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Method of creation and verification of the spacecraft onboard equipment operation model

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Abstract. This article represents the method of creation and verification of a simulation model consisting of graphical structure duplicating the elements of spacecraft onboard equipment and the knowledge base describing the methods of its function. The authors have developed software tools for model building and verification with the help of visual components converting formal description of the model and the knowledge base into interactive graphical images of infographics. The method can be used at any stage of onboard equipment designing, however it is most efficient at the initial stages.

1. Introduction

Modern designing and research of complex technical, economical, organizational and other systems requires creation and improvement of the computer support technologies basing on the uniform methodology of system analysis. The methods of computer modeling are used as a basis for such methodology covering different stages of the scientific activity. Modeling is less expensive than conduction of tests with real systems and allows to study long interval of the system's function quickly or make a detailed analysis of system's function during longer time. In case of creation of a complex high-tech product, the search of original approaches and ideas is completed with the help of heuristic methods. Modeling allows to create abstractions of physical reality and solve the problems dealing with the necessity to study the processes not yet existing.

Although computer modeling is a simple and clear form of analysis of complex technical objects, space industry does not implement it vastly at the moment [1] due to higher requirements to all used technologies, complexity of implementing the existing software solutions, high requirements to qualification and experience of the operation staff. Most of the existing software is designed to optimize the structure and placement of spacecraft onboard equipment allowing to find a solution that will meet the requirements of weight and size characteristics, physical properties and operating conditions [2]. Such approach is not enough for studying the objects with own logics of function. Every modern spacecraft has unique operating characteristics. Wide range of purposes and functional conditions of spacecrafts do not allow building universal engineering solutions, and conduction of experimental studies is economically and technically difficult, which requires new methods of onboard equipment designing support [3]. The task of an onboard equipment engineer in such studies is to design structure, methods of function and interaction with other onboard systems and the ground control complex, create specification, test designer solutions, transform information from specification into the information needed for system's production, and also to prepare the methods of control at the control-and-measurement equipment. In scientific literature we can find examples of creation of a holistic concept of modeling covering the stages of the life cycle of space systems' production from designing to hybrid test facilities [4]. For national space study, the task of creation of a uniform methodology is very important. We need new approaches and methods allowing to study the systems in regular and emergency situations and provide functional continuity of the information resources from the modeling tools to the ready equipment control automation tools. The applied models must provide a true picture of the system's structure and use the terms characterizing its structure and operation. At different stages of designing it is necessary to conduct different researches, so a simulation model must be easily convertible at different levels of abstraction in order to keep the true accuracy with no extra detail [5].

For these tasks' solution, the Institute of Computational Modeling together with the Siberian Federal University have developed a software and tool complex "Software and math model of spacecraft onboard equipment's command and measurement system". This complex includes software for control and verification equipment. The purpose of the complex is to support designing of spacecraft onboard equipment's command and measuring system. It includes tools of graphical modeling of the architecture and configuration of the onboard equipment and the knowledge base representing its functioning and software means of simulation modeling [6]. Besides, it includes: tools for building scenarios, intellectual methods of generating test procedures of command and software control, methods of onboard equipment's testing automation [7], tools for intellectual support of the analysis of the results [8]. Implementation of these methods involves usage of high volumes of formal data of the model and knowledge base, and this together with human factor may lead to engineering mistakes. It's one of the reasons why the methods of building and verification of intellectual simulation models are important scientific task for providing efficient support for designing of complex technical systems.

2. Computer model building method

For spacecraft onboard equipment operating modeling, we use graphical tools and knowledge base editor. An example of graphical presentation of a model is given in figure 1.

