Detailed design and first tests of the Application Software for the Instrument Control Unit of Euclid-NISP

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ABSTRACT

In this paper we describe the detailed design of the application software (ASW) of the instrument control unit (ICU) of NISP, the Near-Infrared Spectro-Photometer of the Euclid mission. This software is based on a real-time operating system (RTEMS) and will interface with all the subunits of NISP, as well as the command and data management unit (CDMU) of the spacecraft for telecommand and housekeeping management. We briefly review the main requirements driving the design and the architecture of the software that is approaching the Critical Design Review level. The interaction with the data processing unit (DPU), which is the intelligent subunit controlling the detector system, is described in detail, as well as the concept for the implementation of the failure detection, isolation and recovery (FDIR) algorithms. The first version of the software is under development on a Breadboard model produced by AIRBUS/CRISA. We describe the results of the tests and the main performances and budgets.

Keywords: Instrument control, Real time systems

1. THE EUCLID MISSION

Euclid[1] is a wide-field space mission concept dedicated to the high-precision study of dark energy and dark matter. Euclid will carry out an imaging and spectroscopic wide survey of the entire extra-galactic sky (20000 deg^2) along with a deep survey covering 10-100 deg^2. To achieve these science objectives the current Euclid reference design consists of a wide field telescope to be placed in L2 orbit by a Soyuz launch with a 6 year mission lifetime. The payload consists of a 1.2m diameter 3-mirror telescope with two channels: a VISible imaging channel (VIS[2]) and a Near Infrared Spectrometer and Photometer channel (NISP[3]). Both instruments observe simultaneously the same Field of View on the sky and system design is optimized for a sky survey in a step-and-stare tiling mode.

The Near Infrared photo-spectrometer instrument (NISP) adopts three near-IR filters for the photometer mode and a set of four grisms (with the dispersion along different directions on the FOV) for the spectroscopic part. The focal plane is a mosaic of 4×4 near-IR detectors, with 2048×2048 pixels each. The non-sensitive space between the detectors is filled by performing successive dithers with slight offsets. A whole pointing sequence is composed by 4 dither positions, with one grism selected for each position, and the three filters photometric exposure repeated for each dither position. The time needed to slew to the next pointing may be used to obtain dark exposures.

NISP is composed by the following units:

- Payload Module units:
    - Opto-Mechanical Assembly (NI-OMA), includes the optics, the filter wheel assembly(FWA), and the grism wheel Assembly (GWA)
    - Detection System (NI-DS), it includes 16 Hawaii2-RG detectors from Teledyne, coupled with 16 SIDECAR boards from the same manufacturer. The SIDECAR boards provide the necessary bias voltages, current sources and clock signals to the detectors, and perform the Analog to Digital conversion of the detector signal. The digital data are then sent to the DPU/DCU in the service module.

- Service Module units:
    - Instrument Control Unit (NI-ICU); as it will be described in the following, controls all the other subunits of NISP (FWA, GWA, DPU/DCU and through it the DS), collects and formats the HK information and deliver TM packets to the CDMU.
    - Focal plane Data Processing Unit/Detector Control Unit (NI-DPU/DCU). It receives the digital data from the SIDECAR and perform the necessary on board data processing; the final results are then stored in the MMU, while additional HK information is sent through the ICU.

The Service module units are kept at warm temperatures (253-313 K), while the payload module is at cryogenic temperatures, with the detectors at around 100 K.

