Comparing satellite telemetry against simulation parameters in a simulator model reconfiguration tool

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Abstract. *Operational satellite simulator models require updates in order to reflect the behavior of the actual satellite, especially after several years of flight operations. Because it can be extremely costly to modify them manually, a software tool for autonomous reconfiguration of operational simulator behavior models is proposed. To implement such a feature, behavior models must be reassessed and reevaluated to identify the need of model updates and to trigger them. This can be achieved by periodically monitoring discrepancies between the satellite telemetry and the simulator parameters. This paper describes a procedure for comparative analysis between telemetry and simulation parameters for an autonomous reconfiguration tool for operational simulator behavior models for synchronization.*

Keywords: Spacecraft Operations; Ground Control Software; Telemetry, Tracking and Commanding; Software Simulation.

1. Introduction

When operational satellite simulators are released, their internal models are built based on the designed behavior of the onboard equipment at the beginning of life. After the satellite starts operating, the simulator behavior model must be reconfigured to account for onboard components degradation and equipment failures. During the simulator development, the pressure to deliver it on schedule may lead to the design of behavior models that are easy and fast to implement, but difficult and time consuming to modify and maintain. Therefore, manual adjustment of simulation parameters may become extremely labor intensive and impossible to achieve within the satellite lifetime. To avoid this, a software tool to perform automatic reconfiguration of simulation behavior models was proposed. [Tominaga et al., 2016]

An overview of the software architecture for a rule-based operational satellite simulator is shown at the right side of Figure 1. Rule-based modeling is adopted by INPE (National Institute for Space Research) to develop the operational simulator for CBERS (China-Brazil Earth Resources Satellites). This simulator consists of a kernel, responsible for simulation control and interfaces, connected to databases that store simulation parameters and behavior rules. Each behavior rule comprises a precondition and one or more effects, which are conceived as mathematical expressions. Simulation parameters representing internal states are stored in the simulation history database at each simulation step. [Ambrosio et al., 2006] [CBERS, 2006] [Tominaga et al., 2012]

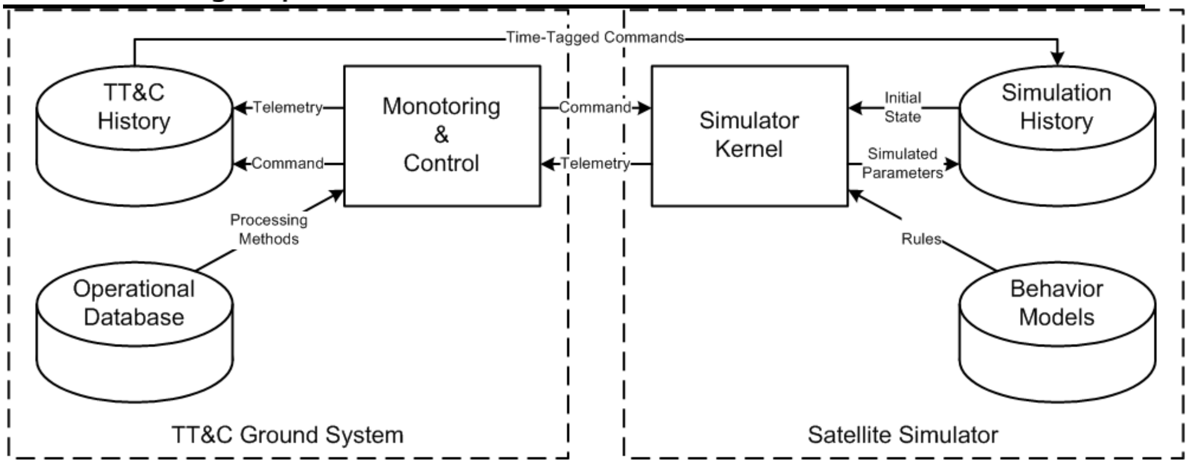


Figure 1. Operational simulator software architecture.

