operated by the Instituto de Astrofisica de Canarias (IAC), on Mount Teide (~2400 m a.s.l.) in Tenerife (Canary Islands, Spain). The ASTRI Mini-Array will be operated by INAF on the basis of a host agreement with IAC. The experience gained during the development of ASTRI-Horn has led us to recognize the benefit of a clear and well-defined Product Assurance (PA) strategy. The ASTRI Mini-Array Software System (MASS) manages observing projects, observation handling, remote array control and monitoring, data acquisition, archiving, processing and simulations of the Cherenkov and Intensity Interferometry observations, including science tools for the scientific exploitation of the ASTRI Mini-Array data. Therefore, at the beginning of the ASTRI Mini-Array project, we have elaborated a coherent and detailed PA Programme (PAP) tailored for the software, which defines the strategy and the organization for the management of the quality control. It identifies the applicable quality requirements to be applied for the whole software development life cycle process of all the software products. This programme was applied since the early phases of the ASTRI Mini-Array project, and allowed us to accept a software release only when it has been verified and validated, it is correctly running on the ASTRI Mini-Array infrastructures, and the ASTRI Mini-Array personnel has been trained. Here we describe the general approach of the ASTRI Mini-Array Software PAP, provide specific details on its content, and report few examples of its application along the project development.

2. ASTRI Mini-Array Software System

The ASTRI Mini-Array system is geographically distributed in three main sites: the Array Observing Site (AOS) at the Teide Observatory, where the nine telescopes and the auxiliary systems are under installation; the Array Operation Centres (AOCs) located in Italy and Tenerife, which will allow the Operator to supervise and carry out the scheduled observations during the night; the Data Centre in Rome, aimed at data archiving, processing, simulations and science user supporting. The figure 1 depicts the MASS software architecture [10]. The array Operator connects remotely the on-site software from AOCs using a web interface named Operator Human Machine Interface (Operator HMI). The Archive System provides a central repository for all persistent information of the ASTRI Mini-Array, such as observing projects, observation plans, raw and reduced scientific data, monitoring data, system configuration data, logs of all operations and schedules. The Science Support System manages the observing projects, the observation plans preparation, the management of science alert events, the dissemination of scientific data and the science tools for their analysis. It is the main interface between the science users and the ASTRI Mini-Array system implemented through a web interface. The outcome of the Science Support System is the observation plan. This system supports the preparation of observations and the dissemination phase of the observing cycle. The Supervisory Control and Data Acquisition (SCADA) system controls all operations at the AOS. SCADA provides a Central Control System which interfaces all the hardware and dedicated software installed on-site. It is responsible for the execution of the short-term plan to perform the observations. SCADA shall be supervised by the Operator for safety reasons, but performs the operations in an automated way. It shall provide scientific data, logging, monitoring, alarm, and online observation quality information to help assess data quality during the acquisition. This system supports the day and night observation executions and the maintenance phases. The Data Processing System performs the calibration of scientific data, data reduction and analyses. It also checks the quality of the final data products. Its primary role is to process data retrieved from the Archive System as soon as enough data has been acquired. The main functions are: (i) the stereo event builder, to perform the off-line software stereo array trigger of Cherenkov data; (ii) the Cherenkov data pipeline, for data calibration, reconstruction, selection, and automated scientific analysis of Cherenkov data; (iii) the intensity interferometry data reconstruction and scientific analysis, for reconstruction and analysis of the stellar intensity interferometry data; (iv) the calibration software. The Simulation System provides the Monte Carlo simulated scientific data for the development of reconstruction algorithms and the characterisation of real observations. The On-site Start-up System manages the sequence of the start-up and shutdown of the onsite hardware systems.