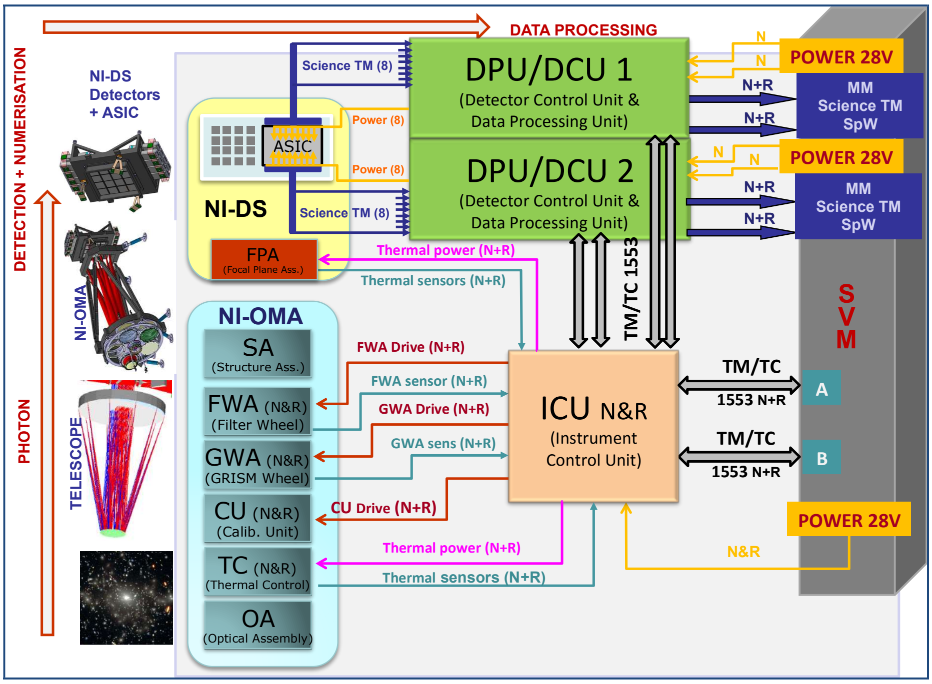

Figure 1. Schematic view of NISP components

2. THE NISP INSTRUMENT CONTROL UNIT

The NI-ICU unit is composed by three boards interconnected by means of a backplane motherboard. In particular:

- Low Voltage Power Supply module provides DC/DC converters and 1553 transceivers for the DPU links
- Central Data Processing Unit module contains a MDPA ASIC, the 1553 transceivers for the S/C link and a test connector. The MDPA ASIC includes a LEON2-FT CPU and an RTAX FPGA that is used to extend the functionalities of the MDPA (implementing, for instance, timers, watchdog and OBT timer) and to interface with the DAS module described below;
- Data Acquisition System (DAS) module manages all the analogue acquisition and driving electronics, including heaters, temperature sensors, calibration LEDs and filters and grism wheels. The DAS board communicate with the processor of the ICU through a Serial Peripheral Interface (SPI) managed by the CDPU FPGA.

In Figure 2 it is shown a schematic view of the different components of the Unit. A detailed description of the ICU HW can be found elsewhere.[4]

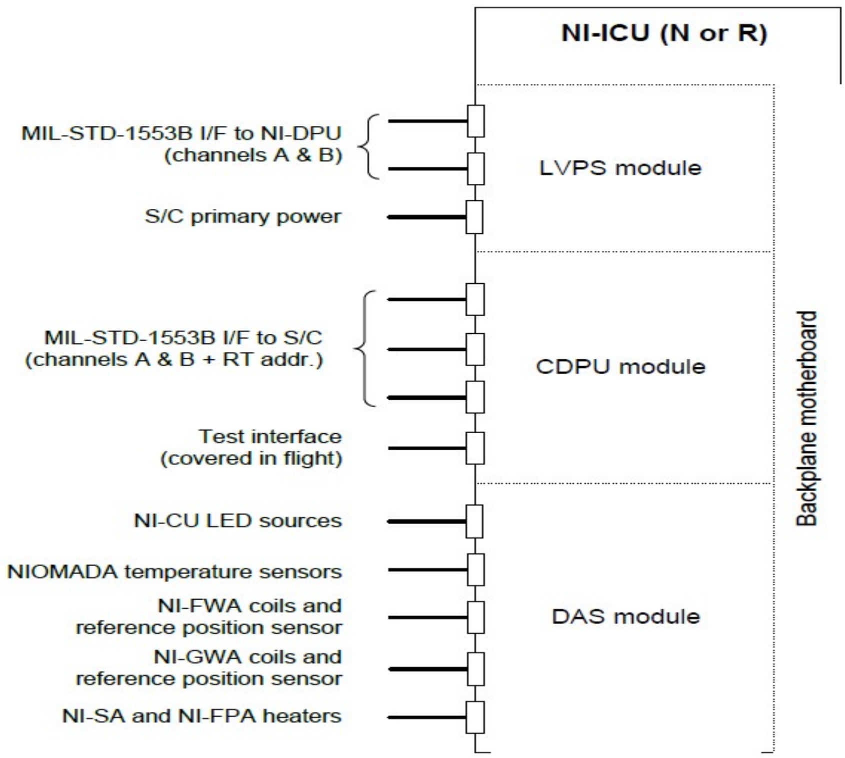

Figure 2. Schematic view of the ICU architecture

3. THE INSTRUMENT CONTROL UNIT APPLICATION SOFTWARE

The ASW is based on the RTEMS real-time operative system in the space-qualified version provided by EDISOFT[5] and use drivers developed by Universidad de Alcalá de Henares (UAH) in Madrid, Spain. The ICU ASW is devoted to manage the satellite/platform interface, the ICU/DPU interface, the NIOMA subsystems (through the DAS board) and all the functionalities related to instrument commanding and monitoring. It is in charge of the following functions:

- Management of NISP operating modes

- TM/TC exchange with S/C CDMU on Nom/Red 1553 link using ECSS standards concerning MIL-STD-1553B interface and communication protocol[6] and TM/TC packet formatting (PUS services)[7]
- TC execution and distribution to NISP instrument units connected through the DAS: NI-FWA electronics, NI-GWA electronics, NI-CU electronics and NI-TC electronics
- TC execution and distribution to NISP instrument units using Nom/Red 1553 interfaces: NI-DPUs, NI-DCUs and NI-SCEs
- TM global instrument monitoring
- Management of the software maintenance, patch and dump functionalities (patching of the files in the EEPROM is done only by the Boot SW)
- Management of on-board time (synchronization with the S/C, relaying information to the DPUs), TM time tagging and the high level instrument internal synchronizations
- Control of the calibration unit (ON/OFF, intensity level and current absorption handling)
- Control of Filter wheels (including management of the reference position sensor)
- Thermal control of the NI-FPA detector cold-plate through temperature sensors and heaters
- High level handling of macro-commands submission and termination verification to detector system
- Thermal control of the NI-OMA through temperature sensors and heaters
- Execution of autonomous functions and FDIR algorithms and processes.

The NI-ICU ASW is launched by the NI-ICU Boot SW, developed by UAH and not described in detail in this paper. The ICU Boot SW will manage the startup steps, checking the content of the EEPROM were two images of the ASW are stored and launching, upon receiving a dedicated TC, the desired ASW image.

The NI-ICU ASW collects HK information from the different subsystem. A selection of those parameters is monitored and a flag, or an event is generated in case of Out-of-limit values; in case of alarms, they will also trigger FDIR algorithms.

Architectural design

We can identify a number of software layers on the on-board SW of the ICU: a hardware layer, corresponding to the drivers necessary to manage the ICU devices under RTEMS; an OS abstraction layer, necessary to allow the development of the upper layer SW independently of the choice of the RTOS; the basic services of the ASW (PUS Services, device management, TC handling, TM packetization), and finally the upper layer components of the ASW.

In Figure 3 is shown a sketch of the Static architecture of the ASW, with the main tasks and relationship between them. The interfaces (either HW, SW or both) are also shown. The configuration data that are managed by the ICU are the following:

• Configuration of the ICU itself, whether it is the nominal or redundant unit. This is necessary because the wheel operation is different between nominal and redundant branch because the home switch position is different (180 degrees displacement)

• Configuration of NISP, for instance the nominal observation sequence, the DPU readout mode selection or the configuration of the wheels and of the Calibration unit for the calibration observations

• Configuration of the DPUs, of the DCUs, and of the SCEs (e.g. Firmware file)

