Models and Methods of Reconfiguration of Complex Technical Objects under Different Situation Conditions

B. V. Sokolov[1]
Saint-Petersburg Institute for Informatics and Automation
of the Russian Academy of Sciences;
ITMO University
[1]sokolov_boris@inbox.ru

V. A. Zelentsov[2], A. Yu. Kulakov[3], I. Yu. Pimanov[4]
Saint-Petersburg Institute for Informatics and Automation
of the Russian Academy of Sciences
[2]v.a.zelentsov@gmail.com, [3]russ69@bk.ru, [4]pimen@list.ru

***Abstract*— To solve the problems of reconfiguration of complex technical objects (CTO) in different conditions of the situation with a single methodological and methodical positions a new modification of the previously developed hierarchical computational g-models of data representation and processing, information and knowledge are proposed in the report. They will provide on the conceptual, model-algorithmic, information and software levels of detail coordination of mathematical (analytical-simulation) models of reconfiguration control (in general - structural dynamics) of CTO with their logical-algebraic and logical-linguistic analogs (models) built on the basis of intelligent information technologies to describe human-machine interaction with the developed set of models. The methodology and technology of complex modeling of reconfiguration processes allows CTO under the service-oriented approach and appropriate information architecture to combine previously developed by the authors of the report methodological and programmatic support for ground and on-Board functional modules of a CTO in a single system.**

Keywords — reconfiguration; integrated modeling; proactive management; onboard equipment; small sized spacecraft

I. INTRODUCTION

In modern conditions, to ensure the required degree of autonomy, quality and efficiency of control of such a complex technical object as a small-size spacecraft (SSS) and its onboard equipment (OE), it is necessary to solve the following main scientific and technical problems. First, to provide a model-algorithmic description of the processes of semantic interpretation of all possible regular and non-standard states of their functioning and, secondly, on this basis to solve the main problems of complex automation and intellectualization of the processes of monitoring of technical condition and control of the UA in different conditions of the situation. However, unfortunately, in the vast majority of cases, in practice, monitoring, forecasting and control of the state of elements, subsystems and the entire onboard equipment in terms of ensuring the required levels of reliability, survivability and efficiency of the SSS is automated, at best, only partially. As a rule, in modern systems of monitoring of technical condition and control of onboard equipment of SSS, operators are provided with semantic information only about the states of their elements and not the objects of control in general. These circumstances lead to the fact that the integral assessment and prediction of the SSS OE as well as the formation of the necessary control actions are performed by operators, mainly manually, based on heuristic rules [1–2].

The issues of autonomy and survivability become particularly relevant in the development and operation of the monitoring SSS (earth remote sensing) [1–2]. For the SSS data, the most important indicator of the quality of their functioning is the indicator of the efficiency of the transmission and implementation of the work programs of the special and ensuring SSS OE, and the receipt of target information and telemetry by the ground control complex (GCC), as well as the possibility of rapid intervention in the implementation of these programs in case of an emergency. Thus, for the SSS, the issues of autonomy and survivability are closely related to the issues of effective functioning of both the SSS and the GCC, and the SSS as a whole.

The problem of increasing the level of autonomy, survivability, efficiency of complex technical objects (CTO), which, in particular, include the listed classes of space facilities (CSF), in the scientific literature is considered in conjunction with the solution of problems of control, evaluation and technical diagnosis of the CTO state, reconfiguration (structural, functional, structural and functional reconfiguration) of CTO structures, management of its reserves, alternative and multi-mode management, analysis and synthesis of fault tolerance and disaster resistance of CTO [2-3]. However, unfortunately, all of these studies are fragmented. In this regard, the authors of the article in the completed project [4] carried out further development of their applied theory of proactive control of structural dynamics of CTO, within which it was possible to approach the issues of ensuring the

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reliability, survivability, disaster resistance and fault tolerance of CTO based on the configuration and reconfiguration of their structures [2–4].

