An Exploratory Analysis and Data Visualization of the NanoSatC-BR2 Telemetry Data

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Abstract. *The NanoSatC-BR2 (NCBR2) is the second satellite of the NanoSatC-BR program and it was launched on March 2021. Its operation was held by a small group of researchers and students in different states of Brazil. This work aims to show the results of an exploratory data analysis and visualization to help the understanding, planning, and scheduling of the NCBR2 operations. Using a series of scripting functions and methods, we automatize the data inputs from different sources, data validation, decode, identification, and visualization for the received operational telemetry data for this spacecraft. With the help of the HamRadio Community, we were able to increase the number of frames and measures from the NCBR2. The analysis was crucial to speed up the meetings and optimize the time spent on decision-making situations. Here, we show a small part but concise results of these analyses during the following 3 months since its launch.*

Keywords: Nanosatellite, Operational Data, EDA, Data Visualization, NanoSatC-BR2.

1. Introduction

The NanoSatC-BR2, NCBR2, satellite was launched on the 22nd March 2021, from Baikonour Cosmodrome, Kazakhstan. And it started sending data since its separation from the launch vehicle. To better understand the NCBR2 behaviour and plan its operation, the authors as responsible for the operation coordination lead an exploratory analysis and set up the visualization of the data received from the satellite to present its information to the Principal Investigators and other NCBR program stakeholders.

The use of exploratory data analysis (EDA) is a well know approach to post process different sources of data and figures as one of the main activities at the Data Science world (BLEI; SMYTH, 2017; MILO; SOMECH, 2020). When we talk about the use of EDA methods for space systems it is common to associate its use with the analysis of products and timing series. It means that most of the work available about satellite data is about the data/info/images generate by spacecraft payloads.

Data visualization (QIN et al., 2020) has been used at the operation engineering as a common tool mainly during the overpass activities, as an easily way for the operator to get access in real time to data and information for decision making, and, of course, at report writing on post-overpasses activities.

Access to spacecraft health information is crucial for a good and successful operation (CATER; QUIGLEY, 2006). The operator has access to real time data from the satellite during the overpass activities in order to deal with FDIR (Fault Detection Isolation and Recovery) protocols, unexpected situations could be handle in post overpasses activities with the operation and satellite specialists bureau. Operation telemetry data builds and feeds a historical database that can be queried, searched and accessed to evaluate the spacecraft evolution and feedback lessons learned to other missions and satellites.

Information about satellites operational data, telemetries, and other housekeeping data is almost unavailable, i.e. for CubeSats, even nowadays. Most of this lack of information is due to: (i) the difficulty on assembling your own tracking ground station to receive these data; (ii) access to the radio-frequency channel through where the satellite is transmitting data; (iii) even if you are able to receive the data frames from a satellite, you have the problem on decoding the frames.

With the miniaturization of the technology, the advent of the CubeSats (PUIG-SUARI; TURNER; AHLGREN, 2001) and access thought software-defined techs, points (i) and (ii) are being more and more knocked out. Initiatives as SatNOGS (WHITE et al., 2018) and Ham-radio communities enables the access to university CubeSats data. The problem still arrives when we need access to the information inside all these zeros and ones data frames that can tell us more about the satellite health and status.

2. The NanoSatc-BR Program

The NanoSatC-BR (from Portuguese, *NANOsSATélite Científico BRasileiro*) is a space scientific program with technological, scientific and human resources objectives developed by INPE (Brazillian National Institute for Space Research) through its Southern Space Coordination (COESU) in Santa Maria, in the southern region of Brazil, in cooperation with the Federal Universiy of Santa Maria, UFSM (SCHUCH et al., 2019).

Nowadays, the NanoSatC-BR, NCBR for short, is composed by two satellites, NCBR1 and NCBR2, launched in October 2014 and March 2021, respectively. Both satellites, as part of the program, shared the main program goals: (i) technological, development of hardware and software for the satellite as subsystems and ground support equipment for the space area; (ii) scientific, study of the Earth Magnetosphere, in special the South America Magnetic Anomaly, and other mesarues for the Space Weather field and; (iii) human resources capacity building, the NCBR program, with its two satellite missions, was able to develop PhD Thesis and Master's Dissertations and journal papers on space technology and science trend areas of study, training human resources on Assembly, Integration and Tests activities for CubeSats, new methodologies for software development and etc.

The Table 1 shows a simple comparison between the satellites NCBR1 and NCBR2 and their main differences.