Satellite control activities are performed by the telemetry, tracking and commanding (TT&C) ground system, shown in Figure 1 at the left side. Under normal conditions, the monitoring and control application is used by the TT&C operator to send commands and receive telemetry from the satellite or, in this case, the simulator. All exchanged data is logged and stored in the TT&C history database in raw binary format. Their processing methods are placed separately in the operational database. To synchronize the simulation parameters initial state with the TT&C ground system, the simulator must retrieve data from the TT&C history. [Cardoso et al., 2006]

For automatic model reconfiguration, the connection between the behavior models and the satellite simulator is changed to an indirect one, as indicated by Figure 2. The model reconfiguration tool, shown in gray, retrieves the original rules from the behavior models database. Commands retrieved from the TT&C history are scheduled for time-tagged execution by the simulator. Telemetry values obtained from the TT&C history archive are compared against corresponding simulation parameters at each simulation step. If discrepancies are found between telemetry and simulation parameters, new rules are generated and introduced in the behavior models.

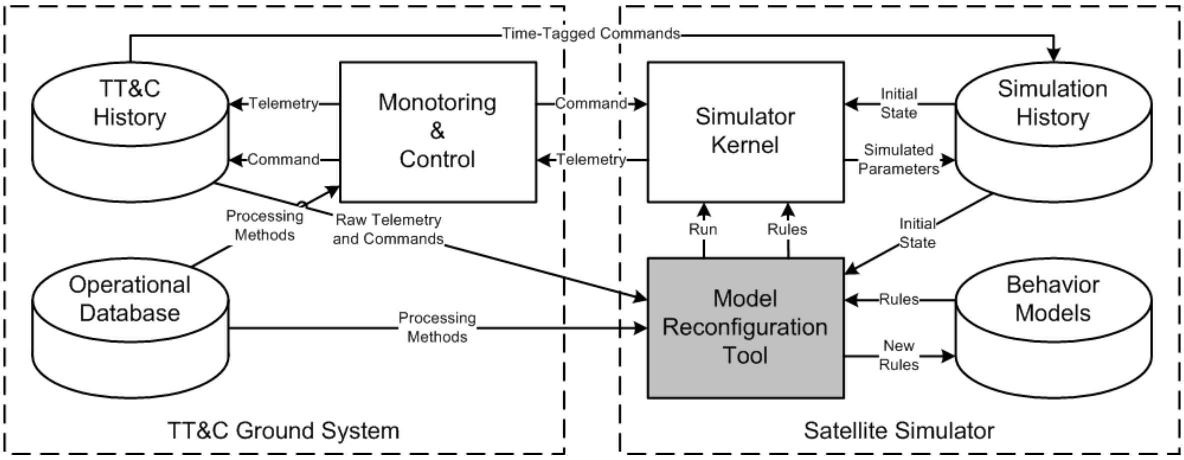


Figure 2. Automatic simulator model reconfiguration software architecture.

The objective of this paper is to describe the comparative analysis method between telemetry and simulation parameters used by the model reconfiguration tool.

2. Methodology

The architecture for comparative analysis between telemetry and simulation parameters used by the model reconfiguration tool consists of three main parts, shown in Figure 3. Firstly, telemetry data must be retrieved from the TT&C history and processed into a format usable by the simulator, which is performed by the telemetry preprocessor. Secondly, simulation parameters, used as both input and output data by behavior models rules, must be retrieved from the simulation history, which contains a log of past simulator internal states sampled at each simulation step. This is done by the states preprocessor. At last, telemetry and simulation parameters are synchronized and then compared by the changes identifier.

