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Mission Monitor and Control Platform for TUMnanoSAT Ground Segment

Valentin ILCO [1] ,Vladimir VĂRZARU [1], Nicolae SECRIERU [1]
[1] Center of Space Technologies of Technical University of Moldova,
Chisinau, Republic of Moldova
e-mail: valentin.ilco@cnts.utm.md, vladimir.varzaru@cnts.utm.md, nicolae.secrieru@cnts.utm.md

***Abstract*—This document will cover the overview, development and implementation of mission control platform for TUMnanoSAT, a CubeSat developed at Technical University of Moldova. A mission control platform is essential for a space mission in order to command and control different subsystems, monitor their health, process telemetry and useful data, receive and control requests but also in presented scenario it should be strongly linked to radio software defined architecture from ground station.**

Keywords—satellite; mission control; ground segment; TUMnanoSAT; communication; Software Defined Radio

I. Introduction

Global space activities in general and CubeSats in particular are experiencing unprecedented growth. Just in 2020 the world registered 1260 new satellites and other space objects with the United Nations Office for Outer Space (UNOOSA). It means that just in one year were registered 10% of all space objects ever registered since 1957 [1]. Also, as for 2021, over 1500 Cubesats were launched [2].

Center for Space Technologies from Technical University of Moldova aligned with those standard and developed a Cubesat which will be launched from International Space Station after winning KiboCube round 4, organized by UNOOSA and Japan Aerospace Exploration Agency (JAXA). TUMnanoSAT was developed based on international Cubesat Standard [3].

Figure 1. TUMnanoSAT – a 1U CubeSat

The basic mission of this satellite is an educational one, in the light of offering students, masters and PhD students the possibility of direct involvement in the design, development, integration, launch and post operation of a nanosatellite. Apart from educational purpose, TUMnanoSAT has other missions, including scientific objectives:

- Research of sensors based on nanostructures under space conditions;
- Establishing an efficient satellite - ground station communication mechanism;
- Research of the total irradiation dose (TID) level using RadFET. [3]

Besides satellite, in every spacecraft system, there is always ground segment which basically consist of ground station and a monitor and control center. In order to assure a successful mission, at Center of Space Technologies was set up a whole infrastructure with two ground stations and a mission control center with the possibility of processing, command and control.

Figure 2. Mission Monitor and Control Room at Center of Space Technologies

II. Ground Station of TUMnanoSAT

The reception of the satellite telemetry data and payload data is achieved through a radio architecture. The functionality of a traditional radio architecture, within a satellite communication, is primarily based on hardware components, with minimal software configurability [4].

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Conventionally, they consist of: modulators, coders, amplifiers, filters, mixers, etc., dedicated to a certain mode of transmission. The software part is dedicated to the control of the interfaces with the communication network.

Given that the hardware predominates in this model, a possible upgrade of the system would mean a total change of the model and a redesign of the system. Taken into account that ground station should be able to communicate with different satellites that have different communication parameters this traditional hardware radio architecture is outdated. SDR or Software Defined Radio solves this problem. The IEEE have defined SDR as a „radio in which some or all of the physical layer functions are software defined" [5].

SDR provides a new approach in designing a ground station, an approach that brings primarily significant reduction in design complexity, cost and offers a flexible environment, versatile radio architecture development.

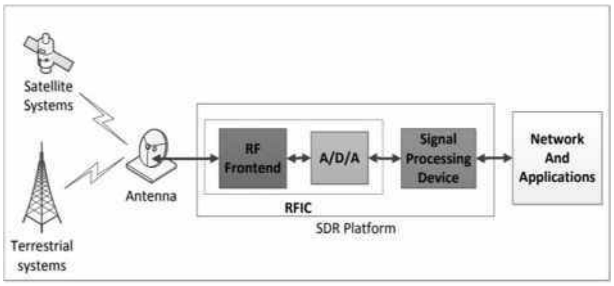

Figure 3. Generic SDR-based radio system [6]

As was mentioned in a SDR platform radio specifications can be implemented entirely by software, making also less complex integration of this platform in mission control platform. At this time, there are a lot of frameworks for implementing radio functions and digital processing units. The most popular being GNU Radio The USRP is usually controlled by GNU Radio software, an open software with a lot of digital processing blocks for signal acquisition, error correction, message handling, etc. Also, this open software allow to create digital blocks from scratch for specific requirements. It can be used with external RF hardware to create software-defined radios, or without hardware in a simulation-like environment [6].

The continuous developing of SDR technology made possible to have Commercial-off-the-shelf (COTS) SDR frontends. One of the most popular is USRP B series from Ettus Research with a coverage from 70 MHz to 6 GHz [7].

This frontend along with GNU Radio and other components of ground station (antenna, feeder, rotor, relays, etc.) is used in TUMnanoSAT ground station.

Those components should be implemented in mission control and communication platform.