Table 1. Comparison between the satellites NCBR1 and NCBR2

ITEM		NCBR1	NCBR2
Mass		$\sim 1kg$	$\sim 1.7kg$
Volume		1U ($10 \times 10 \times 10cm^3$)	2U ($10 \times 20 \times 10cm^3$)
# Payloads		1	5
OBDH Software		heritage	INPE's developement
Launch	**date**	19 June 2014	22 March 2021
	local	Dombarovsky	Baikonour
	vehicle	Dnepr	Soyuz-2
AIT	**facility**	ISISpace, Delft	LIT-INPE, São Jose dos Campos
	team	ISISpace	INPE

3. Methodology

The method used for this paper is based on data processing levels (NASA EOSDIS, 2021), usually for application data but, here, the same logic can be translated. Starting with (i) the identification of the data sources, in this case, the NCBR2 Ground Segment; (ii) acquisition of the KISS (Keep It Simple, Stupid) frames (CHEPPONIS; KARN, 1987), L0 data; (iii) export HEX files with hexadecimal frames, L1 data; (iii) validate and decode this data, L2 data; (iv) identify and geo-reference the information, L3 data and; (v) data visualization. All these steps are presented at the Figure 1.

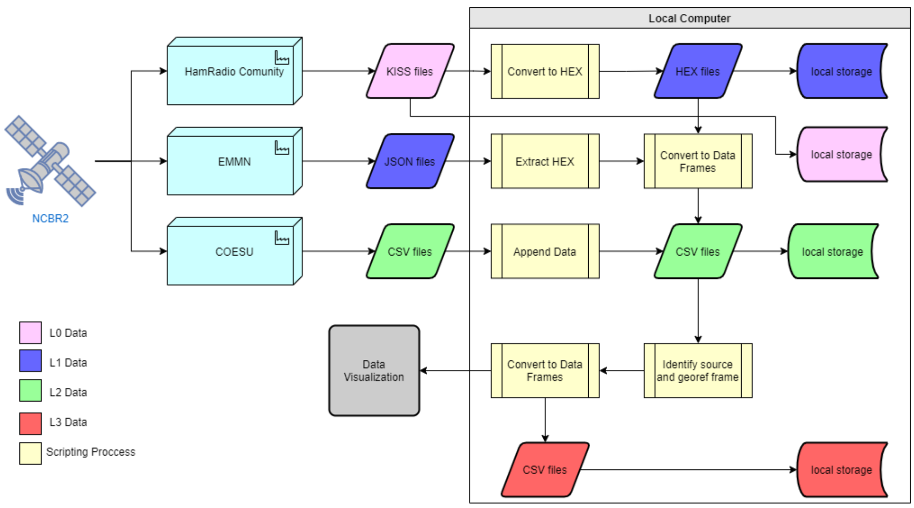


Figure 1. NCBR2 Telemetry Analysis Dataflow

And explained as:

1. Ground Segment: The set of Ground Stations and HamRadio Community Stations that can receive data from NCBR2. The HamRadio community usually sends the frames with the *.kss* extension, or KISS files, that needed to be converted on hexadecimal files and metadata as local reception time. The Natal Multi-Mission Ground Station, or EMMN, can receive the data and make it available through JSON files with the HEX frame other metadata, i.e. local reception time. The INPE's Southern Space Coordination receive the data, and as NCBR2 main ground station can make the data available already decoded and organized as *.csv* files.

2. L0 data: The KISS files from HamRadio Community that needs to be converted to HEX files in order to be validade and decoded.
3. L1 data: The HEX files from the KISS files or exported from the JSON files from EMMN.
4. L2 data: The HEX frames need to be validated (i.e. confirmation of expected size and expected AX.25 header) and decoded into engineering values (e.g. volts, miliamperes, dBm, etc).
5. L3 data: Once decoded, the Data Frames generated are merged with additional information as the reception ground station or HamRadio operator identification and the estimated geo-reference (latitude and longitude) of the satellite at the transmission moment.

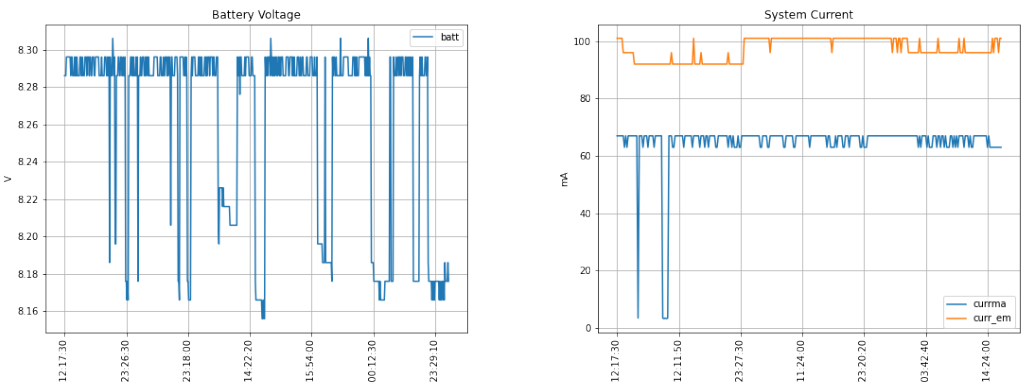
The process between the generation of each data level are python scripts and methods (*.py*) and notebooks (*.ipynb*) available on a GitHub repository.