The reconfiguration of the structure (structures) of CTO (including BA SSS, GCC SSS) is understood as a purposeful process of changing its structure (structures) in order to preserve, restore, and in some situations increase the levels of reliability, survivability, efficiency of application, or to ensure a minimum reduction of their required values with possible degradation and/or failure of elements and subsystems of CTO. In the case of the space sphere, during the project [5-6], several tasks were introduced and, accordingly, scenarios of reconfiguration of the main elements and subsystems of the ACU of the SSS, which can be divided into two large classes: internal reconfiguration, when only own hardware and software (OHS) are used for the SSS OE, and external reconfiguration, when in the conditions of SSS OE degradation, part of the functions of the SSS control is redistributed between the onboard and ground control systems.

II. Main research results

As a result of the research was developed an interconnected set of models, methods and algorithms, providing the solution of the following tasks: automated modeling of control processes reconfiguration OE SSS; automated formation of strategies reconfiguration OE SSS; automatic monitoring and evaluation of the current state OE SSS; automatic (automated) planning reconfiguration OE SSS; formation and issuance of commands to reconfigure the onboard systems and restore the performance OE SSS.

To solve all these problems from the unified methodological and methodical positions, a new modification of the previously developed by the project's executors of hierarchical computational G-models of data representation and processing, information and knowledge, which provided the coordination of mathematical (analytical-simulation) models of management of reconfiguration (in the general case — structural dynamics) BA SSS at the conceptual, model-algorithmic, information and program levels of detail, was proposed with their logic-algebraic and logic-linguistic analogues (models), built on the basis of intelligent information technologies.

The refinement of hierarchical computational G-models of data representation and processing, information and knowledge was carried out on the basis of the proposed by the executors of the project of dynamic interpretation of Petri nets (in the particular case of asynchronous automata used to solve the problem of identification of the state of OE SSS) and the combination of this mathematical apparatus with logical-dynamic models of software management of complex operations, resources and structures of OE SSS. In recent years, Petri networks have gained wide recognition, primarily as a convenient and visual tool for describing models of multi-level processes of parallel, streaming, spatially distributed, asynchronous information transformation. Previously performed studies have shown that using the proposed logic-dynamic interpretation of Petri nets as a dynamic alternative system of graphs with tunable structure, it is possible on a constructive level to integrate such important classes of models for the preparation and adoption of decisions in the reconfiguration of the OE, UA, as: computational models used to describe the algorithms for operational planning and control reconfiguration SSS OE; expert models to describe models of assessment state of SSS BA; as well as interactive models to describe human-machine interaction with the developed set of models.

The proposed methodology and technology of complex modeling of the SSS OE reconfiguration processes allowed to combine the previously developed and the proposed methodological and software of the ground and onboard functional modules of the SSS OE performance recovery into a single system within the framework of the service-oriented approach and the corresponding information architecture. In this case, the following specific models, methods and algorithms were designed and implemented: models of unmanaged motion of the SSS; models of management of technological operations connected with preparation and holding of the reconfiguration OE SSS; models of program management resources (electricity, fuel, information); models of control structures (topological, technical, functional) OE, SSS and formation of strategies (technology) reconfiguration OE; models for the formation scenarios of disturbances on OE; models of operational control and state estimation of SSS OE; models of formation and issue commands to the reconfiguration of onboard systems and restoration SSS OE; methods and algorithms complex (analytical and simulation) the simulation of the control reconfiguration SSS OE in a dynamically changing environment on the basis of scenario modeling languages, methods and algorithms for forming and issuing commands to the reconfiguration of the SSS OE on the basis of logical-dynamic description of these processes; methods and algorithms for forming and issuing commands to the reconfiguration of the SSS OE on the basis of logical-dynamic description of these processes.

In addition, the authors developed the following software prototypes: a prototype software for modeling and control processes, reconfiguration of on-board systems of SSS; prototype software system of formation of strategies (plans) reconfiguration of onboard systems of SSS methods and algorithms for forming and issuing commands to the reconfiguration of the onboard SSS on the basis of logical-dynamic description of these processes; prototype software complex of automatic control and evaluation of the current state of onboard systems of the spacecraft; prototype of the program complex of automatic planning of reconfiguration of spacecraft onboard systems; prototype of the program complex of formation and issue of commands for reconfiguration of onboard systems and restoration of performance of small-sized spacecraft.

