Modeling of onboard systems operation of small satellites

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Abstract. An approach for simulating the operation of onboard systems of small satellites has been developed. The purpose of the technique is to simulate all possible combinations of malfunctions in the onboard systems of the small satellite, leading to the occurrence of abnormal situations during their operation. As a result of using the technique, a list of emergency situations is created, which is later used to create programs for complex testing of small satellite on-board equipment at the ground testing stage. The use of the technique leads to a reduction in time for the preparation of tests and simplifies the process of preparing documentation for small satellite operation.

1. Introduction

During the operation of any spacecraft, a variety of abnormal situations may occur, including those that were not described in the instructions for spacecraft control in flight and that cannot be solved by using the instructions for spacecraft control prepared during the ground testing phase in the event of a failure, malfunction or other emergency [1].

In order to overcome unforeseen emergency situations, the condition of on-board systems is analyzed and the algorithms to restore the functional state are refined. However, the process of clarification, which includes the analysis of causes and consequences of emergency situations, the analysis of on-board satellite systems and the development of a final solution may take a significant amount of time, which negatively affects the performance of the satellite system. For example, the typical process of restoring the functional state of AIST (a joint project of Samara University and Progress Rocket and Space Center) after the occurrence of emergency situations not solved by standard control instructions takes from one to two months [2].

The solution of the problem can obtained with methods of modeling the functioning of satellites on-board systems in order to form a list of all possible combinations of malfunctions in the operation of on-board systems, resulting in emergency situations in the process of operation. The obtained information can be used to facilitate the drawing up of electrical and complex test programs, as well as to reduce the probability of non-calculated failures in the process of satellite operation.

2. Method of modeling the operation of onboard systems

The method of modeling the functioning of satellite on-board systems consists of the following procedures:

- The scheme of functioning of onboard systems consisting of the units of onboard equipment and the links between them is drawn up.
- Necessary and sufficient conditions for the implementation of the operation of the equipment are determined.

- Possible combinations of emergency situations of on-board systems by simulation of failures of onboard equipment units are made.
- The simulated emergency situations and their consequences are classified and arranged for the development of satellite control programmes during operation or for the development of electrical and complex test programmes.

A functional integrity scheme was used to model equipment functioning. It is a logically universal graphical means of representation of the properties of the system objects under study as it implements all the possibilities of logic algebra in the functional basis “I”, “OR”, “NOT” [3] and allows to compactly represent the investigated on-board systems of the satellite.

The following elements were used (figure 1).

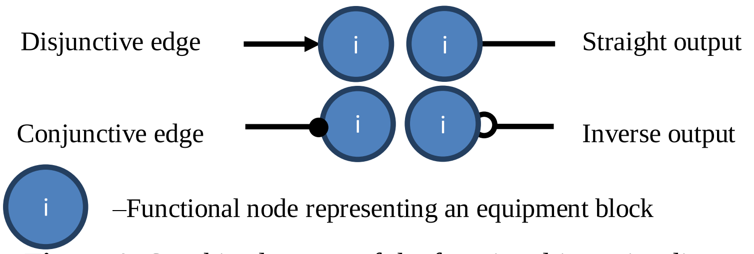

Figure 1. Graphic elements of the functional integrity diagram.

Functional nodes with Latin letters represent equipment blocks. Interactions (electrical and logical) between the equipment units are modeled using two types of directional edges (left half of the figure 1) and two types of outputs from the functional vertices (right half of the figure 1).

A disjunctive rib is a logical OR operator between multiple disjunctive ribs coming into one vertex.

A conjunctive edge is an “AND” logical operator between a set of conjunctive edges coming into one vertex.

Direct output means condition of output function realization by the corresponding element (y_n). The output function of an element (Block of equipment) is to perform its target task.

Inverse output means condition that the output function ($\bar{y}_n$) is not implemented by the corresponding element (logical operator “NOT”) [4].

Figure 2 shows a scheme of one of the simplest onboard systems of the “AIST” satellite - navigation equipment. The letters j, k, m, i and n indicate the units of on-board equipment - the antenna units (j, k), the power and telemetry controller (m), the main unit of navigation equipment (i) and the information exchange module (n). Letters y_j, y_k, y_m, y_i, y_n mark the corresponding output functions.