All the data levels products are stored locally and in cloud repositories in order to make all the analysis traceable and reproducible.

4. Results e Discussion

In this section we will present and discuss the results of the telemetry data analysis and data visualization that had direct impact at the NCBR2 operation.

At the Figure 2, we can see the electrical characteristics of the NCBR2, i.e. battery voltage and total system current. Also, on the Figures 2b and 2c we have a comparison with the measures made at the Engineering Model (EM) located at the LabV&VSis – Laboratory of Software Intensive Systems Verification and Validation.

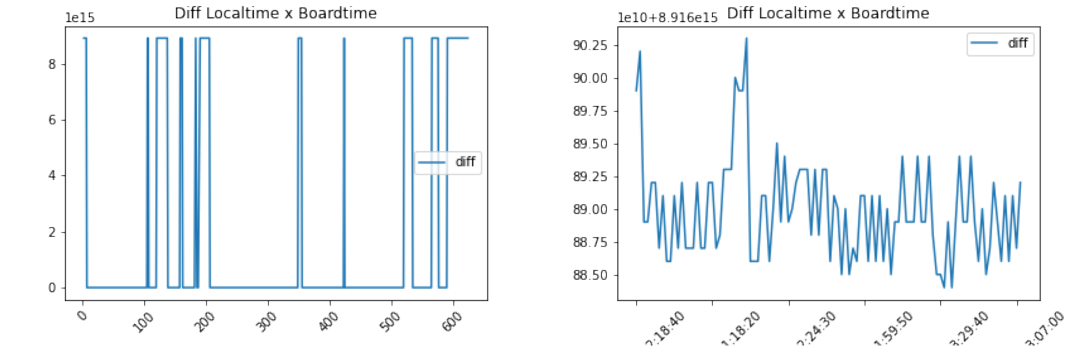


(a) *Battery Voltage* (b) *System Total Current*

Figure 2. NCBR2 Electrical Characteristics (blue) and Comparison with the Engineering Model (orange)

We can see that the battery voltage (Figure 2a) presents an expected set of values, between $8.306V$ at sunlight and $8.156V$ on eclipse. These values tell us that the battery is correctly charging and discharging without the compromising of its characteristics. Besides this nominal functioning of the battery, no perceptive degradation on the voltage level, the measures of the total current (Figure 2b) were lower than expected and measured at the EM (orange lines).

That kind of values may represent a fault in one of the electric power subsystem (EPS) power converter/voltage regulator or something exterior to the EPS is degrading its efficiency, e.g. low operation temperatures.

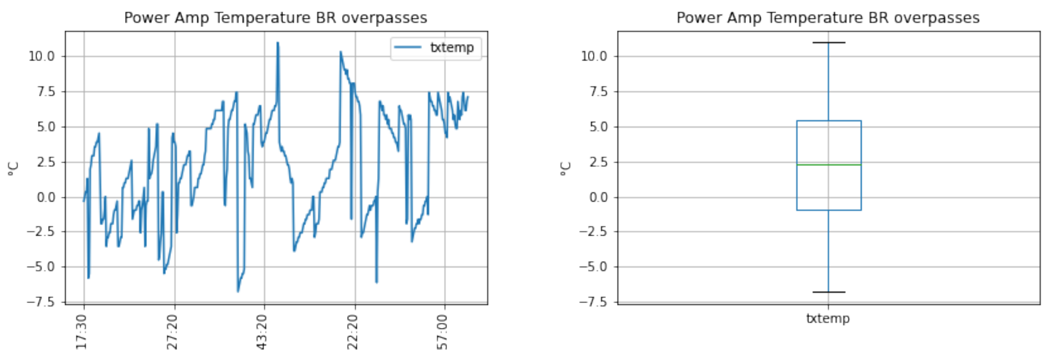


(a) *All received frames* (b) *Only frames with Local and OnBoard Tme*

Figure 3. Difference between the NCBR2 Onboard time and the Ground Reception Local Time

Another thing to pay attention at the received data was find out a way to verify if the OBDH (OnBoard Data Handler) was resetting. As all the received telemetry from NCBR2 has a timestamp from the OBDH on the moment of the transmission and all ground stations also puts a similar timestamp on receiving, the idea was to compare these values. Even if the onboard timestamp was different from local, we can verify if the interval between them (local and board time) is constant. If true, it means the onboard timing system is not resetting, so the OBDH is not resetting also.

