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The DAQ system support to the AIV activities of the ASTRI camera proposed for the Cherenkov telescope array

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ABSTRACT

The Cherenkov Telescope Array (CTA), the next generation ground-based observatory for very high-energy gamma rays, is being built and will be operated by an international consortium. Two arrays will be located in the northern and southern hemispheres. Each telescope array will operate different numbers and types of telescopes. The Italian National Institute for Astrophysics (INAF) is leading the ASTRI (Astrofisica con Specchi a Tecnologia Replicante Italiana) project in the framework of the small size class of telescopes (SST). A first goal of the ASTRI project is the realization of an end-to-end prototype in dual-mirror configuration (SST-2M). The ASTRI camera focal plane is composed of a matrix of silicon photo-multiplier sensors managed by innovative front-end and back-end electronics. The ASTRI SST-2M prototype is installed in Italy at the INAF “M.G. Fracastoro” observing station located at Serra La Nave, 1735 m a.s.l. on Mount Etna, Sicily. The ASTRI Data Acquisition (DAQ) system acquires, packet by packet, the camera data from the back-end electronics. The packets are then stored locally in one raw file as soon as they arrive. During the acquisition, the DAQ system groups the packets by data type (scientific, calibration, engineering) before processing and storing the data in FITS format. All the files are then transferred to the on-site archive. In addition, we implemented a quick-look component that allows the operator to display the camera data during the acquisition. A graphical user interface enables the operator to configure, monitor and control the DAQ software. Furthermore, we implemented the control panel algorithms within the framework of the Alma Common Software, in order to integrate the DAQ software within the ASTRI control software. The ASTRI DAQ system supports the camera AIV activities and operations. We provide the instrument workstation to support the AIV activities in the laboratory, and the camera server on-site. In this paper, we assess the ASTRI DAQ system as it has performed the AIV tasks for the ASTRI SST-2M prototype. **Keywords:** data acquisition, camera server, bulk data, ASTRI, Cherenkov telescope array, software engineering, software integration test,

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1. INTRODUCTION

The Italian National Institute for Astrophysics (INAF) is leading the ASTRI (Astrofisica con Specchi a Tecnologia Replicante Italiana) project within the ambitious Cherenkov Telescope Array (CTA) [1], the next generation of ground-based observatories for very high-energy gamma-ray astronomy. The goal of the ASTRI [2] project is the realization of an end-to-end Cherenkov Telescope prototype, in dual mirror configuration (2M), with a Cherenkov camera composed of a matrix of silicon photo-multiplier sensors managed by innovative front-end and back-end electronics[3]. The prototype, ASTRI SST-2M, is installed in Italy at the INAF “M.G. Fracastoro” observing station located at Serra La Nave (SLN), 1735 m a.s.l. on Mount Etna, Sicily. Profiting from experience with the prototype, the ASTRI project focusses next on the production of ASTRI telescopes, proposed to be placed at CTA southern site [4]. The ASTRI project includes the Assembly, Integration, and Verification (AIV) plan. The first step foresees the assembly and integration of the camera as a whole in the laboratory. The next step is to integrate the ASTRI camera to the telescope on site. The ASTRI Data Acquisition (DAQ) [5] system supports the AIV and maintenance activities in the laboratory through an Instrument Workstation. On site, we provide the DAQ system software running on a camera server, which is installed in the server room. Both the Instrument Workstation and the camera server run the same software in different configuration. The ASTRI camera Back End Electronics (BEE) – DAQ interface control document details the interaction between those systems. The DAQ system connects directly the camera BEE and acquires data as a continuous stream of packets. The packet is a discrete unit of raw data. Concerning the data transmission protocol, the DAQ system is compatible with either UDP (User Datagram Protocol) or TCP (Transmission Control Protocol). The DAQ system sorts

the data packets by data type (scientific, calibration, engineering) using one queue for each type. The complete list of data types is as follows:

1. S21: scientific data only;
2. S22: scientific data with housekeeping;
3. C11: dark stair calibration data;
4. C12: fiber stair calibration data using the internal light pulses generator;
5. C13: dark photo-electron equivalent calibration data;
6. C14: fiber photo-electron equivalent calibration data using the internal light generator;
7. HK: camera housekeeping data;
8. VAR: variance data;