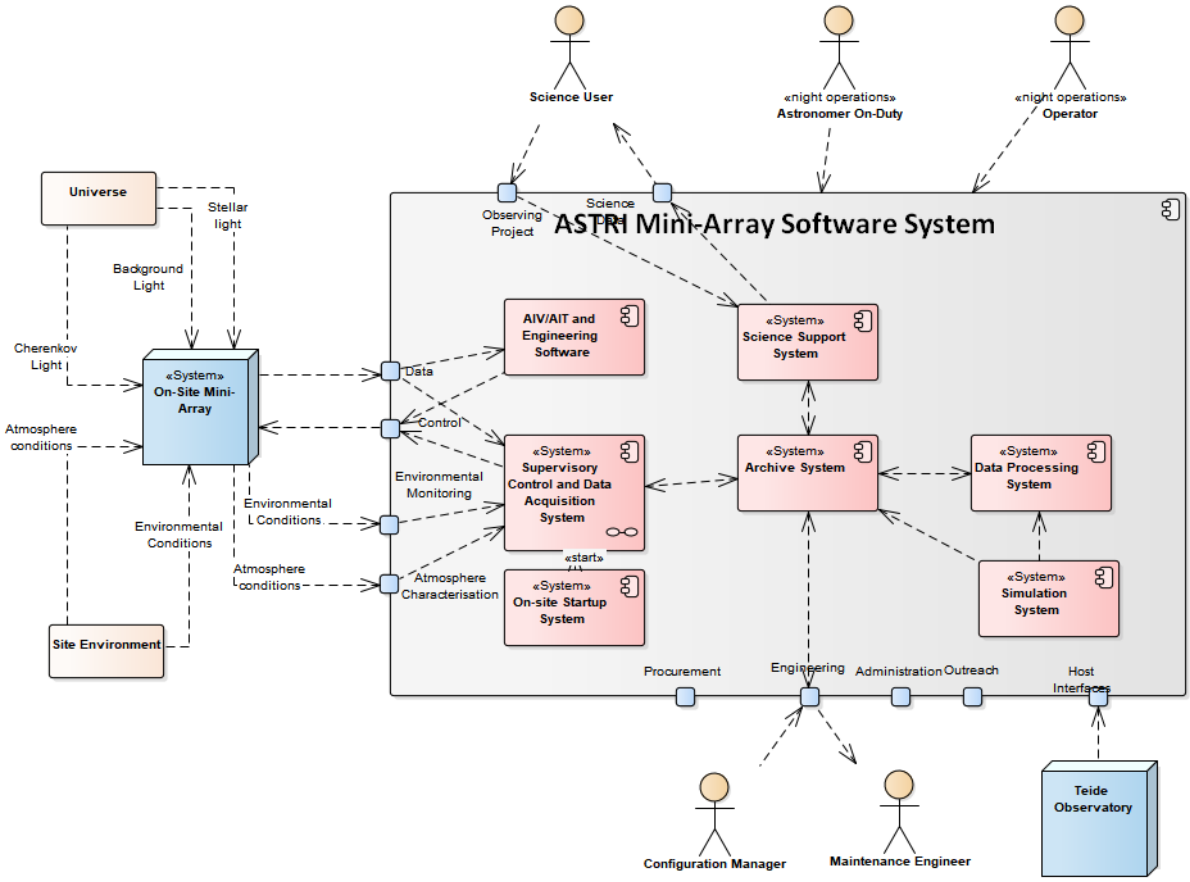

Figure 1. ASTRI Mini-Array Software System architecture.