• Other

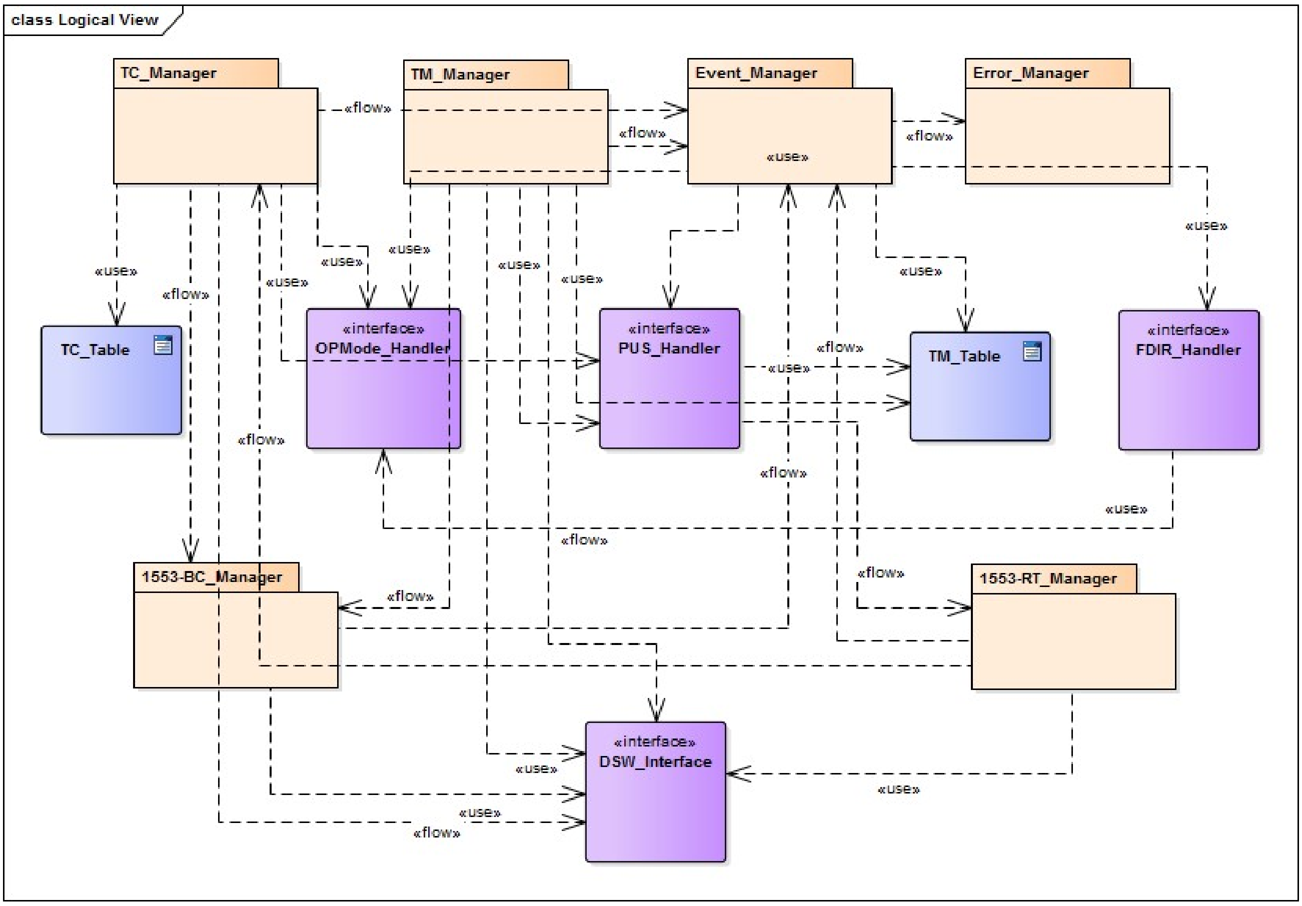

Figure 3. Description of the ICU Application Software

The main SW components are:

- The Command interpreter and sequencer: receives TCs, check the invoked PUS service, then compares with TC prototypes for acceptance and validation, send the decoded commands to the sequencer in order to execute the on-board procedure (if existent) or dispatch the decoded command to the interested device, according, in case of delayed TC, to the time tag of the command: the implementation of the PUS services is done with this task
- The time manager: this task receives the time synchronization information from the S/C 1553 I/F, updates the system time, generate periodic TM packets with sync status.
- TM collection and formatting: this component receives HK data from the devices (by polling in the case of the devices on the SPI), monitors the value of some selected parameter which are associated with thresholds. Generates TM packets and formats them into TM tables to be sent via the S/C 1553 I/F. It invokes the Event Manager (described below) in case of threshold crossing.
- Event manager: send events/alarms to the 1553 I/F: manages autonomous actions in case the failure detected through the HK parameter requires it and manages FDIR algorithms
- Errors Manager: handles all SW errors (from all the tasks), provides error codes, generate event sent to the Event Manager
- S/C 1553 I/F manager: (1553RT) polls the 1553 buffer for new data, sending new TC to the command interpreter. Reads the TM tables and provides them to the S/C according to the adopted bus profile.