We have defined the measure session as a set of idle and run periods. During the run period, the camera performs calibration and science sessions. In the idle period instead, the camera sends only HK data. The camera is in idle for example at the camera start-up and shutdown, or while the telescope is slewing to acquire at the next target. The DAQ stores the data acquired within one period in one raw file packet by packet. In addition, the DAQ system saves the data in FITS format and stores it one file for each data type. Upon closure, the DAQ system transfers each file to the on-site archive. The DAQ system also provides the quick-look software, which allows the operator to display the camera data during the acquisition. The control panel provides the graphical interface that enables the operator to configure, monitor and control the DAQ software. We implemented this control panel algorithm using the Alma Common Software (ACS) framework in order to integrate the DAQ software within the ASTRI control software. This paper outlines the DAQ system in the context of the ASTRI SST-2M camera AIV activities. The next section details the DAQ system model; section three presents the DAQ software provided during test activities that focused on the user perspective. Section four highlights the DAQ AIV plan in the context of the overall ASTRI AIV plan. The last section discusses the activities that will follow.

2. THE DAQ SYSTEM MODEL

The goal of the DAQ system is to support the ASTRI cameras data acquisition processes. It operates in three main contexts:

1. camera AIV activities;
2. telescope AIV activities;
3. telescope operations for scientific observations;

2.1 The software

During the camera integration and test, the DAQ software is deployed in the Instrument Workstation (IW), which provides the capabilities required to support the development and test activities of the ASTRI camera (see, Figure 1). The DAQ software running on the IW performs the data acquisition and buffering, quick-look and local data storage of the bulk data acquired from the camera BEE, both in raw format (so-called Data Level 0 raw or DL0 raw) and FITS format (DL0 FITS). The local GUI allows the operator to configure, monitor and control the DAQ system.

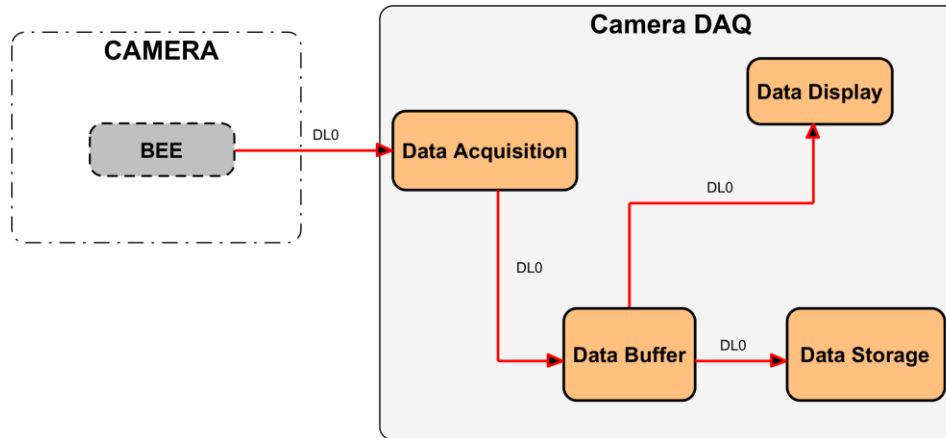


Figure 1 - Logical model of the Instrument Workstation

During the camera integration at the telescope and the telescope operations, the DAQ software is installed on the camera server, in the server room at SLN. The camera server connects directly the camera BEE via optical fiber. The DAQ software running on the camera server provides the same functionalities as the one running on the instrument workstation. The DAQ system interfaces the ASTRI telescope control software [6] through an ACS component. Furthermore, the camera server sends the data files to the ASTRI on-site archive. The camera server can be configured and commanded through the local operator GUI or, remotely, through the telescope control system [7].