3. ASTRI Mini-Array Software Product Assurance Programme

The experience gained during the development of ASTRI-Horn has led us to recognize the benefit of a clear and well-defined Product Assurance (PA) strategy [11]. Therefore, at the beginning of the ASTRI Mini-Array project, we have elaborated a coherent and detailed PA Programme (PAP), which defines the strategy and the organization for the management of the quality control. It identifies the applicable quality requirements for design, procurement, assembly/integration/test (AIT), and verification, and the guidelines to manage the acceptance of the deliverable items provided by the external suppliers. This programme was applied since the early phases of the ASTRI Mini-Array project, and allowed us to evaluate the quality level of both the manufacturing processes and the deliverable items. According to the ASTRI Project Management Plan, the ASTRI Mini-Array project is coordinated by a Project Office (PO), which includes the Principal Investigator (PI), the Project Manager (PM), the Project Scientist (PS), the System Engineer (SE), the Product Assurance (PA) manager, and the Assembly, Integration, and Verification (AIV) manager. In this framework, all the ASTRI PA activities are managed by the PA Office. This office is coordinated by the PA Manager (PAM) and is composed of the PA responsible for each of the telescope items, i.e., mechanical structure, optics, camera, and software. The PA responsible for the software prepares, maintains, and applies a specific Software Product Assurance Plan (SPAP), based on the principles of the standard ECSS-Q-ST-80C [12], which defines the software quality assurance and product assurance requirements to be applied for the whole software development life cycle process of all the software products. The SPAP describes how to produce the software deliverables which pass the quality gates through the verification and validation activities. Each software release is accepted only when it has been verified and validated, it is correctly running on the ASTRI Mini-Array infrastructures, and the ASTRI Mini-Array personnel has been trained. The PA responsible for the software coordinates the software development teams concerning the quality activities and identifies specific mechanisms for planning, controlling and reporting on the PAM, as well as the procedures for alerts, audits, non-conformances, and for resolving detected software problems. The production of the ASTRI Mini-Array Software System requires the cooperation of several INAF work groups and external organisations that share the common objective of providing a software system that satisfies the overall scientific and technical requirements of the ASTRI Mini-Array. To organise the overall team, a customer-supplier relationship model has been adopted, where the customer accepts the software, having one or more software suppliers that must develop and deliver the software according to the customer's requirements. This relationship is recursive, i.e., the customer could also be a supplier to a higher-software-level customer. The software supplier has in charge the software designing, development and testing of a specific subsystem. The supplier shall also produce the software verification plan which defines set of metrics to provide a valid assessment tool to reach the science goals. The process assessment is guaranteed by a PA planning for individual processes and activities, documentation and configuration management, the software requirement analysis architecture and design, the verification and validation test and, eventually, the delivery and the acceptance. We have defined the documentation required. The Project Scientist is in charge of the releasing the science requirement document. The Software Engineer shall provide the software engineering management plan, the software development plan and the software requirements. For each software item the supplier shall provide the following documents: software verification, software requirement specifications, software architecture and design, test reports and artifacts, interface control documents, software user manual, software release document. The customer shall provide the validation plan and is in charge of accepting the software release. The quality of documents is envisaged by a supervisor who has proper skills according to the kind of document.

4. Status of Software quality assessment

The software system engineering team has defined a software development plan that integrates aspects of agile development methodologies, including: (i) frequent iterations and releases; (ii) feature-driven development; (iii) unit and component tests created with the source code by the development teams during each iteration; (iv) automated testing and continuous integration; (v) distributed configuration management. The supplier performs the verification procedures to test the system as a white box; the customer conducts the validation with the system as a black box for the acceptance of the delivered software. The following major reviews are foreseen in the ASTRI Mini-Array software life cycle.

- The Concept Design Review (CoDR) demonstrates that a full view of the software complies with science requirements, system requirements, observing cycle, and operation concepts.
- The Preliminary Design Review (PDR) demonstrates that the preliminary design of the subsystem meets all system requirements with acceptable risk and within the cost and schedule constraints. The end of this review starts the iterative and incremental phase of the development.
- The Critical Design Review (CDR) aimes at demonstrating that the design reached an appropriate level of detail to support the production of the code, assembly, integration and test, meeting all performance, scheduling, and operational requirements.
- The Acceptance Test Review (ATR) needs to verify the completeness of the developed software, documentation, and test and analysis reports. Also, it ensures that the software reaches a level of maturity to be deployed. After this review, the software is delivered to the customer and deployed at the Array Observing Site or in the Data Centre.
- The Operational Readiness Review (ORR) establishes that the software system is ready to be used for operations by examining test results, analyses, and operational demonstrations.