III. CONTROL AND COMMUNICATION PLATFORM

The main problem of existing open source or commercial platforms for mission control is that there is almost no possibility to integrate SDR component in their framework. Therefore, was decided to develop and implement a custom solution for mission monitor and control.

The mission control and communication platform for TUMnanoSAT is divided in 3 general blocks. The first block represents the USRP E310 which is the frontend device in this SDR architecture. The second big block is the signal processing algorithm, created using GNU Radio Companion and the third component represents the application itself that makes the interaction with the user. The tool that chains all the mentioned blocks into a complex system is the ZMQ protocol. Here are used push/pull types of ZMQ sockets to make the main blocks communicate between them.

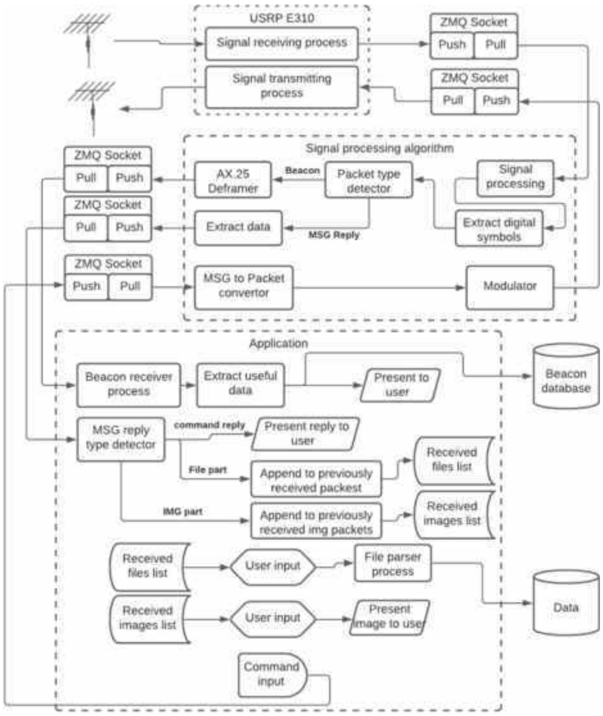

Figure 4. Architecture of mission monitor and control platform

The USRP E310 device doesn't have much responsibility in this architecture when it comes to processing. The main tasks for this device here are digitalizing the signal that it receives from the satellite and sending the digital data to the signal processing algorithm via LAN or, if speaking of transmitting signals than the task consists of receiving the digital samples via LAN from the processing algorithm and sending them through air to the satellite.

The signal processing block is basically a very complex python script created with the help of GNU Radio Companion software. The main functionality of this block consists of receiving the digitalized data from the USRP E310, demodulation of the signals, extracting digital symbols, detecting whether there is a beacon packet or a command reply type of packet and sending the data to the corresponding ZMQ Socket. On the other hand,when there is the need to transmit data, this block receivesthe message of the command through ZMQ from

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the upper layer application, packs the message into a corresponding packet, modulates the message and sends the samples to the USRP E310 where the signal is emittedthrough the air.

The application closes the loop in the architecture. Besides interaction with the user using its graphical interface, there are some more tasks that this block has to complete. One of the tasks is running a beacon receiver which receives the beacon packets from the signal processing algorithm, extracts the useful data from the packet and presents the data in a user-friendly way. The extracted data is also sent to the beacon database to be stored for later processing if needed.

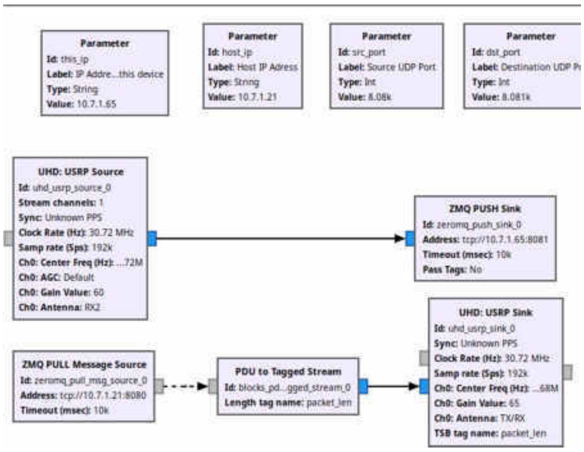

Figure 5. Flowchart of Frontend USRP

Another task that has to be done at this level is running the message reply receiver. This is the process that receives the data related to answers for the sent commands. The answer to the commands can be one the next three types: command reply text; file part; image part. If the receiver detects the command reply type of message the message is simply presented to the user in the log window. Otherwise, if the received message is a file part or a image part, it is appended to the corresponding packets that were received earlier and represent the same file or image. When the process of receiving a file/image is finished, the file/image is appended to the list of the received files/images. The user can select any image from the list and it will be presented or it can select the files from the received files list and extract the useful information from the file. When the information is extracted from a received file it is automatically sent to the database, if the database is connected, where it is stored for later.