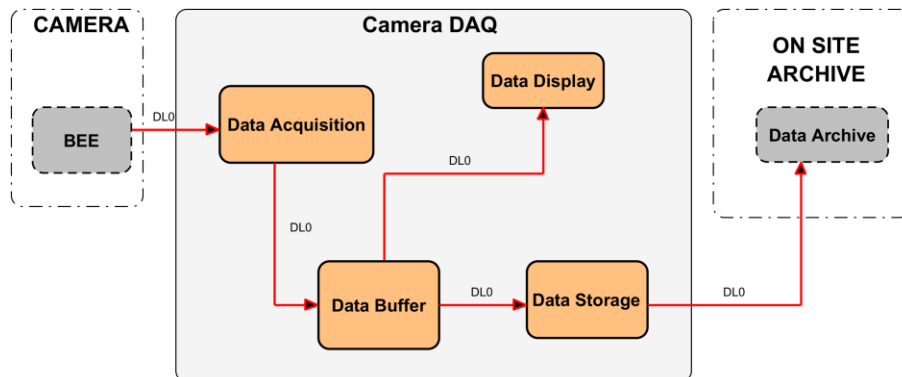


Figure 2 - The logical model of the camera server

2.2 The hardware

The hardware makeup of the DAQ system supports compliance with ASTRI specifications, derived from the CTA requirements for the SST telescopes. The DAQ system shall acquire data, packet by packet, from the camera BEE continuously at the minimum data rate 6 MB/s. The DAQ system shall record the whole data packets in raw and FITS format files. During the acquisition, the buffered data shall be accessible in near real-time and in retrieval mode for health monitoring and quick-look purposes. In addition, the DAQ system shall continuously transfer the files to the archive. In order to satisfy those requirements and to effectively support the tests, we selected the following hardware configuration. The instrument workstation is a Case 4U super micro super chassis (Figure 3). The equipment of the instrument workstation is:

- 2 CPU Xeon with 6 cores at 2.1 GHz;
- 32 GB RAM provided by 4 modules of 8 GB DDR3-1600;
- The RAID SAS/SATA storage provide by the Adaptec 6805 with 8 ports PCI-EX;
- 2 hard disks (500 GB each) SATA III in RAID 1 for the operating system;
- 6 hard disks (3 TB) SAS II in RAID 10 for the data storage;

- 1 video board PNY Quadro, PCI 2GB DDR5.
- 2 LAN board, 1Gbit – Intel i350 (Intel pro 1000)

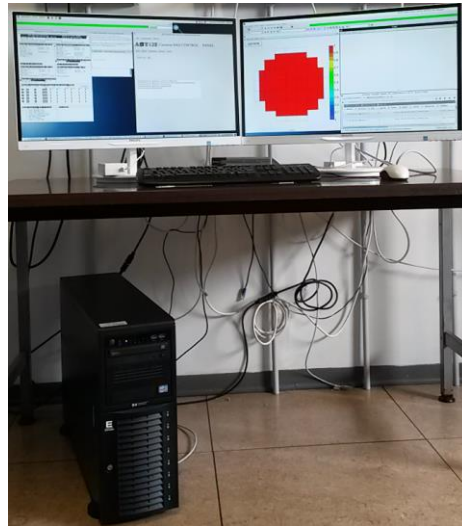


Figure 3 - The instrument workstation

The camera server (Figure 4) is a case 4U super micro chassis. We mounted the camera server on the rack in the server room [8]. The hardware of the camera server consist of:

- 2 CPU Xeon with 10 cores at 2.3 GHz;
- 64 GB RAM provided by 4 modules of 16 GB DDR3-2133;
- The RAID SAS/SATA storage provided by the Adaptec 6805 with 8 ports PCI-EX;
- 2 hard disks (1 TB each) SATA III in RAID 1 for the operating system;
- 6 hard disks (4 TB each) SAS II in RAID 10 for the data storage;
- 1 video board PNY Quadro, PCI 4GB DDR5.
- 2 LAN board, 1Gbit – Intel i350 (Intel pro 1000)
- 2 board 10 Gbit SFP



Figure 4 - The camera server

The hardware selected and assembled for the camera server and the instrument workstation provides a very powerful, reliable and expandable machine. It supports intensive work from the networking, processing, storage, and display points of view. The hardware has been certified for the operating systems Scientific Linux 6 and 7. The architecture of the hard disks controller allows the operator to perform the hot swap of the hard disks during maintenance activities. The machines also includes the GPUs, not used in the current software version.

3. THE DAQ SYSTEM SOFTWARE

This section details the software component used during the last ASTRI camera AIV activities from the user perspective.

3.1 The control Panel

The camera DAQ control panel is the local GUI, (see Figure 5) that allows the operator to monitor and control the DAQ system. The local GUI provides a user-friendly interface to configure the DAQ software based on the different operation modes of the camera. Furthermore, the user can fully configure the GUI views with customized layouts of buttons and commands, through a web application that stores the active configuration. When the user starts the GUI, the software loads the configuration and displays the desired interface. The local GUI has been implemented in Java and uses the MySQL database management system. This customization feature proved its worth during a test session when we were able to add a new command in a few seconds without modifying any source code.

