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Ariel Spectrometer Instrument Control and Data Processing Software

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Abstract

The scientific payload of the ESA ARIEL Mission consists in a 1m-class telescope feeding a two channels near infrared spectrometer (covering the wavelength from 1.2 to 7.8 microns at low and medium resolution) and a four channels photometric instrument (bands between 0.5 and 1.2 microns).

An Instrument Control Unit (ICU) implements the commanding and control of the ARIEL Spectrometer (AIRS). To maximize the overall instrument scientific return, it is important to have an efficient and effective onboard software system implementing both the instrument functionalities control and the necessary onboard data preprocessing activities. This contribution describes the preliminary high level architecture of the ICU control and data processing software.

1. Introduction

The Atmospheric Remote-sensing Infrared Exoplanet Large-survey (ARIEL) is a mission devoted to the characterization of gaseous and rocky exoplanets atmospheres through the direct measurement of their atmospheric chemical composition and structure with transit, eclipse and phase-curves spectroscopy and photometry.

The ARIEL main instrument is a two channels infrared spectrometer (ARIEL InfraRed Spectrometer, AIRS) covering the wavelength range between 1.25 µm and 7.8 µm. The AIRS detection chain is based on the use of Teledyne Imaging Sensors (TIS) H1RG in both spectral channels (512 x 512 pixel with 15 to 18 µm pixel pitch, based on the technology used for the NASA NEOCam payload). The sensors are well suited to detect the infrared wavelength absorption band of all the molecular species expected to play a key role in the physics and the chemistry of planetary atmosphere.

The detectors data are acquired by dedicated cold front end ASIC Sidecar. The analog detection process is digitally controlled by a proper warm front-end electronics (Detector Control Unit, DCU) which is part of the payload Instrument Control Unit (ICU). ICU implements the interface with the Spacecraft, executing the telecommands scheduled by ground and controlling the overall instrument behavior. The unit is structured in four main sub-units: Data Processing Unit (DPU), Housekeeping and Calibration source Unit (called TCU, Telescope Control Unit), Power Supply Unit (DCU) and DCU. The ICU hardware design strongly depends on the data rate and volume to be managed on-board and on the system needs in terms of real time data pre-processing. ICU functionalities are related to both the scientific data handling and the ARIEL scientific payload control.

2. ARIEL ICU On board Software

The ICU on-board Software will implement all of the ICU functionalities and will be composed by the three main components: Basic Software (BSW), Application Software (ASW) and Real Time Operating System (RTOS). The on-board data processing software (scientific SW) will be implemented as a part of application software.

1. Basic Software: it is the component more strictly linked to the ICU HW electronics. It includes the ICU Boot SW (i.e. the SW procedure that is executed at unit switch-on and initializes all the unit functionalities, included the management of the unit interface with the spacecraft) and the Basic I/O SW, Service SW & Peripheral Drivers (i.e. a HW-dependent Software including the Software Drivers for all the internal and external ICU digital interfaces).

2. Application Software: it implements the ARIEL scientific payload handling, controls the spectrometer, monitors the instrument health and runs FDIR

procedures. It implements the interface layer between the S/C and the instrument. The Application Software includes the Data Processing and Compression functions (i.e. all the necessary on-board processing procedures, included the on-board lossless compression, if needed). After the processing the SW prepares CCSDS packets for the transmission to the S/C Mass Memory (SSMM).

3. Real-Time Operating System: the selected baseline operating system is RTEMS.

The role and the interconnections between the three listed components can be clearly identified in the layered representation reported in Figure 1.

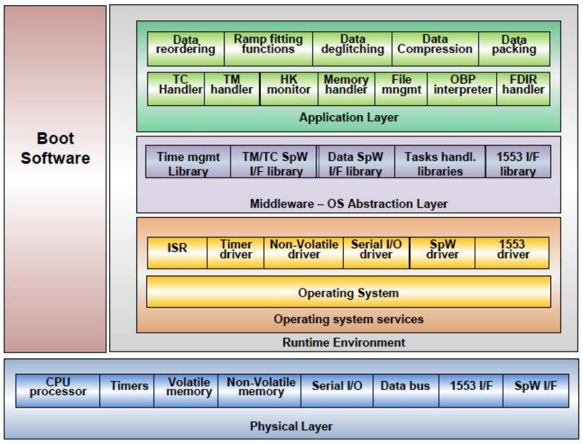

Figure 1: SW layers structure of the ARIEL payload instruments on board software.