• DPU 1553 I/F manager: (1553 BC): manages communication with the DPU through the 1553 link. Sends TCs (using an internal protocol) and receives TM packets to be included in the telemetry flow toward the S/C. It sends system time information to the DPU through the time sync utilities of the 1553 so that the synchronized system time is distributed to all the CPUs of the DPU

• TC table: static information with the format (and limits) of the different TCs. Used to validate and decode TC packets

• TM tables: static table (each HK parameter shall have a fixed position in memory), updated with information from the subsystem and sent to the 1553 at time intervals defined by TM group.

PUS Services

The NISP ICU ASW, and the corresponding ASW of the VIS CDPU, will make use of the PUS standard[7] in the communications of the Telecommand and Telemetry packets with the CDMU of the Service Module. This standard will be tailored according the specific needs of the Euclid mission, and not all services and capabilities are implemented. The services that are included are the following:

• Service 1: Telecommand Verification

• Service 3: Periodic reporting

• Service 5: Event reporting

• Service 6: Memory management

• Service 8: Function management; NISP specific TCs

• Service 9: Time management

• Service 17: Connection test

The ASW implements a procedure that initialize TM/TC exchange protocols used with the spacecraft. This protocol manages two counters: one for telemetry packets and another for telecommands. The TC counter must be incremented each time the spacecraft sends a telecommand to the ICU, instead the telemetry counter must be incremented each time the ICU sends telemetry to the spacecraft. At the end of the initialization procedure TM and TC counters must be 0.

After these operations the NI-ICU ASW is ready to receive Telecommands through the CDMU of the SVM. These telecommands are either from a Timeline file stored on the S/C (for normal operations) or real time commands received from ground (for troubleshooting in case of anomalies). The telecommands are received by the NI-ICU and then are either executed in the NI-ICU itself (if it involves the ICU or one of the ICU connected devices), or are dispatched to the NI-DPU for the commands that involve the DPU/DCU/SCS chain. The list of available TCs and HK telemetry parameter is in [RD4].

Software interface with DPU

The ICU is the only interface of the NISP instrument with the SVM and, through it, with ground control. The mechanisms, the CU, the thermal sensors and heaters are considered as devices directly connected to the ICU (in fact they are all accessed through a single SPI interface with functions provided by the driver SW), while the Data Processing Unit (DPU) is an intelligent unit, able to receive commands and produce telemetry. The capabilities of this unit need to be controlled from ground and this is done via the ICU. The interface, from the physical point of view, is a MIL-STD-1553 bus. This bus follows the same standard of the bus which connects the ICU and the CDPU of VIS to the CDMU, but it is a distinct link and is treated as an internal interface in NISP. Therefore, the ICU ASW is managing two MIL-STD-1553, being the Remote Terminal on the S/C side and the Bus Controller on the DPU side.

The communication protocol is partially based on the same approach used for the SVM bus, but it is simplified as much as possible in order to minimize the computational load on the DPU, since the data processing activities are very demanding and the margin for additional activities is not large. The DPUs are therefore not PUS terminals, and the PUS services concerning the DPUs are actually processed by the ICU. So, for instance, a PUS TC packet commanding the exposure will be decoded, interpreted and validated by the ICU, and it will result in a sequence of actions on the two

DPUs using the private internal protocol. Similarly for the flow of HK parameter, which will be collected by the ICU, formatted in PUS TM packets and delivered to the S/C.

The main functions of the DPU that are controlled by the ICU are the setting up and execution of the observing sequence. As described in Corcione et al.,[8] there are three possible read-out schemes implemented by the DPU. In the Multi-accumulation mode, a non-destructive sequence of frames is taken where only some selected frames are read out, organized into several groups, and a linear fit is performed on the average of these groups.

In the Fowler mode the final signal is computed subtracting two averaged groups of frames, one at the beginning and one at the end. Finally, for some calibration a simple up the ramp is performed, where all the frames are stored in memory without further processing (this mode is limited to a single detector at a time). The ICU must then, for each observation, instruct the DPU on what scheme is to be followed and what are the parameters (e.g., for MACC mode, number of groups, number of averaged frames per group, number of frames to be skipped between groups), and to send the command to start the acquisition. In this case, the fine synchronization of the read-out of each detector is managed in HW by the DPU, so the ICU command has the only purpose to synchronize the acquisition with the whole of Euclid activity (for which a coarser synchronization, with an accuracy of the order of a few tens of ms, is sufficient). The On-Board Time (OBT) received by the ICU from the spacecraft will be relayed to the DPUs and synchronized by aligning the start of the major communication frame of the DPUs with the one on the S/C bus.