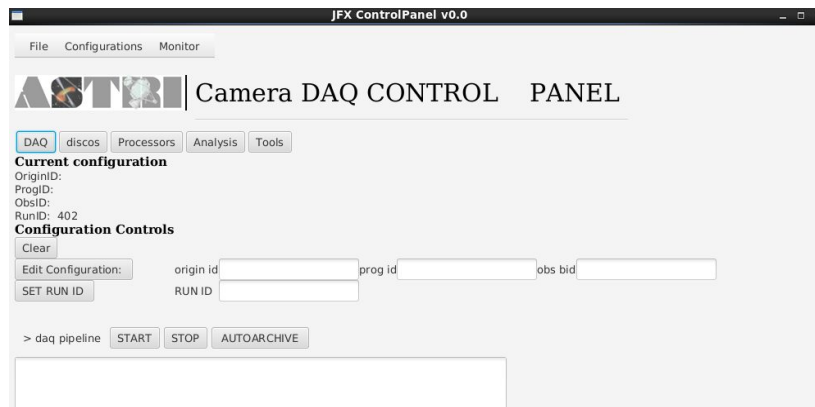


Figure 5 - ASTRI DAQ local GUI. It allows the operator to configure the measure and run all the acquisition processes. The log panel on the bottom detail the state of any running process.

3.2 The monitor of acquisition and processor components

The activation of the START button in the control panel runs the data acquisition and processor components. The acquisition monitor appears in a new window (Figure 6), which provides details about the incoming packets stream. It displays, for each packet type, the current acquisition rate, the average acquisition rate, the number of packets losts, and the raw- FITS conversion rate. These data are also saved in a log file.

3.4 The DAQ persistence component

The DAQ acquisition system encompasses the persistence subsystem. This subsystem includes a database, the libraries to interface to the database, and a web application, which supports the acquisition processes. The persistence modules are:

- the web interface for the control panel configuration;
- the web interface for the DAQ configuration;
- the “persistenceC” library to support the synchronization among the acquisition processes;
- the “persistenceC++” library to support the synchronization among the conversion raw-FITS processes;
- the web interface to display the status of files created upon data arrival.

The screenshot shows a web interface titled "ASTRI CAMERA SERVER LOCAL ARCHIVE". It includes a search section on the left with fields for "Starting date between", "and:", "Origin ID:", "Program ID:", and "Observation ID:", along with an "Apply filter" button. The main content area, titled "Myfiles", displays a table of files with the following columns: Id, Measure, Filename, Startdate, Enddate, Creationdate, Sent, Last Update Time, and Actions. The table contains 20 rows of data, each with a "View" link in the Actions column. At the bottom of the table, it indicates "Page 1 of 126, showing 20 records out of 2509 total, starting on record 1, ending on 20" and includes a pagination control.