For specification of initial data and modeling scenarios, the verification of the developed model-algorithmic and software was carried out on the example of the onboard equipment of the motion control system (MCS), solving the problems of radar observation of the Earth's surface [3–4].

Functionality check of the listed prototypes of software systems was carried out for the following scenarios of the

reconfiguration of OE SSS: 1) "standard" reconfiguration, which is carried out only by commands from the GSS in the areas of radio visibility of the SSS, 2) "standard" reconfiguration, conducted automatically by the MCS, except in an emergency, when it is necessary to analyze the emergency situation in the flight control center on the Ground, 3) structural and functional reconfiguration, conducted automatically by the MCS of the SSS. A series of experiments was conducted that confirmed the advantages of the structural and functional reconfiguration of the SSS compared to the "standard" reconfiguration.

III. Conclusion

The results of the simulation of the reconfiguration control processes of the SSS onboard systems have shown that the application of the proposed algorithms of structural and functional reconfiguration show greater efficiency compared to the standard reconfiguration algorithms. Thus, the number of successful sessions increased by ~50% compared to the standard reconfiguration carried out with the GCC, and by ~30% compared to the "standard" reconfiguration carried out in automatic mode. At the same time, the values of complex reliability indicators are increased for the coefficient of technical use and for the coefficient of efficiency preservation for the sessions by ~45% and ~25%, respectively, for reconfiguration carried out with the GSS and reconfiguration in automatic mode.

In general, as a result of the research the following scientific and practical results were obtained: first, with regard to the modern SSS, reconfiguration should be considered not only as a technology for managing the structures of OE SSS for compensation of failures, but also as a management technology aimed at improving the efficiency of the OE SSS; secondly, for the implementation of this concept of reconfiguration OE SSS is necessary in the future to develop such means of formalization (models, methods, algorithms, prototypes of special software (SPO), which would allow on a constructive basis to link the processes of reconfiguration OE SSS with the processes of its use for its intended purpose at different stages of the life cycle.

The developed prototypes of the special software confirmed the advantages of the proposed structural and functional reconfiguration onboard the SSS.

References

[1] Akhmetov R.N.. Makarov V.P.. Sollogub A.V. The concept of autonomous control of the survivability of automatic space vehicles for Earth remote sensing in anomalous situations. *Izvestiya samarskogo nauchnogo tsentra RAN* [Bulletin of Samara scientific center of RAS], 2009, no. 3-1, vol.11, pp. 165–176. (in Russian)

[2] Kirilin A. N.. Akhmetov R. N.. Sologub A. N.. Makarov V. P. *Metody obespecheniya zhivuchesti nizkoorbitalnykh avtomaticheskikh KA zondirovaniya Zemli: matematicheskiye modeli. kompyuternyye tekhnologii* [Methods for ensuring the survivability of low-Earth orbit automatic earth probing systems: mathematical models, computer technologies]. Moscow, Mashinostroyeniye, 2010. 384 p. (in Russian)

[3] Kulakov A.Yu. A model for estimating the fuel consumption of a spacecraft taking into account abnormal situations. *Izvestiya VUZov. Priborostroyeniye* [Journaol of Instrument Engineering], 2014, vol. 57, no. 11, pp. 30–34. (in Russian)

[4] Kulakov A.Yu.. Pavlov A.N.. Pavlov D.A. Functional reconfiguration of the sensing elements of the spacecraft motion control system. *Trudy SPIIRAN* [SPIIRAS Proceedings], 2013, vol. 28, no. 5, pp. 169–181. (in Russian)

[5] Ohtilev M.Yu., Sokolov B.V., Yusupov R.M. *Intellektual'nye tekhnologii monitoringa i upravleniya strukturnoj dinamikoj slozhnyh tekhnicheskih ob"ektov* [Intellectual technologies for monitoring and control by the structural dynamics of complex technical objects]. Moscow, Nauka, 2006. 410 p. (in Russian)

[6] Pavlov A. N. Complex modeling of structural-functional reconfiguration of complex objects. *Trudy SPIIRAN* [SPIIRAS Proceedings], 2013, vol. 28, no. 5, pp. 143–168. (in Russian)