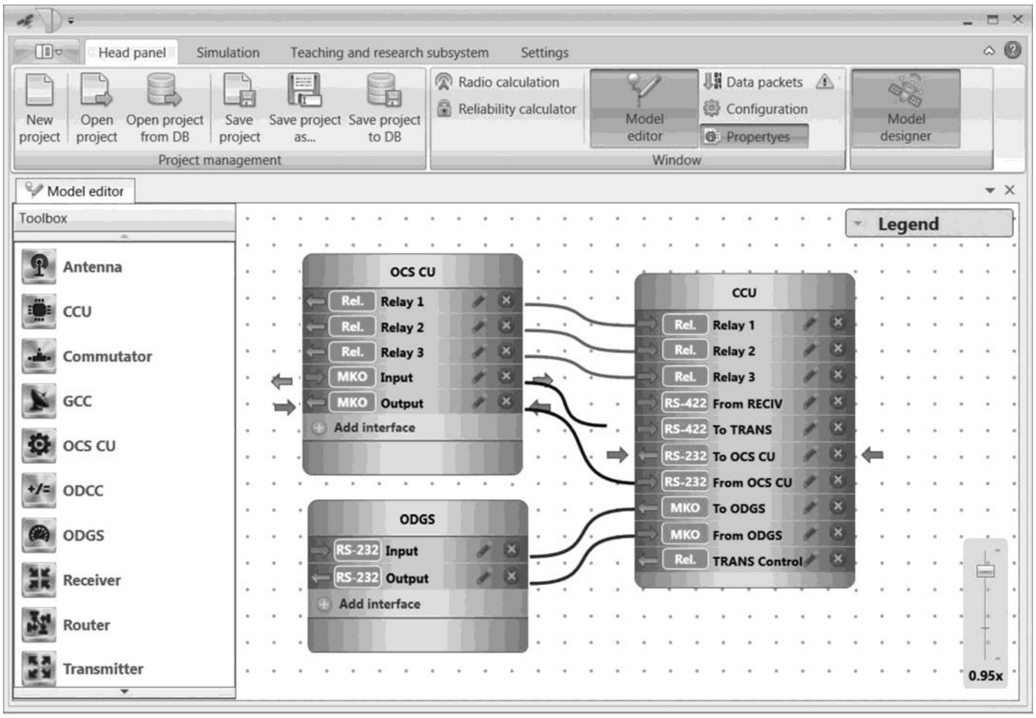

Figure 1. Model building (example).

For all figures in this article we use the following code: OCS CU – onboard control complex, CCU – command-measuring system’s interface module, GCC – ground control complex, ODGS – onboard remote signaling equipment, TRANS – transmitter, RECIV – receiver.

Software allow to form the model’s structure, set configuration of functional blocks and commutation links and describe the logics of its work in form of rules. Onboard equipment completes many tasks including: exchange of information with ground control complex, measurement of current navigation parameters of spacecraft’s movement at the orbit, collection, storage, procession and transmission of telemetry data, spacecraft systems’ operational control and other. Depending on the purpose of modeling, there is a model structure and a set of its functions.

Tools for model building control propriety of its elements’ connection in commutation interfaces. Graphical presentation of a model may contain dozens of functional blocks simulating onboard systems and describing methods of their interaction with each other and with the ground control complex.

The rules in the knowledge base are presented in form of the constructions: *“If A than B”*. The left side sets condition for rule’s fulfillment and the right side – the actions required for changing the model’s condition. Rules describe transmission of command and command-and-software data from a ground control complex’ simulator to spacecraft systems’ simulator, execution of commands, reception and delivery of telemetry data, control of the onboard equipment’s condition, setting of modes and interfaces for operation and other. An example of a rule built in the knowledge base editor is given in figure 2.

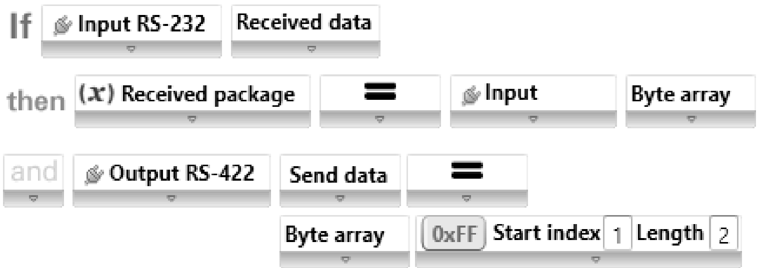

Figure 2. Rule in accordance with which a receiving device gets data through communication interface RS-232 and sends a two byte of the received package through interface RS-422 back to the device, from which it has received the data.

This structure simplifies interpretation of knowledge and allows natural manipulation of graphical elements of the model and their informational characteristics in order to prepare and complete different simulation tests. Solution of tasks that an onboard equipment designer faces during modeling, may require model’s detailing or generalization either in whole or in its functional blocks. For example, in order to study transmission of data via a certain digital interface it is necessary to consider the commutation links corresponding with this type of interface.