| Id | Measure | Filename | Startdate | Enddate | Creationdate | Sent | Last Update Time | Actions |
|------|---------|--|---------------------|---------------------|---------------------|------|---------------------|----------------------|
| 2514 | 1828 | astri_000_01_003_00001_I_001063_9.raw | 2018-03-20 18:59:46 | | 2018-03-20 18:59:46 | 1 | 2018-03-20 18:59:46 | View |
| 2513 | 1827 | astri_000_01_003_00001_R_001062_9.raw | 2018-03-20 18:24:40 | 2018-03-20 18:59:45 | 2018-03-20 18:24:40 | 1 | 2018-03-20 18:59:45 | View |
| 2511 | 1826 | astri_000_01_003_00001_F_001062_9.raw | 2018-03-20 18:20:33 | 2018-03-20 18:24:39 | 2018-03-20 18:20:33 | 1 | 2018-03-20 18:24:39 | View |
| 2512 | 1826 | astri_000_01_003_00001_F_001062_000_1002.iv0 | 2018-03-20 17:21:26 | 2018-03-20 17:22:34 | 2018-03-20 18:21:28 | 1 | 2018-03-20 18:24:44 | View |
| 2509 | 1825 | astri_000_01_003_00001_I_001061_9.raw | 2018-03-20 15:03:48 | | 2018-03-20 15:03:48 | 1 | 2018-03-20 15:03:48 | View |
| 2508 | 1824 | astri_000_01_003_00001_R_001060_9.raw | 2018-03-20 14:59:30 | 2018-03-20 15:03:47 | 2018-03-20 14:59:30 | 1 | 2018-03-20 15:03:47 | View |
| 2507 | 1823 | astri_000_01_003_00001_F_001060_9.raw | 2018-03-20 14:55:27 | 2018-03-20 14:59:29 | 2018-03-20 14:55:27 | 1 | 2018-03-20 14:59:29 | View |
| 2506 | 1822 | astri_000_01_003_00001_I_001059_9.raw | 2018-03-20 13:19:10 | | 2018-03-20 13:19:10 | 1 | 2018-03-20 13:19:10 | View |
| 2505 | 1821 | astri_000_01_003_00001_R_001058_9.raw | 2018-03-20 13:14:14 | 2018-03-20 13:19:09 | 2018-03-20 13:14:14 | 1 | 2018-03-20 13:19:09 | View |
| 2504 | 1820 | astri_000_01_003_00001_I_001058_9.raw | 2018-03-20 12:56:56 | 2018-03-20 13:14:13 | 2018-03-20 12:56:56 | 1 | 2018-03-20 13:14:13 | View |
| 2503 | 1819 | astri_000_01_003_00001_R_001057_9.raw | 2018-03-20 12:49:24 | 2018-03-20 12:56:55 | 2018-03-20 12:49:24 | 1 | 2018-03-20 12:56:55 | View |
| 2502 | 1818 | astri_000_01_003_00001_F_001057_9.raw | 2018-03-20 12:45:36 | 2018-03-20 12:49:23 | 2018-03-20 12:45:36 | 1 | 2018-03-20 12:49:23 | View |
| 2501 | 1817 | astri_000_01_003_00001_I_001056_9.raw | 2018-03-20 12:41:39 | | 2018-03-20 12:41:39 | 1 | 2018-03-20 12:41:39 | View |
| 2499 | 1816 | astri_000_01_003_00001_R_001055_9.raw | 2018-03-20 12:20:04 | 2018-03-20 12:41:38 | 2018-03-20 12:20:04 | 1 | 2018-03-20 12:41:38 | View |
| 2498 | 1815 | astri_000_01_003_00001_I_001055_9.raw | 2018-03-20 12:19:29 | 2018-03-20 12:20:03 | 2018-03-20 12:19:29 | 1 | 2018-03-20 12:20:03 | View |
| 2497 | 1814 | astri_000_01_003_00001_R_001054_9.raw | 2018-03-20 12:14:05 | 2018-03-20 12:19:28 | 2018-03-20 12:14:05 | 1 | 2018-03-20 12:19:28 | View |
| 2496 | 1813 | astri_000_01_003_00001_I_001054_9.raw | 2018-03-20 12:13:31 | 2018-03-20 12:14:04 | 2018-03-20 12:13:31 | 1 | 2018-03-20 12:14:04 | View |
| 2495 | 1812 | astri_000_01_003_00001_R_001053_9.raw | 2018-03-20 12:10:02 | 2018-03-20 12:13:30 | 2018-03-20 12:10:02 | 1 | 2018-03-20 12:13:30 | View |
| 2493 | 1811 | astri_000_01_003_00001_F_001053_9.raw | 2018-03-20 11:59:08 | 2018-03-20 12:10:01 | 2018-03-20 11:59:08 | 1 | 2018-03-20 12:10:01 | View |
| 2491 | 1810 | astri_000_01_003_00001_I_001052_9.raw | 2018-03-20 11:24:50 | | 2018-03-20 11:24:50 | 1 | 2018-03-20 11:24:50 | View |

Figure 8 - Web interface to display the status of the DAQ files.

The web interface depicted in Figure 8, displays the list of files stored in the DAQ system. The user can order the list by measurement session, filename and date. The software also provides filter functionality for searching specific subsets of data. The value in the column “sent” is 1 when the file has been forwarded to the on-site archive, 0 otherwise. The DAQ system includes a daemon configured to send the closed files to the on-site archive during the acquisition process.