The ICU must also collect Housekeeping information from the DPU; the amount of data to be exchanged and its frequency will be chosen in such a way as to minimize the load on the DPU, which main task is the processing of the scientific frames. Moreover, since the allowed data rate for HK data to the CDMU is limited, the generation rate of TM packets is designed to fulfill this requirement.The HK data from the DPU will be packetized into standard PUS TM packets by the ICU and sent to the SVM as part of the normal telemetry flow.

4. OPERATING MODES AND MODE TRANSITIONS

In this section we illustrate the NISP operating modes and allowed transitions as defined in the NISP Instrument Operations Concept Document (IOCD). Each NISP mode is defined by a set of HW and SW configurations of the subsystems involved. All subunits, except NI-ICU and NI-DPUs, have only two states: ON or OFF. NI-ICU and NI-DPUs (the active units that execute their own application software) implement more operation modes with their own transition rules.

In fig. 4 it is shown a schematic view of the NISP operating modes as currently foreseen, and the mode transitions allowed. It is also indicated whether mode transitions can be triggered by telecommand or by automated action, or both. Failure detection and recovery procedures are illustrated in the section below.

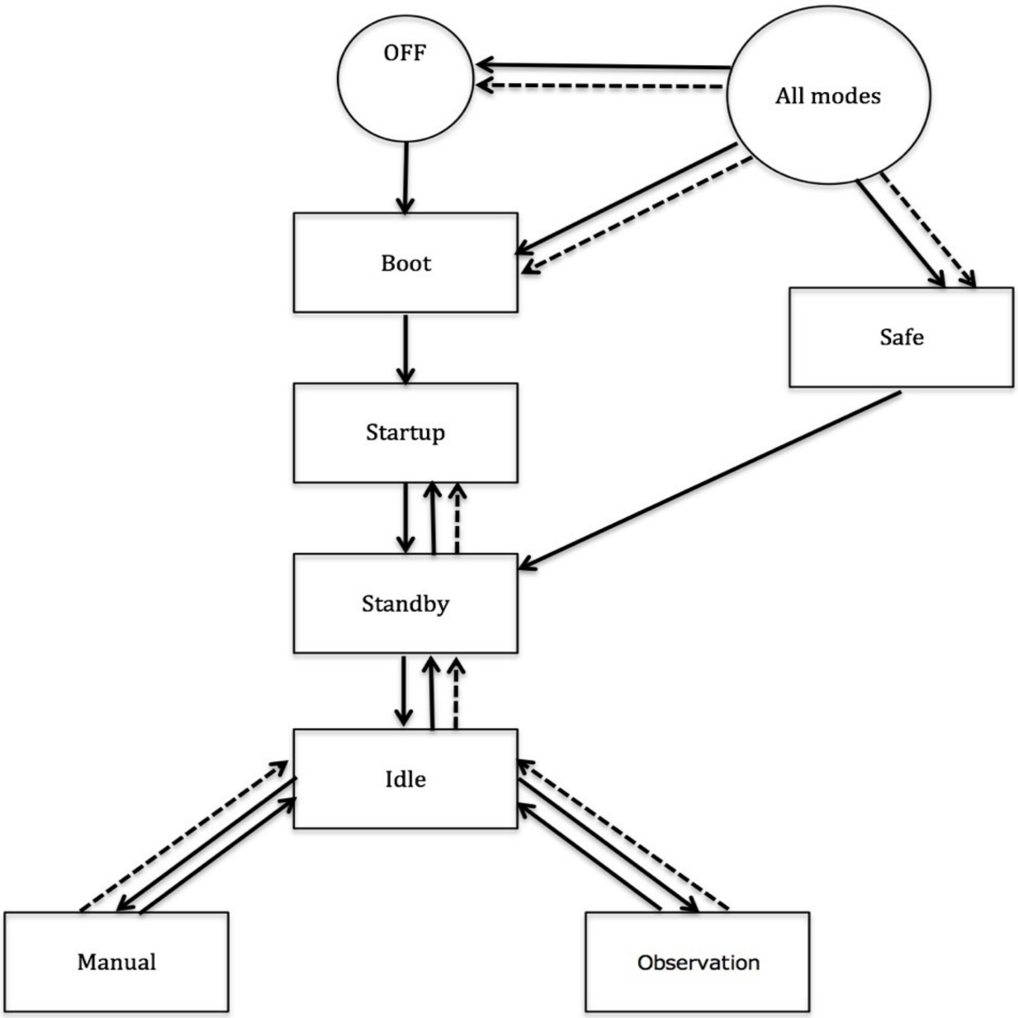

Figure 4. NISP operating modes and transitions. Solid lines indicate commanded transition, dashed lines refers to autonomous transitions