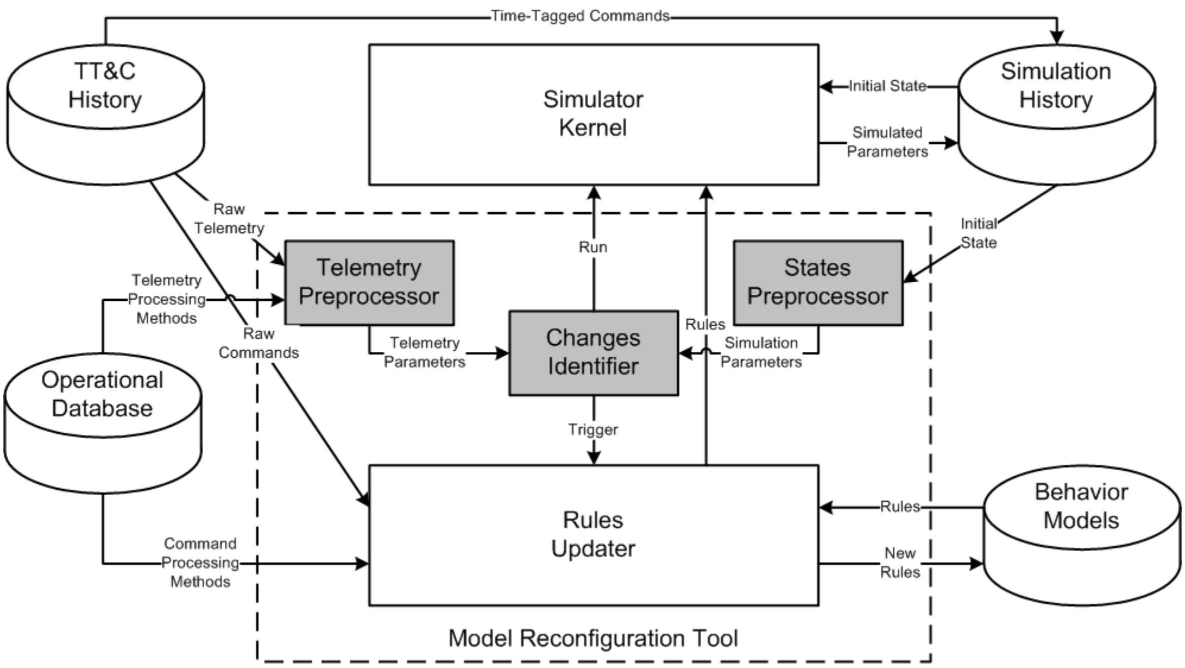


Figure 3. Software architecture for comparative analysis between telemetry and simulation parameters.

In the operational version of the model reconfiguration tool, the telemetry preprocessor shall obtain raw telemetry data from the TT&C history database. These may be stored as frames, segments, packets, or a combination of them, depending on the satellite mission. Telemetry processing methods, by which binary data are converted to meaningful information expressed in engineering units, are stored in the operational database. The telemetry preprocessor could either access the operational database to process the raw telemetry data, or process them using its own internal methods. But for the sake of reconfiguration and compatibility issues, the recommended solution makes use of the TT&C ground system operational database for this task. [MECB, 1990] [MECB, 1993] [XSCC, 2013] [XSCC, 2014] [CAST, 2016] [INPE, 2013]

However, for the purpose of evaluating capabilities of the comparative analysis between telemetry and simulation parameters software, a simpler interface solution can be adopted for the telemetry preprocessor. This consists of comma-separated values (CSV) datasheet files, which can be exported by the TT&C ground system. The CSV standard allows representation of data tables in text format, by separating rows with new line characters and columns with comma characters. An example of such a file is shown in Figure 4 and Figure 5. In these CSV files, telemetry data already processed into parameters in engineering units by the TT&C ground system are presented separately as columns, while rows represent time stamps at which the telemetry parameters were sampled. [INPE, 2014]