4. THE ASSEMBLY INTEGRATION AND VERIFICATION PLAN

We defined the ASTRI DAQ system development plan according to the ASTRI AIV plan [9][10]. The ASTRI camera is a complex instrument where many subsystems must work together to detect the Cherenkov light [11]. The DAQ system interfaces the camera (through the camera BEE and the camera controller) to the on-site archive. We defined the DAQ system integration and verification plan, which presents the overall verification approach, with respect to the requirements, on the ASTRI SST-2M camera DAQ.

The goals in the system integration process are:

- to build the overall software from software items (building logic);
- to ensure that the instructions between software items are consistent;

- to ensure that the interactions with external interfaces are consistent;

The ultimate goal of the integration is to deliver the DAQ system that can support the ASTRI camera AIV activities and operations.

4.1 The integration levels

We consider different levels of product integration, corresponding to the architectural principles below:

- The component-level integration. It encompasses all the tasks needed to deliver a component ready for its verification with respect to its technical specification.
- The subsystem/product level integration. It encompasses all the tasks needed to deliver a subsystem ready for its verification with respect to its requirements baseline. It may include specific verification tasks that correspond to the subsystem technical specification.
- The camera BEE - DAQ product integration. It encompasses all the tasks needed to deliver a DAQ version ready for validation.

4.2 The integration plan

According to the integration levels defined in the previous subsection, we defined a plan (Figure 12) to develop, integrate and test the software in different contexts. We developed, tested and verified all the software components. The DAQ_001 version includes the components detailed below.

- DAQ acquisition component that provides:
 - acquisition and check of the data stream packet by packet;
 - the operator GUI;
 - the storage of raw files;
 - a web based application to configure and retrieve the measurements;
- DAQ processor component that provides:
 - the conversion if raw to FITS-format packet by packet during the acquisition;
 - storage of FITS files;

We tested this software version with simulated data. Then we used this software version deployed in the instrument workstation to perform the BEE factory acceptance test (Figure 9). We verified the interface between BEE and DAQ in terms of connection, data packet structure and performance (percentage of packet loss at different bit rates).

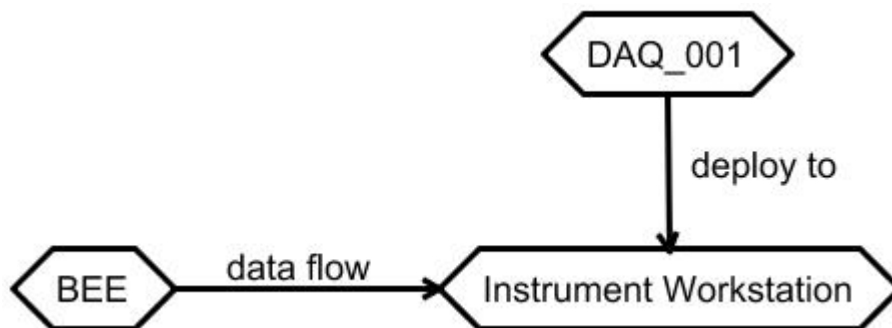


Figure 9 - Factory acceptance test.

Then we integrated the software with the quick look and released version DAQ_002. The quick look provides two execution modes:

- off-line: display the measurements contained either in a raw or FITS file;
- on-line: display the measurements in near real time during acquisition;

This software version was deployed in the instrument workstation, which was delivered to Palermo to support the camera tests in the laboratory (Figure 10). In this case, the BEE was into the camera, and the QL displayed the measurements taken with lid closed.

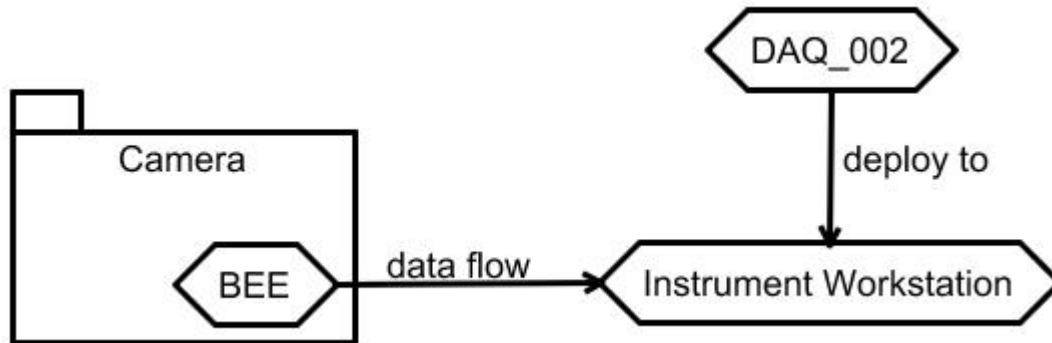


Figure 10 - Camera test in lab.