The list of the defined NISP operation modes with a briefly description is the follow:

- OFF: all instrument are powered off
- BOOT: only NI-ICU is powered on and NI-ICU Boot software is executed
- STARTUP: All units could be powered on and the full housekeeping is available. NI-ICU boot sequence is successfully completed and other subsystems could be initialized
- STANDBY: NI-ICU and NI-DPUs are powered on. NI-ICU is ready to receive telecommands from the Spacecraft and N-DPUs have completed the boot procedure
- IDLE: This is the mode to be used in case of minor failure.
- MANUAL: Only NI-ICU must be powered on. This is the mode to be used to have the maximum flexibility. In this way the NISP instrument is commanded by the ground
- OBSERVATION: All units are powered on and NISP is in nominal state.
- SAFE: This is the mode to be used in case of major failure.

Failure detection, isolation and recovery

System failures detection, isolation and recovery (FDIR) is a critical activity that is handled by the ICU ASW. The main requirement for autonomous activities are the following:

- Due to the location of Euclid in L2 orbit, and the limitations of the ground segment, autonomous operations without ground intervention must be guaranteed for up to 72 hours
- Management of other active units (DPUs), and monitoring of possible failure modes
- Necessity to reduce the number of failure modes requiring to switch off the detector system, sincecthe SCS require a long time to reach a stable temperature

The ICU ASW must be ready to react to different anomalies and failures based on type and complexity. The general approach of NISP instrument is the follow:

- Major anomalies will lead to put the NISP instrument in SAFE mode with automatic transition. After that the NISP instrument could be powered OFF (this operation is responsability of the S/C) or could wait a ground interaction.
- Minor anomalies will lead to put the NISP instrument in IDLE mode (in this way the Detector System could be powered ON)

All kind of failures with corresponding recovery actions and response time are described in a Failure Mode and Effect Analysis (FMEA) document. The ICU ASW is designed to implement these functions.

5. DEVELOPMENT PLAN AND CURRENT STATUS

The ICU ASW is currently at the end of the architectural design phase. In September 2016 will be held a Critical Design Review of the ASW. In the meantime the ASW code is under development, in particular code concerning PUS services, telecommands and telemetry handling and 1553 protocol used for ICU-Spacecraft communication.

The ASW image runs on Elegant Breadboard (EBB) representing the CDPU of the flight unit, while the DAS board is replaced by a setup board containing an FPGA that can emulate the operation of the Secoia ASIC that will be used in the DAS board. The setup board, in addition to providing the DAS emulation capabilities, provides also the power to the CDPU board and convert the signal to the debug interface to an RS-232 connector.

Spacecraft simulator

Currently, the 1553 interface is simulated with a Ballard 1553 USB device. This can be operated using a high level GUI (Copilot) or programmed through C APIs. The S/C simulator is being developed using these APIs. It provides the same timing and synch activities expected from the S/C (each major frame lasts one second and is subdivided in 60 subframes, only a fraction of which is dedicated to the NISP ICU), so that the timing of the operations can be simulated in a realistic way.

The exchange of TC and TM packets is also simulated using the same protocol adopted by the S/C, so that it is possible to verify the management of the protocol and the correct generation of the related TM (e.g. acknowledgement of TCs, priority-based generation of TM packets, event generation).

The S/C simulator will be used to implement the different test cases foreseen for the validation tests.

DPU simulator

Similarly to the S/C simulator, a DPU simulator will be created using the Ballard APIs. This will allow to test the behavior of the ICU ASW in presence of one or two DPUs, and this is particularly important since the configuration with two units will not be tested with the real HW until the FM delivery (before that only one DPU unit is available). With respect to the S/C simulator, the DPU simulator will be simpler to develop, but it is coming later in the project because the commanding of the DPU is not completely fixed.