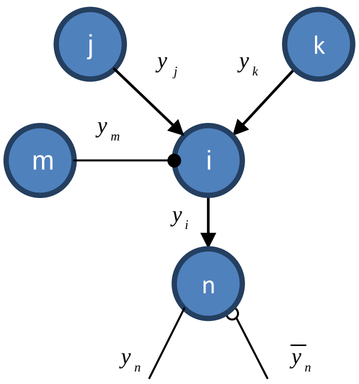

Figure 2. Functional integrity diagram of the “AIST” navigation equipment.

After drawing up the scheme of the onboard satellite system, its output functions are drawn up which combine conditions of realization by the system of the target task and conditions at which this task is not carried out (that corresponds to infringement of working capacity).

Output functions of navigation equipment:

$$y_n = x_n \wedge y_i \wedge y_m \wedge \left(y_j \vee y_k \right) \tag{1}$$

$$\overline{y}_n = \overline{x}_n \vee \overline{y}_i \vee \overline{y}_m \vee \left(\overline{y}_j \wedge \overline{y}_k \right) \tag{2}$$

From the first function it follows that the navigation equipment of the satellite is able to perform the target task, provided that the power supply and telemetry controller, the main unit of navigation equipment, the information exchange module are functioning normally, and at least one of the two antennas.

The second function suggests that malfunction of the power and telemetry controller, or the main unit of navigation equipment, or information exchange module failed, or both antennas is enough to in lose the performance of navigation equipment.

Then, according to the output functions of the on-board system, combinations of conditions are prepared under which a malfunction of the system is possible (while maintaining partial operability) or a failure of the whole system (total loss of operability).

The combinations are recorded in tabular form and then interpreted in a form understandable to the satellite operator, which may be in the form of the same tables or algorithms linking the cause of the failure with the procedure for its elimination. According to the function (1), failure of navigation equipment may occur due to failure of one of the two antennas (table 1).

Table 1. Causes of navigation equipment malfunction.

Effect	Reasons	Interpretation
y'_n [a]	$\overline{y}_j$	Failure of the antenna #1
	$\overline{y}_k$	Failure of the antenna #2

[a] Navigation equipment malfunction function

The reasons for complete loss of navigation equipment performance according to function (2) can be presented in the following form (table 2).

Table 2. Causes of failure of navigation equipment.

Effect	Reasons	Interpretation
$\overline{y}_n$ [a]	$\overline{x}_n$	Failure of the communication module
	$\overline{y}_i$	Failure of the main navigation circuit
	$\overline{y}_m$	Failure of the power supply and telemetric control module
	$\overline{y}_j \wedge \overline{y}_k$	Failure of the antenna #1 and #2

[a] Navigation equipment malfunction function

Table 3. Operators procedure in case of malfunction of the navigation equipment.

Malfunction	Reasons	Procedure
The integrity of navigation data has been compromised	Failure of the antenna #1 or #2	Double the operating time of the navigation equipment the next time it is turned on
Navigation equipment does not generate navigation data	Failure of the communication module	Reboot the data exchange module, try again to turn on the navigation equipment
	Failure of the main navigation circuit	Work with NORAD navigation data
	Failure of the power supply and telemetric control module	Switch the telemetry controller to the backup half kit, try again to switch on the navigation equipment.
	Failure of the antenna #1 and #2	Work with NORAD navigation data

The procedures presented in table 3 may serve as an example of operator's actions in case of an emergency situation related to failure to receive or violation of navigation data integrity from navigation equipment.

The information on the functional subordination of individual equipment units, which is reflected in the developed scheme and output functions, can also be used as a tool to verify the compliance of on-board systems behavior with the embedded algorithms during ground-based complex tests and simulation of emergency situations.

3. Results

As a result of application of a method of construction of functioning schemes for research of properties of system objects, schemes of five onboard systems of “AIST” satellites have been developed, and also their output functions are determined. It allowed to create a tool to support decision making on satellite management and to reduce time of response to emergency situations.

The developed schemes can be used in ground testing of similar satellites as an additional testing of subsystems compliance with their intended algorithms of operation.

4. References

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