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Articles

Remote Control of Spacecraft Flights

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Abstract

The article explores the technology of spacecraft flight control. The expansion of technologies for the use of spacecraft was noted. The main tasks of spacecraft control are described. The increase in the complexity of the flight situation entails an increase in the complexity of spacecraft control. It is shown that such control is remote. Remote control of space vehicles is spatial. Therefore, it requires the use of methods of geoinformatics and space geoinformatics. The article introduces a new concept of "flight control loop". This model serves as the basis for controlling the spacecraft. The spacecraft flight control system is described. The article shows that the quality of spacecraft flight control depends on the training of operators of ground control services. It is shown that the best way to train flight control center operators is to use simulators. The methodology for the use of simulators is described. The content of the principles of remote control of spacecraft flights is revealed. The features of the collection of spatial information for management are highlighted. The value of information units for flight control is shown. The connection of flight control models with models of spatial information situations is substantiated.

Keywords: space research, spatial control, geoinformatics, space geoinformatics, spacecraft, flight control operator, control loop, information spatial situation, information perception channel, cognitive perception channel model.

1. Introduction

The current stage of development of space research is characterized by an increase in the number of functioning spacecraft, an increase in the duration of their flight, an expansion of the scope of their use (Rozenberg i dr., 2009). Currently, permanent orbital scientific complexes, space systems for the study of natural resources and the environment, space communication systems, meteorological systems, etc. Are being operated their research was led by the development of a new scientific direction – space flight control (UCP). The tasks of the UCP consist in the creation of both methods and means to control the flight of the spacecraft. Space flight control is an integrated technology that includes various technologies methods and approaches (Markelov, 2013). In controlled flight, spatial information is the most important. This leads to the use of

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geoinformatics and ballistics methods for controlling spacecraft (SC). Geographic information systems (GIS) are a decision-making tool (Markelov, 2013). Geoinformation technologies are used to support decision-making (Tsvetkov, 2001). This brings together geoinformatics and the theory of UCP in the field of application of spatial information. Flight control of spacecraft requires the use of space geoinformatics methods. Mission control can be divided into two areas: direct flight control, training of mission control specialists. Remote flight control is carried out by the operators from the mission control center (MCC). There are no educational institutions that train flight control operators. Flight control operators are trained with additional training and advanced training. Thus, remote control of spacecraft missions includes the following components: training of specialists in management, the use of spatial information for control, monitoring the state of the spacecraft, the use of general control principles in relation to the UCP, the use of situational control technologies during the movement of the spacecraft, the solution of spatial problems to determine the location of the position.

2. Discussion and results

Technological flight control solution

When controlling flights, you have to process a large amount of various information. The volume and variety of this information exclude its processing by one person. To reduce the information load on the operator, automated control systems (ACS) are used (Soloviev, 2006; Savelyev, 2019; Rozenberg, Tsvetkov, 2010). When controlling for space flights, an automated control system is used, which performs the functions of decision support systems. The main technological link in the control of the flight of the space apparatus is the “flight control circuit” (Bronnikov, 1987). This circuit includes a feedback line and a direct control line. Fig.1 shows a generalized diagram of the control loop.

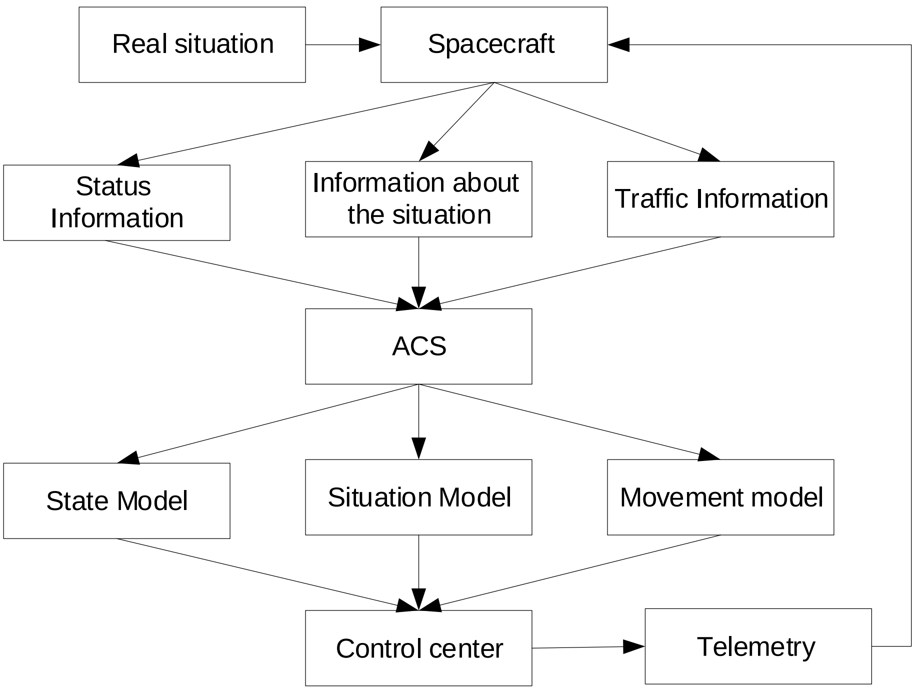

Fig. 1. Flight Control Loops

The flight control circuit has two information flows: informing and controlling. The information channel is based on the modification of monitoring and geomonitoring technologies (Markelov, Tsvetkov, 2015; Kudzh, 2015; Hohensinn et al., 2021). The informing channel describes the state of the spacecraft. Spatial information informs about the location of the spacecraft. Dynamic information informs about the speed and direction of movement. Information about the state of the spacecraft, its location and position, and its movement together forms a model of the information situation (Tsvetkov, 2012).