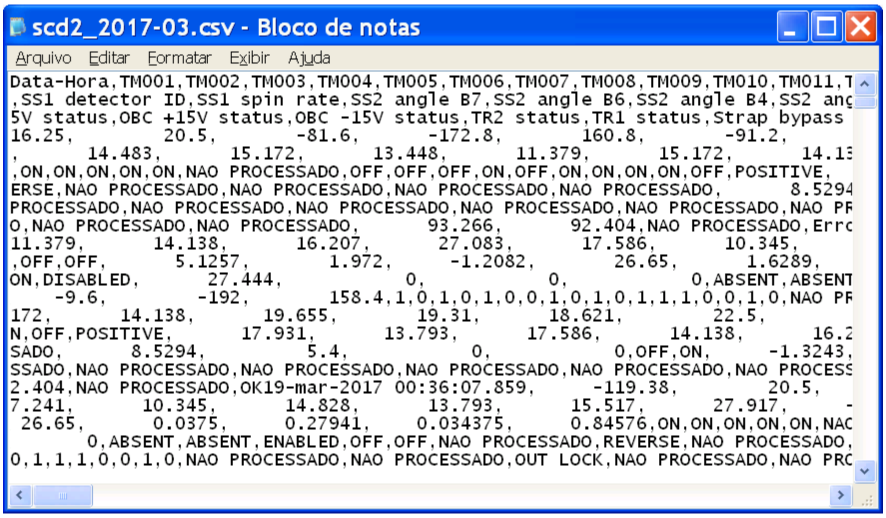
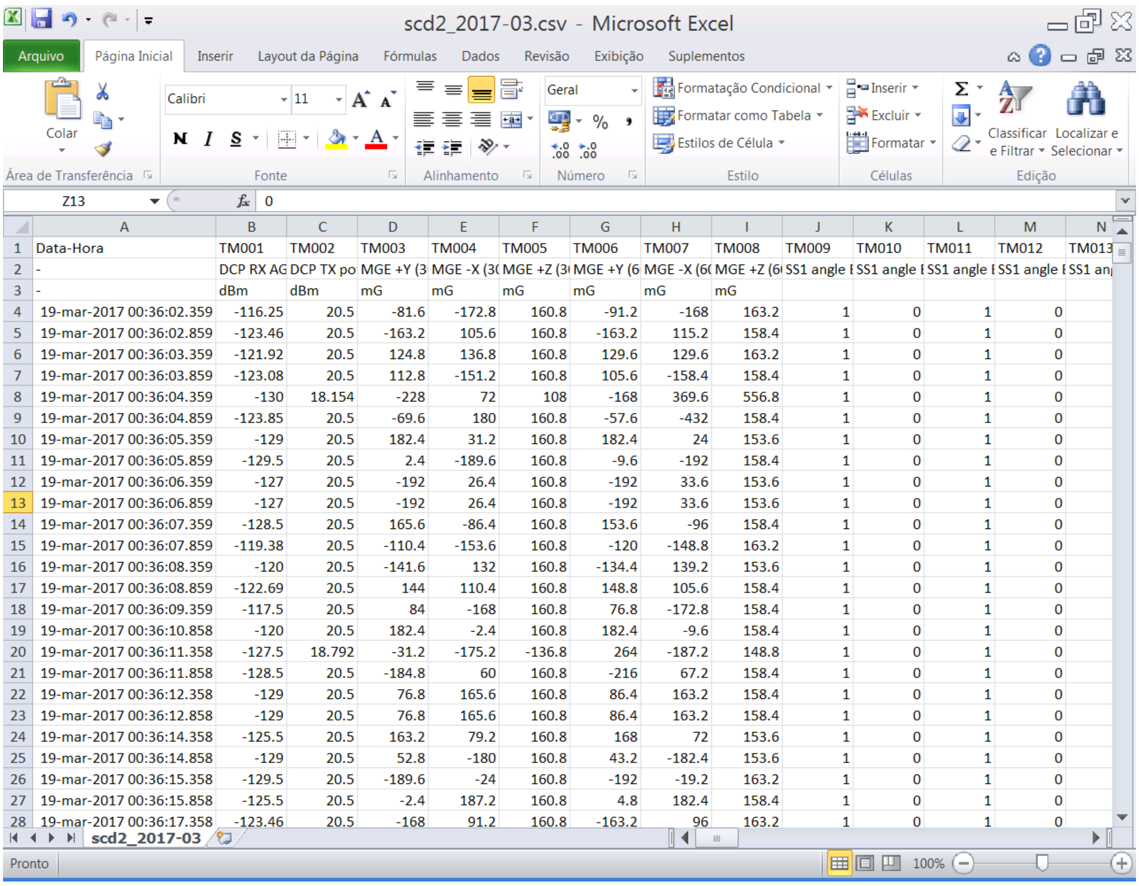


Figure 4. Example of a telemetry CSV file opened as a text file.