Figure 3a shows us that, when we have both information (local and board time), the interval is constant, or nearly constant, which means that the NCBR2 is not resetting for any reason. We say nearly constant because Figure 3b demonstrate that is not exactly constant but it is on error margin due to the nanoseconds to seconds approximation when we perform the calculation (max of 29 seconds of difference in 3 months of operation)



(a) *Temperature measures* (b) *Temperature BoxPlot*

Figure 4. NCBR2 Temperature Profile on Brazilian stations overpasses

At last, we perform a analysis on the temperature for the NCBR2. The measures came from the temperature sensor installed at the Transmitter Power Amlplifier. Looking at the Figure 4 we can see that during the overpasses in Brazil, the NCBR2 is operating between 0 and 5 degrees Celsius (Figure 4b). This low temperature can be the cause of the low current saw earlier or even an effect of this low power if we think on a electrical problem, e.g. fault on one or more power converters. But, one problem that is caused by this low temperature levels is the high correlation between the temperature and the down- and up-link frequencies. As this said, the frequencies trends to shift (a lot sometimes) due to the low temperatures of operation. At the downlink is easy to see, as we track the satellite, we can see the frequency shift on our ground radios.

For the uplink, is a little bit more tricky. We have to analyse the radio-frequency characteristics of the satellite in order to understand how the uplink frequency changes over the time due to the temperature. For this, we analysed two other data from the telemetry frames: Received Signal Strength Indication (RSSI) and the Doppler Effect shift, as show at the Figure 5.

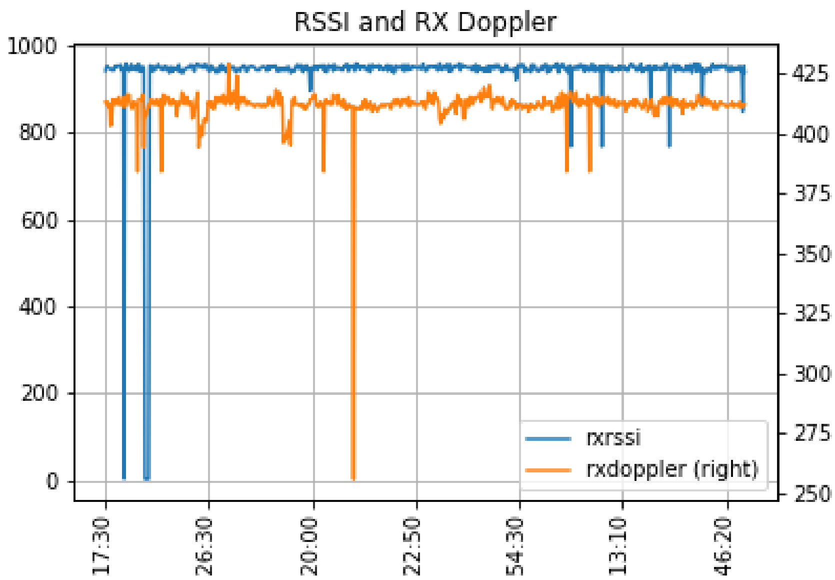


Figure 5. NCBR2 Received Signal Strength Indicator and Doppler Shift on the Uplink Channel

With these indicators, we can look back to the onboard receiver datasheet and point out the change on the uplink frequency over time and plan the operation. Every valley on the RSSI value, means a signal strong enough to be received by the satellite, and the doppler shift can tell us whats was the frequency at that moment that caused this sensibility. A series of telecommands can be send to the NCBR2 to power on different payloads and subsystems in order to elevate the total system power and, consequently, rise the operational temperature of the spacecraft. That is one the approaches tried by the operations team of the NCBR2.

5. Conclusion

An well done exploratory data analysis and visualization at the telemetry data of any satellite can be the difference between a successful operation and not. The teams can better understand whats is happening to the satellite, can better define behaviours, expected or not, of the subsystems. And they can plan better and more efficient fight plans for the spacecraft and the use of its resources.

Even more, with the use of automation, and scripting of these analysis, they can feed and teach new planning and scheduling algorithms to not only help the operations team on decisions making but also optimize the use of resources, on ground and onboard.

This exercise was fantastic for the NCBR2 and helped the operational team to fill up plans during the LEOP (Launch and Early Orbits Phase) and Commissioning Phase. These visualizations speeded up the meetings and helped not only the operations team but also the payload PIs to better understand what was going on with their experiments.

Also, all these data and analysis remains as lessons learned and historical database, public and open-access, to everyone that wants to study these data, learn from it, or even exercise their capabilities with the data, the scripts and the hypothesis from this work.

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