The physical layer includes all ICU HW components with a direct level of interaction with the on-board software. The Runtime environment includes the RTOS layer, necessary to provide multi-tasking support. The other indicated system services are those not directly provided with the OS kernel, but included in the Basic Software Component mentioned above. An OS abstraction layer is included, in which all middleware libraries have been considered. The middleware services are based on the use of RTOS function calls. They include all library functions dedicated to the low-level handling of the ICU HW devices/interfaces. All the middleware libraries will be developed in house and will provide a mean for developing the Application Software virtually independent from the HW and OS below it. This layer is very important and will ease the testing activities. The Application Layer includes both the ICU Instrument Control software and the Data Processing software.

The ICU Instrument Control SW will implement the TM/TC S/C interface handling, the payload housekeeping data acquisition and monitoring, the instruments operating modes management and the autonomous function execution. In case stringent timing requirements have to be met for subsystem commanding, an interrupt driven command sequencer (On Board Control procedures, OBCP interpreter) can be included into the ICU on board software.

3. AIRS data on board processing

The AIRS detectors data will be acquired and pre-processed onboard, to minimize the overall data volume [1]. The possibility to implement a non-destructive readout strategy is a powerful tool for the on-board data analysis, allowing for an evaluation and, possibly, the elimination of the radiation effects on the detectors data [2]. A gain in the signal to noise ratio can be achieved as well [3].

In Figure 2 a generic and preliminary onboard data processing chain is shown. The sequence of activities is based on the heritage and experience obtained with the simulations made for the instrument VNIR designed for the ECHO mission [4]. The main processing steps are: 1) Bias correction: an internal bias is subtracted to bring all samples to the same “ground”; 2) pixel reordering: pixels are extracted from the readout electronics output serial stream and reordered, to increase the effectiveness of the subsequent data processing steps; 3) saturated pixels identification, by defining a cut-off value for the upper limit of the linear region of the detector’s response curve; 4) responsivity correction, based on radiometric calibration, using an array responsivity map; 5) spatial and spectral pixel binning to build spaxels; 6) temporal samples co-addition: depending on the ramp fitting algorithm, (“scans” and “groups” have to be formed) if needed; 7) rejection of the data that don’t satisfy the noise requirement at the beginning of the ramp, when necessary; 8) non-linearity correction; 9) progressive linear least square fit to calculate ramps slope (pixels/spaxels photocurrents) ; 10) cosmic rays and other glitches identification: proper glitch detection and rejection strategies will be implemented, if necessary, with a proper algorithm still to be defined; 11) bad spaxels correction and linearization; 12) frame generation:

processed science frames created here will be received on ground; 13) frame buffering; 14) lossless compression (compression of the data to save data volume and bandwidth); 15) packetization according to the required TM format: all data products will be packaged; 16) storage in the spacecraft mass-memory and scheduling for transmission

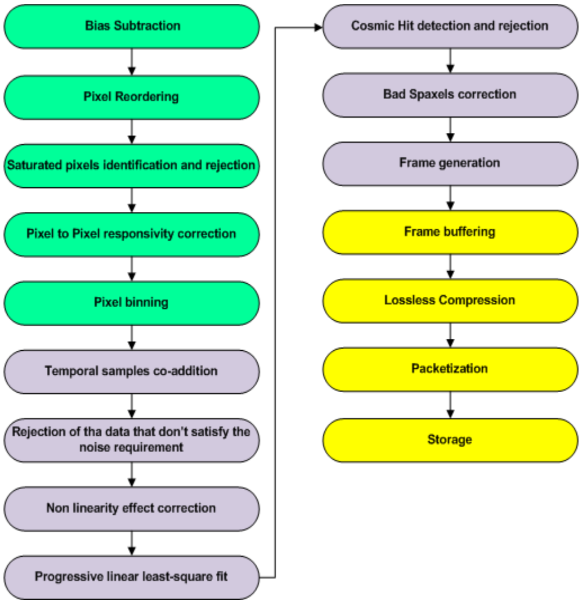

Figure 2: Green blocks refer to pixel pre-processing activities; purple blocks refer to processing steps at spaxel level and yellow blocks identify frame level processing activities.

The listed steps refer to the processing of a single focal plane spectrometer channel. A parallel processing of the two channels operating simultaneously will be implemented.

4. Summary and Conclusions

The final overall processing of AIRS data will be defined in the next phases of the mission and tailored for each one of the spectrometer channels. Dedicated simulated data flows will be used to verify the effectiveness of the data reduction steps, starting from the evaluation of the best detector sampling strategy as a function of the ARIEL targets luminositiy. In addition, the deglitching algorithm performances should be verified against the expected data redundancy, the data acquisition rate and the spaxels (*NxN* binned pixels along the spatial and spectra resolution) dimensions. Since the need to implement lossless compression on-board will be strictly related to the effectiveness of the on-board deglitching study, a dedicated trade off analysis will be done to evaluate the expected level of compression.

Finally, once assessed the real onboard data pre-processing needs, the possibility to perform some of the needed steps via hardware and/or on Ground will be considered.

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