	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	Data-Hora	TM001	TM002	TM003	TM004	TM005	TM006	TM007	TM008	TM009	TM010	TM011	TM012	TM013
2	-	DCP RX AG	DCP TX po	MGE +Y (3	MGE -X (3(	MGE +Z (3(	MGE +Y (6	MGE -X (6(	MGE +Z (6(	SS1 angle [	SS1 angle [	SS1 angle [	SS1 angle [	SS1 an
3	-	dBm	dBm	mG	mG	mG	mG	mG	mG					
4	19-mar-2017 00:36:02.359	-116.25	20.5	-81.6	-172.8	160.8	-91.2	-168	163.2	1	0	1	0	
5	19-mar-2017 00:36:02.859	-123.46	20.5	-163.2	105.6	160.8	-163.2	115.2	158.4	1	0	1	0	
6	19-mar-2017 00:36:03.359	-121.92	20.5	124.8	136.8	160.8	129.6	129.6	163.2	1	0	1	0	
7	19-mar-2017 00:36:03.859	-123.08	20.5	112.8	-151.2	160.8	105.6	-158.4	158.4	1	0	1	0	
8	19-mar-2017 00:36:04.359	-130	18.154	-228	72	108	-168	369.6	556.8	1	0	1	0	
9	19-mar-2017 00:36:04.859	-123.85	20.5	-69.6	180	160.8	-57.6	-432	158.4	1	0	1	0	
10	19-mar-2017 00:36:05.359	-129	20.5	182.4	31.2	160.8	182.4	24	153.6	1	0	1	0	
11	19-mar-2017 00:36:05.859	-129.5	20.5	2.4	-189.6	160.8	-9.6	-192	158.4	1	0	1	0	
12	19-mar-2017 00:36:06.359	-127	20.5	-192	26.4	160.8	-192	33.6	153.6	1	0	1	0	
13	19-mar-2017 00:36:06.859	-127	20.5	-192	26.4	160.8	-192	33.6	153.6	1	0	1	0	
14	19-mar-2017 00:36:07.359	-128.5	20.5	165.6	-86.4	160.8	153.6	-96	158.4	1	0	1	0	
15	19-mar-2017 00:36:07.859	-119.38	20.5	-110.4	-153.6	160.8	-120	-148.8	163.2	1	0	1	0	
16	19-mar-2017 00:36:08.359	-120	20.5	-141.6	132	160.8	-134.4	139.2	153.6	1	0	1	0	
17	19-mar-2017 00:36:08.859	-122.69	20.5	144	110.4	160.8	148.8	105.6	158.4	1	0	1	0	
18	19-mar-2017 00:36:09.359	-117.5	20.5	84	-168	160.8	76.8	-172.8	158.4	1	0	1	0	
19	19-mar-2017 00:36:10.858	-120	20.5	182.4	-2.4	160.8	182.4	-9.6	158.4	1	0	1	0	
20	19-mar-2017 00:36:11.358	-127.5	18.792	-31.2	-175.2	-136.8	264	-187.2	148.8	1	0	1	0	
21	19-mar-2017 00:36:11.858	-128.5	20.5	-184.8	60	160.8	-216	67.2	158.4	1	0	1	0	
22	19-mar-2017 00:36:12.358	-129	20.5	76.8	165.6	160.8	86.4	163.2	158.4	1	0	1	0	
23	19-mar-2017 00:36:12.858	-129	20.5	76.8	165.6	160.8	86.4	163.2	158.4	1	0	1	0	
24	19-mar-2017 00:36:14.358	-125.5	20.5	163.2	79.2	160.8	168	72	153.6	1	0	1	0	
25	19-mar-2017 00:36:14.858	-129	20.5	52.8	-180	160.8	43.2	-182.4	153.6	1	0	1	0	
26	19-mar-2017 00:36:15.358	-129.5	20.5	-189.6	-24	160.8	-192	-19.2	163.2	1	0	1	0	
27	19-mar-2017 00:36:15.858	-125.5	20.5	-2.4	187.2	160.8	4.8	182.4	158.4	1	0	1	0	
28	19-mar-2017 00:36:17.358	-123.46	20.5	-168	91.2	160.8	-163.2	96	163.2	1	0	1	0	

Figure 5. Example of a telemetry CSV file opened as a datasheet file.