Quality control is very important at building models. After a model is build, it is put through a validation process in order to guarantee that it is real at the set level of trust [9]. Validation allows to detect errors in structure, links and parameters of the model. Such can be unconnected blocks and interfaces, cycles or breaks between inputs and outputs, etc. If errors are detected in communication lines, software shows them on graphical model. For the model’s blocks built with base elements, validation allows to find errors in structure dealing with the parameters that participate in realization of functions. Besides automated validation, graphical presentation can be used for manual check of compliance of the models with technical documentation.

An other important aspect of providing model’s quality is its verification – the process in order to guarantee that the model works as it should [9]. In traditional studies, verification of simulation models, as a rule, is based on statistical analysis and evaluation of mistakes of simulation, however, the traditional approach cannot be applied at the initial stages of onboard equipment designing, when there is no functional tests’ data that can be used to compare with the simulation tests. In this case, specialists use the methods based on quality expertise [10] in order to form and assess the knowledge of the subject area that stands as a benchmark for model verification. For this purpose, we suggest a method of structural and graphical analysis performing interpretation of formal description of the model and the knowledge base in interactive images of infographics. The method can be used at all stages of model modification, but it is most efficient at the initial stages of onboard equipment designing.

3. Simulation model's verification method

Simulation model's verification method is designed for visual confirmation of the compliance of its structure and functionality. Graphical structure of the model does not display the functional links set in the knowledge base. For their analysis we suggest to use a "dependency circle chart" allowing to briefly visualize all the existing links in the knowledge base and trace their directions. For creation of this diagram, we used the library of interactive infographics D3.js [https://d3js.org/]. Sections of the diagram are the elements of a model, for example, simulators of onboard devices, and rows between them are interactions set in the knowledge base. Section's direction is set from its wide part to the narrow part. If two parts are wide, it means that the communication between the elements is bidirectional.

The diagram allows to interactively choose dependencies of different elements of the model, detect errors of the knowledge base, reveal lacking or excessive data and structures that do not have rules set in the knowledge base, provide control of completeness of functional presentation. An example of the dependency circle chart is given in figure 3.

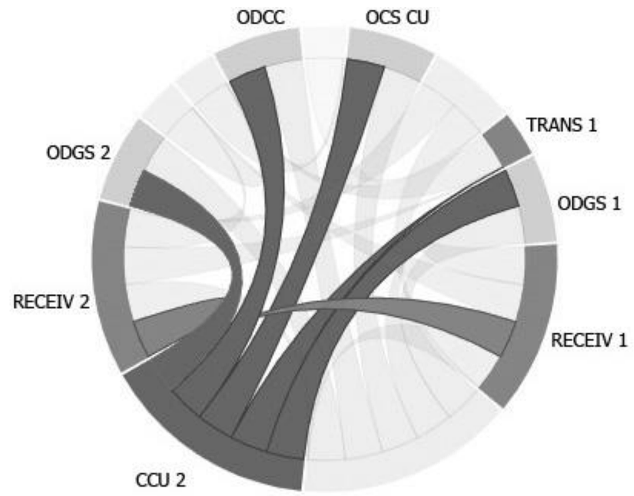

Figure 3. Dependency circle chart of interaction between model's elements.

In order to exclude mistakes in commutation of the model's elements, we suggest to use graphical presentations displaying links between their interfaces. Figure 4 gives an example of a piece of the diagram showing the existing links with commutation interfaces of other blocks. On studying the diagrams, we can assess compliance of the model's structure and the knowledge base.

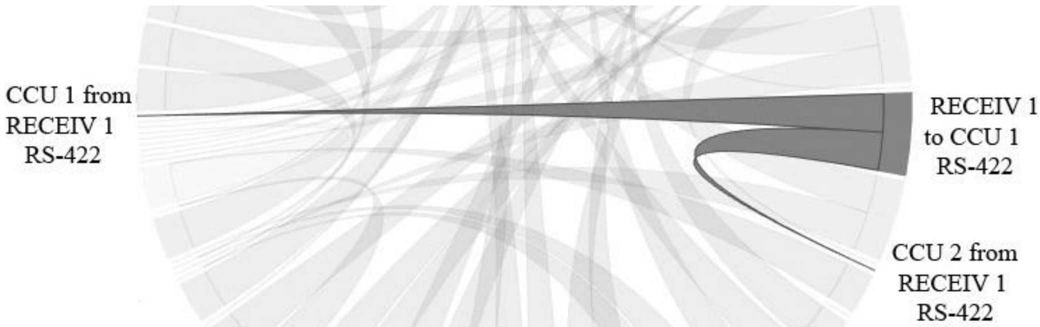

Figure 4. Links between interfaces of a simulation model.