The CoDR was conducted in June 2020 by a panel of external reviewers. After this review, the set of the required documents was released. We also completed the CDR for the SCADA subsystems by a panel of internal reviewers. The documents affected by this review were the software requirement specifications, use cases, detailed design and the verification plan. We plan to perform next reviews according to the iterative incremental approach and the project schedule. Concerning the development and test we are implementing a Continuous Integration (CI) pipeline at the subsystem level, exploiting the GitLab CI environment for automated subsystem verification (figure 2). The developer writes the source code through the Eclipse tool [13], that is an integrated development environment for many programming languages which can also include the Sonar Lint plugin (https://www.sonarlint.org). Sonar Lint helps the developer to detect and fix quality issues during the coding. Like a spell checker, Sonar Lint detects flaws so that they can be fixed before committing code. Once the new version has been committed, Gitlab triggers the CI pipeline. The subsystem software is released with updated documentation if all tests pass and all foreseen functionalities have been developed. In addition, SonarQube has been installed and connected to the GitLab projects. The new code commit also triggers the Sonar scanner, which provides the quality report and a tag pass/fail according to well-defined quality metrics. We are implementing the feature-branch workflow in our repository Git: once a new capability has been developed and the quality gates pass the metrics, the developer open a merge request from the feature branch to the main branch. The subsystem responsible is in charge of checking the source code and the test/quality reports before to accept the merge request. Once the subsystem version has been released, it is candidate for the next integration tests with the other subsystems. We provided a virtual machine to support the development activities. The virtual machine is equipped with the common software and libraries such as: Alma Common Software, Apache Kafka, MySQL; common versions of python, Java and C++; common operating system (actually the Linux Centos 7.4, but we are forwarding to the Linux Red Hat licenses). In order to support the test activities, we provided instrument workstations for performance tests, and a test bed for the functional requirement verifications. The test bed is a pool of virtual machine which simulates real on-site system, also in term of networking configuration.

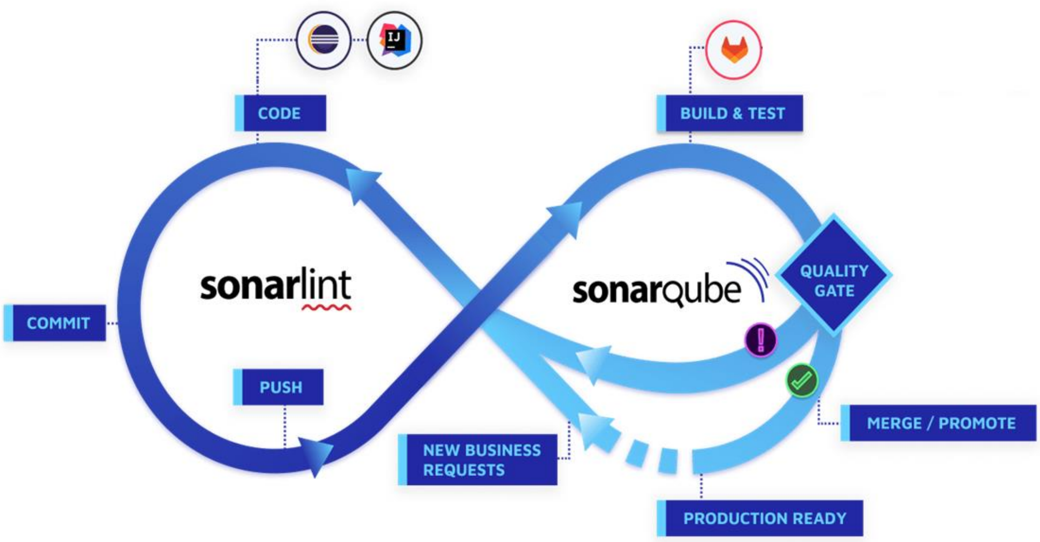

Figure 2. ASTRI Mini-Array software development, test and deployment model.

5. Conclusions

At earliest stage of the project, we defined and documented very well the guidelines and procedures concerning the software quality for the software products and processes. We exploited the lessons learned from the ASTRI-Horn prototype and, in particular, the needs to apply an iterative approach according to the project schedule, in order to release software version with a subset of functionalities but deeply tested and verified to support the validation activities. The PA team provides continuous support to the development teams, software suppliers and all the stakeholders. In addition, the PA team performs a continuous assessment of the QA processes within the PA office through periodical meetings.

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