The states preprocessor is responsible for retrieving simulation parameters from the simulation history database. Simulation parameters are stored in this database as extensible markup language (XML) elements. The states preprocessor must parse the XML file in search of simulation parameters that have their telemetry counterparts in the TT&C ground system. The simplest solution for this problem would have been to obtain the list of telemetry parameters from the telemetry preprocessor and link them to simulation parameters with matching identifiers, if compatibility requirements had been set properly for the software development teams responsible for the TT&C ground system and for the satellite simulator. However, this may not be the case, and the simulator design may be such that telemetry identifiers used by the TT&C ground system are assigned to digital parameters containing their corresponding physical values in binary encoded form instead. In such a case, an initial screening would be necessary to prepare a configuration file containing the correct mapping between telemetry parameters in the TT&C ground system and the satellite simulator.

The changes identifier compares the outputs of the telemetry preprocessor and the states preprocessor to signal a change in the behavior model. Identifying a behavior change that justifies a model reconfiguration requires finding significant discrepancies between simulation parameters and their corresponding telemetry counterparts. If the difference between a simulation parameter and the corresponding telemetry is found to be greater than a predetermined threshold, then a new behavior is identified.

All relevant satellite telemetry and the corresponding simulated parameters are compared against each other at every verification step, which is set according to the satellite telemetry acquisition rate. During initialization, the changes identifier retrieves the default simulation step and the simulation state corresponding the closest simulation time before the first telemetry sample time. The simulator is then run until this sample time, in order to set the initial state. If necessary, several runs may be necessary using the default simulation step time, before a final step is run for this synchronization.

Discrepant values found in a single verification should not start the search for a new behavior model, since telemetry values can be affected by errors due to noise and interference in communication channel between the satellite and the ground station. Also, small errors and in the modeling and update delays between telemetry and simulation parameters may also lead to different behaviors between the simulator and telemetry, especially during state transitions.

3. Results and Discussion

The previous section described the methodology adopted by a simulator model reconfiguration tool to perform the comparison between telemetry and simulation parameters to start the evaluation of new behavior models. Open points left included the determination of error thresholds between these parameters to trigger the update and a criterion to filter out false alarms caused by corrupt telemetry or state transition phenomena.

In actual satellite operations, telemetry data may be received by more than a single TT&C antenna at the same time. In such cases, discrepancies between corresponding telemetry values acquired at the same onboard time by different locations could be used to identify corrupt data reception in one of them. INPE currently operates two main TT&C antennas for satellite control, one located at a ground station at Cuiabá (CBA), and another one at Alcântara (ALC). The TT&C ground system marks received raw telemetry data with identification codes representing the baseband equipment at each station. Thus, if two telemetry parameters sharing the same onboard time tag are found with different values, this is an indication that at least one of them contains corrupt data.

For low earth orbit satellites such as those operated by INPE, it is known that telemetry data acquired at the beginning and at the end of satellite passes over ground stations are more prone to include corrupt data than those received at the middle portion of a pass. This is because the relative distance between satellites and TT&C antennas are greatest at the horizon, and smallest at the zenith. Therefore, using the ground station pass information could be useful to indicate which station data should be considered more reliable. However, a stronger indication could be obtained by means of the automatic gain control (AGC) telemetry, which indicates the power level measured at the onboard TT&C receiver of the uplink communication signal. Figure 5 exemplifies an AGC telemetry plot against time over the course of several passes.