The last but not the least important task that is done by the application block is giving the user the opportunity to send the commands to the satellite. The command for the satellite can be typed in manually or selected from the dropdown menu. When the command is selected, or typed and checked, it is then sent, via ZMQ, to the signal processing algorithm where it is further processed and sent to the satellite.

The mentioned application has an extended functionality. First of all, the application allows the transmission of commands to the TUMnanoSAT educational nanosatellite and the reception of the answers from it. The commands can be configuration (commands that allow setting the parameters of the nanosatellite subsystems), resetting (commands that allow resetting the parameters to the default values or resetting the subsystems in part), data request (commands that allow the nanosatellite to request the data recorded by the subsystems image request (commands that allow you to request images taken in a specified orbit).

In addition to the service communication with the nanosatellite, mentioned above, the application allows the reception of the beacon that it emits with a determined interval depending on the energy budget available to the nanosatellite. The beacon involves a series of parameters that describe the operation of the nanosatellite. Parameters such as the number of pictures taken, the voltage on the battery, the voltage on the solar panels, the error codes if any, the operating time of the nanosatellite, the number of its resets and much more. The beacon is packaged using the AX.25 amateur radio protocol on the 436.68 MHz frequency. This information is public and anyone who has a resonant antenna in the UHF band with sufficient sensitivity, as well as a device or algorithm capable of extracting information from AX-25 packets can receive and decode the beacon emitted by the nanosatellite.

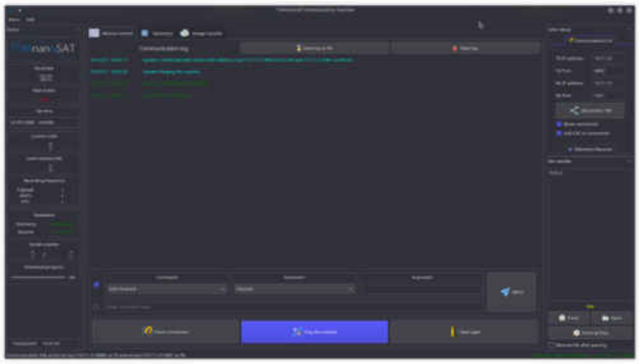

Figure 6. Application interfce of Mission Monitor and Control Platform

IV. THE MISSION MONITOR ANT CONTROL PLATFROM VALIDATION

The validation part of the monitoring and control platform with the integration of the functionalities of the SDR component within the architecture was performed in a typical scenario of ground station – satellite communication through the application presented in the previous chapters.

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There were validated 4 basic functionalities of the mission monitor and control platform with the scenario described above:

- Checking the command-response grid between the satellite and the earth station
- Decoding the telemetry from the satellite with the presentation of the states on each subsystem
- Download, decode and present the images captured by TUMnanoSAT
- Downloading, decoding useful data and entering them in the database for further processing

Figure 7. Application interface of Mission Control Platform

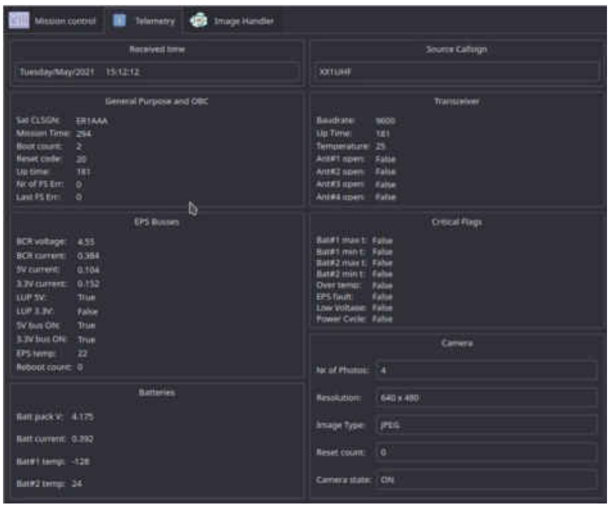

Figure 8. Decoded telemetry of TUMnanoSAT

For the first validation was tested the command-response grid of satellite. There were checked all possible commands from ground station to satellite. Each time the satellite responded with corresponding messages. An example is presented above.

Telemetry was sent from satellite at 30 seconds interval (depends of battery state). The platform successfully decoded all AX.25 and the state off all subsystems off satellite was monitored.

The image and useful data acquisition, decode and storage also passed the verification within the mission monitor and control platform. Also, it was decided to apply automatic request for missing packets on important data acquisition.

V. CONCLUSIONS

In this paper was presented the architecture, development and implementation of the mission monitor and control platform for TUMnanoSAT ground segment.

It was described the possibility of integrating the Software Defined Radio communication component in the general architecture of the monitoring and control, predominantly using the ZMQ sockets as an abstraction of an asynchronous message queue.

Analyzing the validation of mission control platform, it was observed that proposed architecture with 3 general blocks: SDR frontend, signal processing block and application could be a solution for a ground segment in a typical Cubesat mission.

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