In the last integration step, we added the archive capabilities to forward the files to the on-site archive. The DAQ ACS components allow the camera controller (CAM CTRL) to monitor and control the DAQ software. The ASTRI camera developer team used the DAQ_003 software version. Furthermore, the camera server at SLN runs the DAQ_003 software version to support the camera AIV activities on-site and operations. In this context, the telescope operates as a whole with the monitoring system support [12], the preliminary science pipeline runs on site [13]. During the first tests, we controlled the camera server through the local GUI. The ACS components are ready for the next test campaigns.

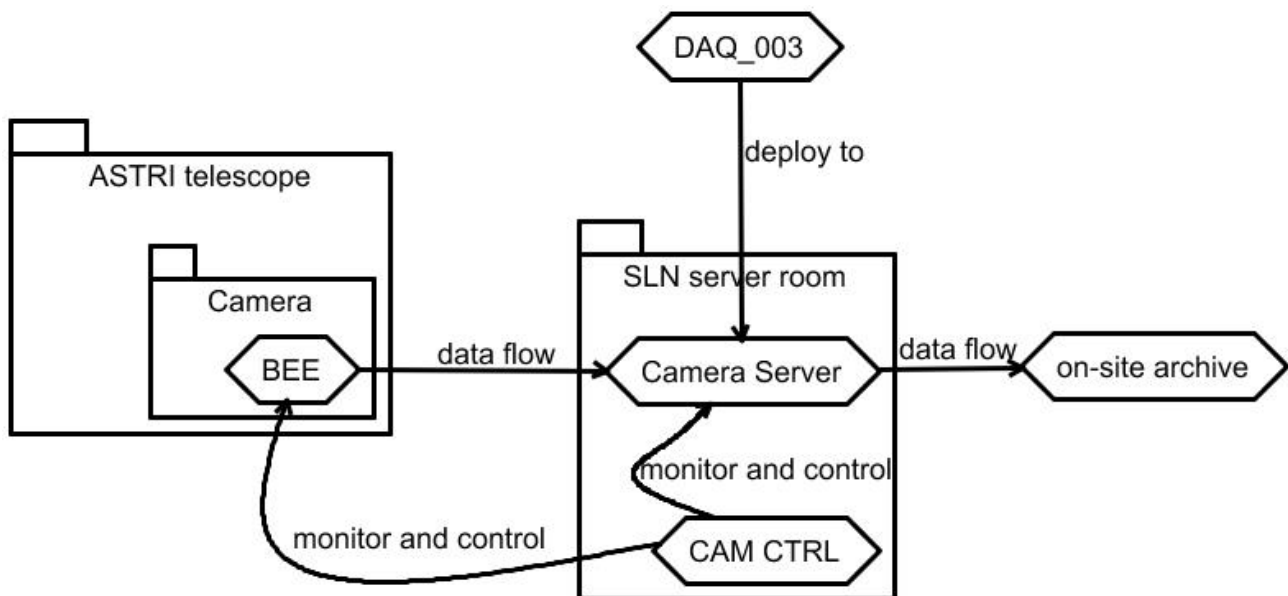


Figure 11 - Camera test on telescope.