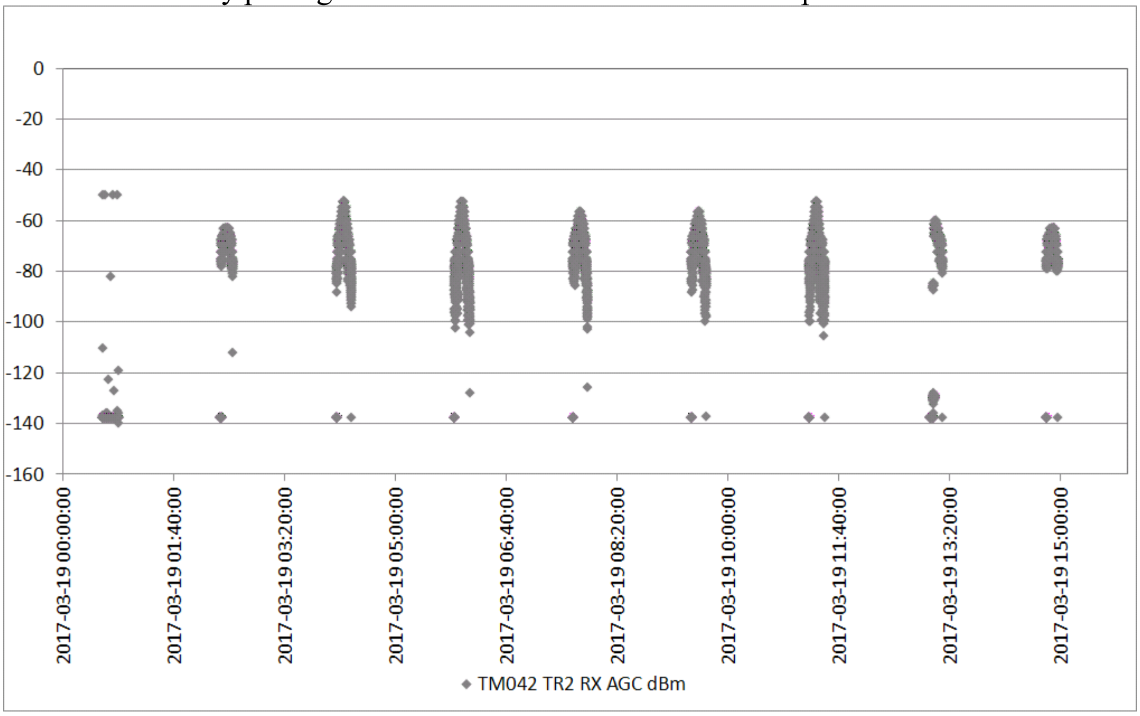


Figure 6. Example of AGC telemetry values plotted against time.

A procedure to consider the AGC level to evaluate the reliability of telemetry data could be easily implemented as a new simulator behavior model rule, at the cost of increased behavior model complexity. However, it has been observed in practice that telemetry data corruption due to channel noise and interference tend to follow single error patterns, meaning that the invalid data comes in a single value within several consecutive samples, rather than bursts containing several consecutive errors spanning over a time interval greater than the telemetry acquisition rate. Taking this information into account, discrepancies should be found in no less than three consecutive verification steps before a behavior change analysis is considered. Even after errors are found which durations are longer than that, false bursts can be often ruled out by statistical data analysis heuristics carried out inside a moving window, since physical measurements tend to increase and decrease somewhat smoothly within a sufficiently small time frame, and not swing violently inside its variation range spectrum.

Concerning the definition of thresholds for triggering the evaluation of new model rules, such statistical analysis also shows the typical variation range of the difference in values between telemetry and simulation parameters. The standard deviation should be maintained within one sigma and the mean value should remain the same for at least one week. Samples which errors are bigger than expected should be discarded. If the mean value changes without significantly affecting the deviation, then the simulation parameter must be flagged and the behavior model updated.

4. Conclusion

This paper described how a simulator model reconfiguration tool, currently under development, compares satellite telemetry against simulation parameters. By running the satellite simulator for synchronization, this solution attempts to make telemetry and simulation parameters values as close as possible to each other before comparison. However, this approach may be extremely computing-intensive and, therefore, unsuited for use with complex simulation models that would include thousands of parameters.

Proposed future works include finding an alternative procedure that avoids the use of a simulator to perform the synchronization between telemetry and simulation parameters. The new solution to be achieved should enable proper comparison between these parameters, without compromising performance.

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