DAS emulator

As it was described above, the current development hardware is not equipped with the Secoia Asic foreseen for the flight model (the first delivery will be with the EQM model foreseen in 2017). Instead, a setup board equipped with an FPGA is available. In order to create a DAS emulation flexible and capable enough to support the development and test of the ICU ASW (and also the Driver software being developed by UAH), it has been decided to program the FPGA of the setup board to provide an efficient emulation of the Secoia ASIC capabilities. This effort (named SecoiaSim) is performed jointly by Italy (INFN) and Spain (UAH, UPCT), and the FPGA firmware should be available in July 2016.

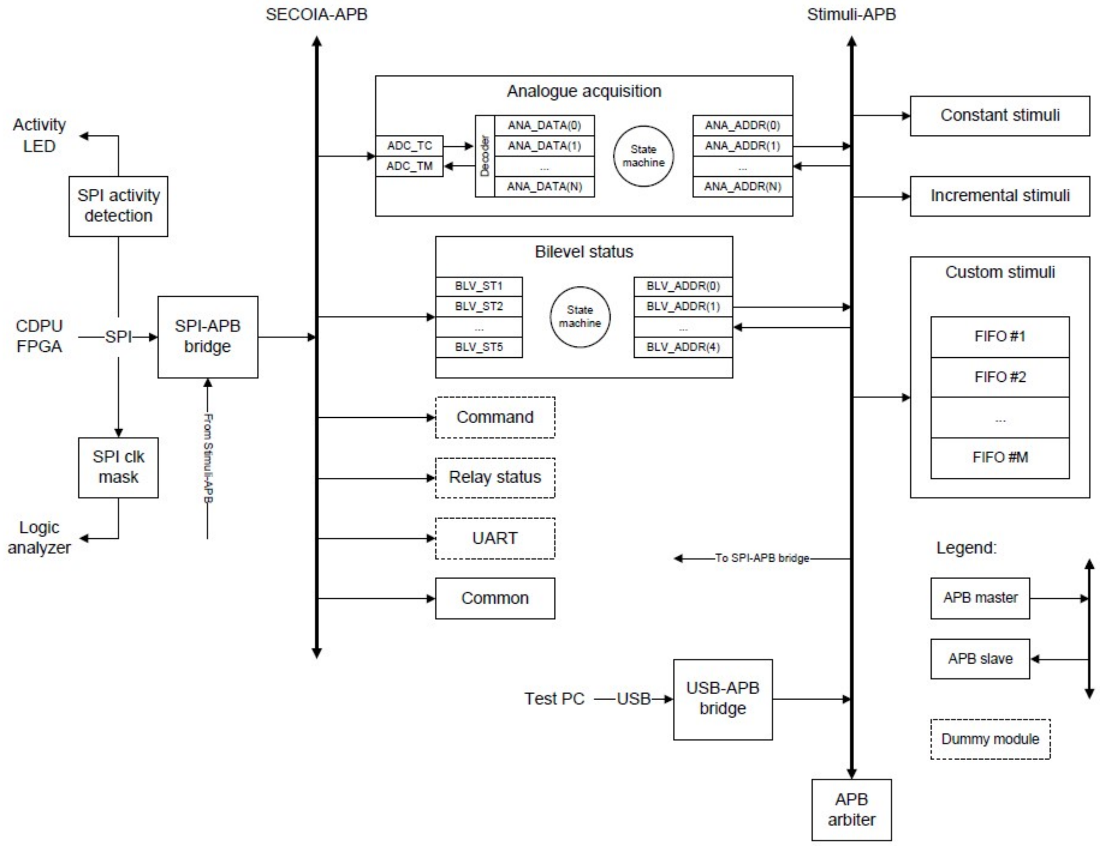

Figure 5: SecoiaSim Block diagram

ICU-DPU integration test

An integration test between ICU and DPU units was performed during April 2016. It was a very preliminary test which served to prove the correct communication between the units via 1553 link. During this activity the initial core of the ICU ASW was debugged. The tasks executed by the ICU ASW were the following:

- Interpretation of messages received on the 1553 link with the spacecraft simulator
- TC interpretation, acceptance and execution (limited to few telecommands to be sent to the DPU through the 1553 link)
- Data acquisition from DPU and generation of TM packets to be send to the Spacecraft simulator

At the moment the ICU ASW handles commands used by the DPU to trigger the start of an exposure and generate a telemetry packet based on parameters received by the DPU Application Status Table. Also an initial version of the Spacecraft simulator was used to transmit TCs and to retrieve the telemetry packets.

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