Automated support for spacecraft onboard equipment design on the basis of a heterogeneous model

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Abstract. This article presents methods and software tools for modeling and analysis of space system onboard equipment operation. The authors suggest the design of a heterogeneous model uniting knowledge bases and virtual devices simulating work of data reception and transmission equipment. Model design considers tasks appearing during preparation of satellite production at a company-manufacturer of the space industry. The model can be used at the stages of designing and testing of the onboard equipment. For design support, the model allows assessment of parameters of the reception-and-transmission path and of destabilizing factor influence on communication line quality. For ground test support, the model simulates functions of the onboard equipment during command-and-software control of a spacecraft, providing reception and transmission methods for a wide range of commands and methods of generation of telemetry frame values. The comparison of precedents obtained during simulation tests with the results of the finished equipment testing, allows determination of special features of the onboard system operation that can stay unnoticed if other methods of test preparation and analysis are applied.

1. Introduction

Modern spacecraft designing is a science-intensive and expensive process dealing with lots of factors that are often difficult to formalize. These factors affect characteristics of the onboard system hardware. The application of the methods of simulation modeling allows reduction of project risks and time required for generation of technical specification and for agreement of the parameters of the designed systems. It also helps to automate testing of the designed equipment.

Space industry leaders design and successfully implement simulation modeling methods, technologies of simulation model transferability and integration for support at different stages of space systems’ production and operation life cycles [1]. The concepts of modeling providing solutions for the research tasks from the level of a design bureau and up to hybrid test facilities are created [2]. The choice of the method of simulation and the necessary detailing of models depend greatly on the stage of the life cycle of building of a complex technical system. At the stage of technical specification generation, models are described; they have the purpose of providing most full and compact information about the object that is regarded as an integrated set of elements aimed at achievement of specific goals [3]. For further stages of designing, systemic logical structure is specified in order to demonstrate the processes of its functioning and the dynamics of models’ elements’ interaction.

This article describes design automated support methods that provide efficient tools for study of the onboard equipment operation and analysis of the results of its testing on the basis of a simulation model.
For the description of the onboard equipment operation methods, we use artificial intelligence technologies based on formalized experience of specialists-experts in the study area. The authors have built a knowledge base which is a storage of functional and technological processes allowing not only observation, but also control of decision making. Technical characteristics of onboard systems are modeled with the help of virtual devices created in Labview [5] information system, allowing building virtual engineering simulators of electronic systems and logical devices.

Such approach is widely used in different systems of technical design. It allows not only producing quality solutions, but also exchanging knowledge with teams of engineers having big experience in different areas of the tasks that need to be solved [6]. The systems based on knowledge complete analysis and control of technical object condition, they help to detect or forecast possible problems and model their consequences [7].

Building of heterogeneous models uniting knowledge bases and virtual devices for the tasks of real practical importance and complexity has required tight integration of the artificial intelligence paradigm with a whole lot of methods, approaches and technologies from other areas. Simulation of designed devices will provide economically most efficient choice of proper configurations of the onboard equipment. Simulation tests with different scenarios of system function will allow working out technical solutions and analyzing operation of satellite onboard equipment systems during functional control.

2. Onboard equipment heterogeneous model design

In order to support task solution of the onboard equipment design, the authors suggest the design of a heterogeneous model describing software simulators of the onboard systems and functions of the environment systems simulating command-and-software control of spacecraft onboard equipment. Graphical model blocks demonstrate different elements of the equipment, fields in the blocks are physical devices interfaces, lines between the blocks are commutation links and arrows are directions of data transmission. In this article: OCS CU – onboard control complex, CCU – command-measuring system’s interface module, GCC – ground control complex, ODGS – onboard remote signaling equipment, TRANSMIT – transmitter, RECIV – receiver.

The methods of software simulator function are set by rules in the knowledge base. The rules are presented in form of constructions: «If A then B». The left part sets condition of rule’s fulfillment, and the right one is actions completed in order to change the model’s state. The rules allow describing different methods of the onboard systems’ interaction, transmission of command and command-and-software data from ground control complex’ simulator to spacecraft systems’ simulators, execution of
commands, reception and delivery of telemetry information, control of the onboard equipment’s condition, setting of modes and interfaces for equipment operation, etc. [8].

The simulation of a reception-and-transmission path including devices and data transmission environment is completed in form of virtual devices. Figure 2 shows decomposition of the model elements describing configuration of receiver and transmitter.

![Figure 2. Decomposition of a model for analysis of a reception-and-transmission path](image)

The model provides simulation of the following processes: signal generation in a DVB-S2 standard; signal generation from OFDM in a DVB-T standard; signal amplification and attenuation; generation of a mixture signal-noise; bandpass filtering (Butterworth, Bessel, Chebyshev filters with changeable order); bringing of nonlinear distortions in the signal (exponential, quadrature performance characteristics and severe restriction of signal); measurement of BER, MER for signals DVB-S2, DVB-T; presentation of signal’s constellation and spectrum.

The model shows the work of main units of reception-and-transmission devices: mixer, oscillator, power amplifier, input and output filter. The result of modeling is parameters demonstrating possibilities of errors during test signal’s passing through the model – BER (Bit Error Rate) and the value of deviation of the produced modulation from the transmitted one – MER (Modulation Error Ratio). The obtained parameters are determinative at the assessment of the efficiency of different configurations of receiver and transmitter.