Study of model's communication workload is performed with a special graph, its junctions are model's elements, arcs are ways of their interaction with other sub-models. An example of the graph is given in figure 5. The size of junctions and width of arcs show the intensity of load calculated as power of many rules for the model's elements. High workload of the elements may be a reason for revision of the model or for additional reservation of equipment and commutation.

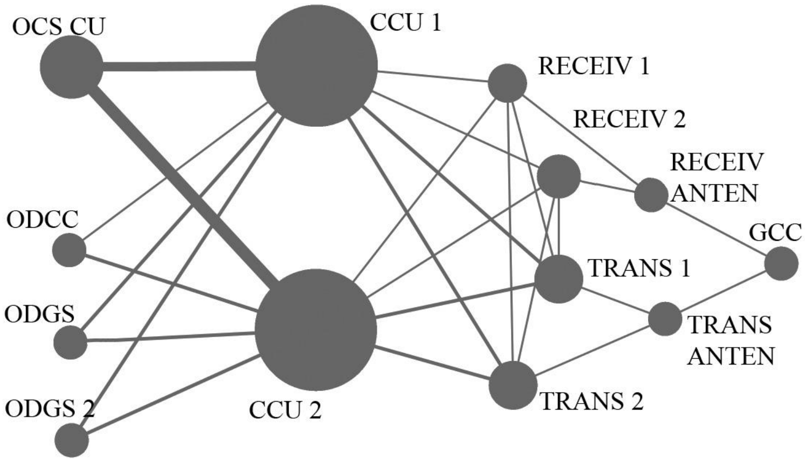

Figure 5. Model's workload graph.

Interaction of the knowledge base's rules describing processing of data in different interfaces of the model is displayed with the graph of coverage. By changing the scale of the graph, we can examine the model in whole, and detail elements of the model or all commutation links described in the knowledge base. Figure 6 provides fragments of a coverage graph for chosen onboard devices, figure 7 gives detailing for each rib with description of initial and final interfaces.

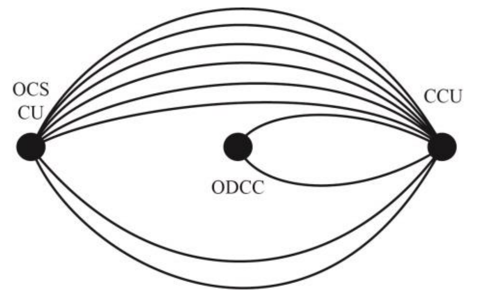

Figure 6. Fragment of the coverage graph which shows the availability of rules for the chosen elements of the model.

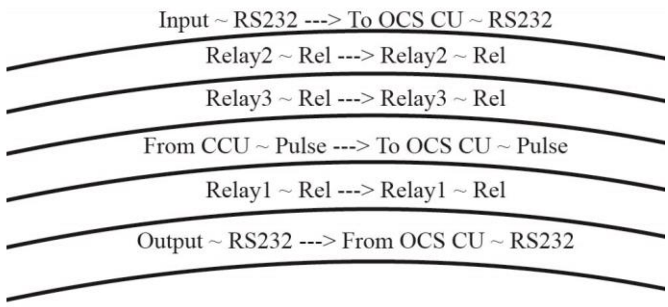

Figure 7. Fragment of graph with detailing of interfaces.

Interactive graphical elements allow to visualize the parameters of the model's structure coverage with the rules of the knowledge base. Highlighted are the elements of the model where all interfaces are described by logical rules, and some junctions do not have any rules. It means that there are commutation links that do not bear data transmission and it is an error in model's design. The fragment of the graph provided in the figure demonstrates links between interfaces of the blocks and allows to detail rule coverage for each interface.

Visualization of the model's structure and the knowledge base with graphs allow a designer to make analysis of completeness and consistency of knowledge.

4. Conclusion

This article describes the methods of building and verification of a simulation model of spacecraft onboard equipment's operation. Model building and usage at the stage of onboard equipment designing will help cost reduction, shorter production cycle and higher quality of final solutions. Our graphical tools allow to examine the model's completeness and validity. Software acts as an intellectual partner of a designer allowing to conduct simulation tests for building and analysis of designer solutions. Knowledge bases integrate onboard equipment designers' experience and can be used for preparation of tests at different modes of space systems' operation and ways of their usage.

Acknowledgments
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