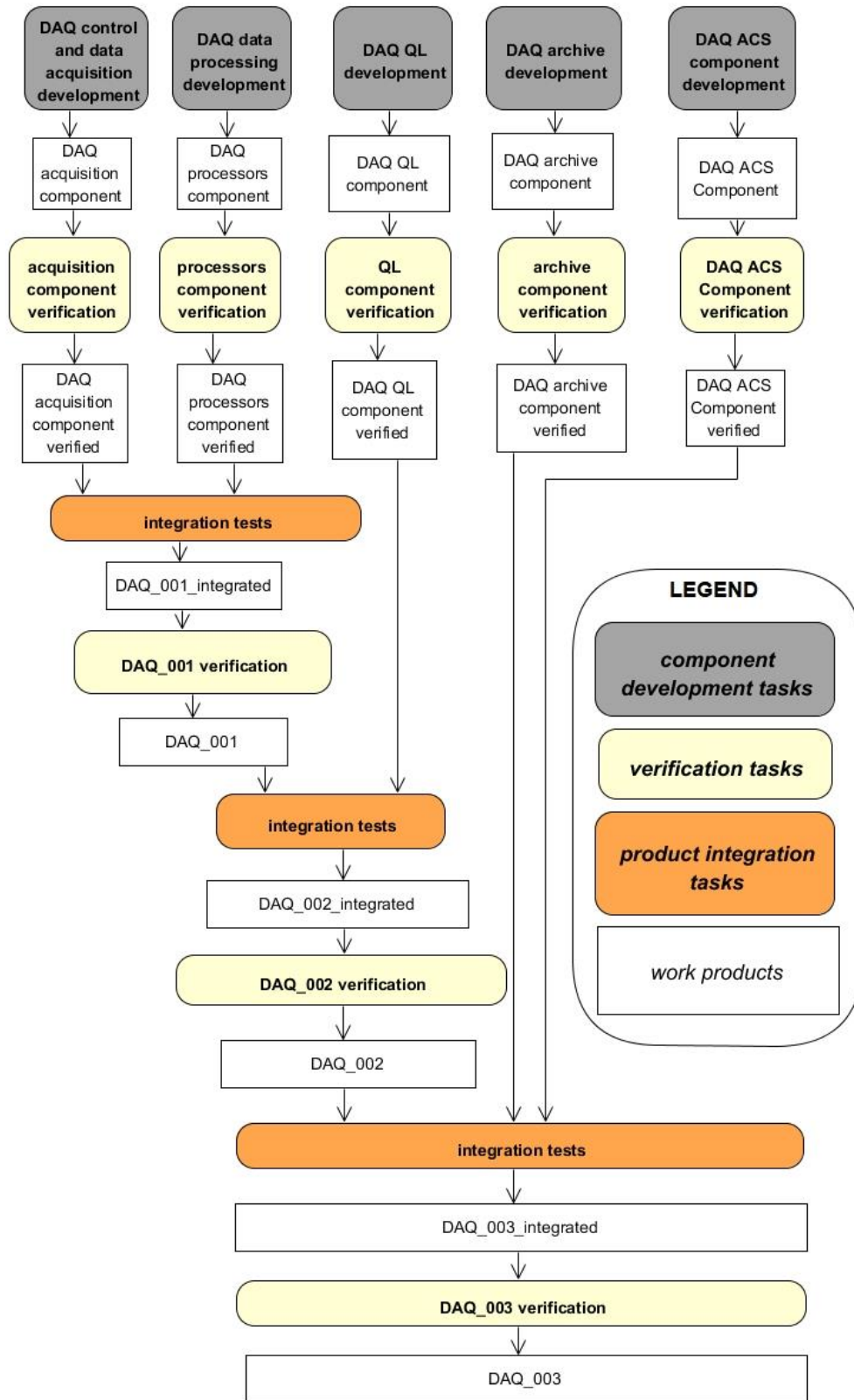


Figure 12 - DAQ AIV plan.

5. CONCLUSIONS AND NEXT STEPS

We designed and implemented the DAQ system adopting the iterative-incremental approach, in order to provide the required functionality in time for each ASTRI camera AIV milestone. We have performed an assessment of the DAQ system at each step. The DAQ system successfully supported all the camera AIV activities providing the required functionalities at the requested bit rates. During the test sessions, we fixed some bugs not detected during the local tests. In addition, we implemented some new minor features to support the test activities:

- we added to our system's data transfer protocol based on the TCP/IP (as requested in the ASTRI specification) the UDP connection immediately before the start of the BEE factory acceptance tests;
- we implemented the user logbook software to support the test on-site;
- we added to the control panel the button to check the physical connection between the BEE and the DAQ;
- we implemented three acquisition modes, that the user can select at run time, to support many tests on-site:
 - o TPC/IP: the BEE sends the ASTRI packet through a TCP/IP connection;
 - o UDP in firmware: the BEE sends the ASTRI packet through multiple UDP datagrams;
 - o UDP in operating system: the BEE sends the ASTRI packet through a single UDP datagram;
- we implemented a daemon to automatically send the data files from the DAQ system to the on-site archive;

The next step foreseen in the AIV plan is the integration with the ACS components. The ACS software has been locally tested. We will release the next software version after the integration tests on the test bed and eventually on-site.

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