3. Application of a heterogeneous model for onboard system design
Designing of reception-and-transmission devices’ characteristics requires assessment of the efficiency of receiver and transmitter’s configurations providing the set noise immunity of data exchange between a ground segment and a spacecraft. The analytical scheme for reception-and-transmission devices’ configuration is shown in (Figure 3).

![Figure 3. Analytical scheme for reception-and-transmission devices’ configuration](image)

When working with a model, a designer sets parameters of the onboard equipment’s transmitter in accordance with the designed equipment’s specification. Optimal settings of a transmitter are completed on the basis of the set parameters. In addition, the deviation of values is determined in order to get settings for the worst case (for example, deviation of the carrier frequency considering the set short-time frequency instability or choice of signal’s minimum power rating from the range of values given in the specification).
The obtained optimal parameters are transferred to transmitter’s simulator that has modulators, coder, noise sources, generators and mixers allowing generating different signal-and-code constructions. The produced signal comes to the atmosphere’s effect simulation block and antenna-feeder devices. The block weakens the signal and adds noise simulating an effect of the atmosphere. Further, the signal arrives to a ground reception-and-transmission device’s simulator that has settings matching the optimal values of the parameters. The configured receiver provides efficient reception of the signal produced by the onboard equipment’s transmission block. Basing on the received signal, errors of data transmission BER and MER are evaluated. The results of modeling are compared with the designed equipment’s specification. Study of receiver’s characteristics is completed the same way.

Models allow assessing influence of intrinsic noise, oscillator’s settings failure, non-linear distortions of amplifier, passband and characteristics of the atmosphere, etc., on the quality of the communication line.

The authors study the example of atmosphere destabilizing factors’ influence on communication line’s noise immunity. Noise power increase in the simulator of atmosphere from -20 dBm to -60 dBm reduces MER at the receiving side from 33 dB to 28 dB. Constellation diagram and spectrum of the signal that has passed through all simulation model blocks are shown in Fig. 4-5. The increase of the intrinsic noise power in the simulator of atmosphere does not lead to interruption of reception, because BER is equal to 0. Bit errors at reception are not detected.

Noise power increase in the simulator of atmosphere from -60 dBm to -80 dBm leads to reduction of MER at the receiving side from 33 dB to -2,4 dB, and causes interruption of signal reception. Herewith BER becomes equal 1, the rate of bit errors at reception is 100%.

In that way, heterogeneous models help to study the boundaries of signal reception for verification of designer solutions, determination of optimal parameters of configurations of the reception-and-transmission path and acceptable deviations from optimal values.

4. Application of heterogeneous models for automation of the analysis of spacecraft onboard equipment testing

In order to check the logics of the onboard equipment function during reception and execution of commands, the authors have designed a method of test analysis in accordance with the results of the simulation modeling. This method allows examining all value options of telemetry parameters obtained during simulation experiments and comparing them with the data obtained during testing.

The simulation modeling starts with assessment of the parameters of the reception-and-transmission path on the basis of virtual tools. Further, the authors model the logics of the onboard equipment operation during command-and-software control. The algorithms of modeling are described by the rules.
of the knowledge base. The process of modeling includes completion of a logical output in the knowledge base: the rules applicable to the model current state are chosen, actions are completed, the processes of generation and transmission of data packages are simulated and command execution is visualized. The command execution results obtained during simulation modeling, telemetry parameters and rules become precedents of the simulation model.

The testing of finished onboard equipment is completed with the help of control-and-verification equipment. The object of control is a command-and-measuring system that includes interface module and reception-and-transmission devices. The functions of the environment and paired devices are performed by software-and-hardware simulators. A designer during generation of tests in the control-and-verification equipment’s software, defines the sequence of command transmission, sets responses of simulators and enters telemetry fields’ reference values. In the process of testing, the commands are sent to the object of control; set parameters are received and analyzed.

In order to automate the analysis of testing, the authors use simulation model precedents. Because a simulation model is built in accordance with technical specification, it sufficiently simulates command-and-software control of the onboard equipment. During tests, a command is sent to the object of control and to the simulation model. The precedents obtained during simulation of command reception, transmission and execution, are compared with the parameters of telemetry from the object of control. Software visualizes the telemetry, knowledge data rules, transmitted commands and the results of command execution (Figure 6).

![Command verification](image)

**Figure 6.** Software for analysis of the command-and-software control testing

The comparison of the results of modeling with the object of control telemetry complements the methods of test conduction and analysis, and thus can help to increase the quality of the assembly and production of spacecraft subsystem.

5. Conclusion

The proposed methods of automated support for the onboard equipment design increase the quality of decision making during generation of technical specifications for equipment and its further testing. The design of a heterogeneous model considers the tasks appearing during preparation of satellite production
at the company-manufacturer. The model allows easily studying the work of the onboard equipment at the stage of modeling and it is a base for the finished equipment analysis.

The model allows assessing influence of noises, atmosphere and distortions during data transmission, on communication line’s quality. The model simulates wide spectrum of commands, rules and values of telemetry parameters describing different tasks of functioning and simulation of spacecraft’s command-and-software control. Application of heterogeneous model allows detecting nuances that can stay unnoticed if other methods of test analysis are used.

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