The prototype of the model of the information situation is the first situation of the flight. It is recorded using the sensors of the spacecraft. When analyzing spatial information, geodata (Bakhareva, 2016) are formed as systematized data, but built on cosmic information.

Therefore, the methods of space geoinformatics and (Bondur, Tsvetkov, 2015) are used for processing. The ACS of the spacecraft receives a diverse, large amount of information and converts it into models that are more understandable to the operator and intuitively perceived by him. The ACS of the spacecraft forms three groups of models: models of the state of the spacecraft, models of the situation surrounding the spacecraft, models of the motion of the spacecraft. All information is sent to the mission control center for analysis using software and intelligent software and cognitive analysis by the center's operators.

The mission control center is a complex human-machine system and a complex organizational and technical system. Operators make decisions in spacecraft flight control. But they use information from the spacecraft automated control systems. The reliability of flight control determines the work of operators. To increase reliability, group control of the spacecraft is used. Group work of flight control operators reduces the likelihood of individual error. Group work of flight control operators provides a condition for complementarity (Potapov, 2020) of actions in the group. Group work of flight control operators creates accumulated reliability (Titov, Tsvetkov, 2020) of control technologies

Heterogeneous spatial information is converted into systematized geodata (Savinykh, Tsvetkov, 2014). With the help of geodata, the position of the spacecraft and the speed of the spacecraft are determined. The position includes the coordinates of the center of mass, the orientation of the spacecraft relative to the orbit. Velocity is usually defined as the translational velocity of the center of mass and the angular velocity around the center mass.

The main feature of UCP technologies is the transformation of models into systems of information units (Ozhereleva, 2014; Tsvetkov, 2014). This ensures the unification of the development of managerial decisions on the basis of the onomasiological approach. And the information units are included in various qualitative groups. The first group is informational linguistic (ILU) units. The second group is formed by paralinguistic information (PIU) units (Tsvetkov, 2013).

Use of situational control technologies

During the flight control of the spacecraft, various deviations from the originally developed flight program are possible. The statistics of the occurrence of emergency situations during flight control shows that a significant proportion of deviations from the normal course of the flight occurs due to errors of the MCC personnel and the crew.

This leads to the need to use situation models. The external situation is related to the state and position of the spacecraft. The internal situation is related to the state of operators and the quality of their work. Taking into account situations leads to the application of situational management. Situational management uses a semiotic approach.

The actual control of the spacecraft is reduced to the transfer of the spacecraft from one spatial situation to another. Therefore, such management should be considered situational. At the same time, the transfer from one situation to another must be continuous.

The models of spacecraft flight control are closely related to various models of spatial (Pavlov, 2016) and managerial information situations (Ozherel'eva, 2016a). The basic model of the situation is a model of the real situation in which the spacecraft is located. It is transformed through the feedback channel into various smaller models. Hence, the situation model is an indispensable factor in controlling the spacecraft. This leads to the need for systematics of information situations (Tsvetkov, 2016) for informed decision-making.

The models of situations used in the control of the spacecraft are qualitatively different. The real situation exists in real space, and the operator works with the information situation (model), which is a reflection of the real situation and the operator's capabilities to control the spacecraft. The situational analysis performed by the operator and the ACS of the spacecraft has the following varieties: retrospective, current, cause-and-effect, target, predictive. Retrospective analysis is associated with the analysis of previous situations and states. There are the main tasks of situational spatial analysis:

- formation of a model of the current situation in which the spacecraft is located;
- formation of a model of the target situation in which the spacecraft should be located;
- formation of a model of the situation of deviations of parameters from acceptable values;
- formation of causal factors of deviations;
- analysis of the causes of deviations;

The peculiarity of the control of the spacecraft is that it is carried out blindly as an unmanned control of transport. At the same time, different models are used.

Training and retraining of operators

Training and retraining of operators determines the quality of management and leads to a decrease in erroneous actions during management. One of the methods of reducing erroneous actions is the use of a "match scheme". The essence of this scheme is to parallelize the same control tasks to different operators. As a result of the coincidence of management decisions from different operators, the reliability of control is assessed and an adequate management solution is chosen.

Spatial models are the basis of spacecraft control in real space. Therefore, the training and retraining of operators is based on the ability to navigate in space and the skill of spatial modeling. To ensure the ability of spatial modeling, high professional training of operators is necessary. Training and retraining of operators is carried out through the use of special simulators (Bronnikov, Sudachenko, 1979; Bronnikov i dr., 1983) and their modernization during operation.

UCP uses cognitive and information channels for perceiving information. This should be taken into account and implemented in the development of simulators. And the cognitive perception of information is simulated in simulators by creating artificial interference with clear information perception.

When developing simulators, the real situation is transmitted through three-dimensional virtual models. This is the virtual spatial aspect of the software of simulators.

On the simulator, the main flow of information goes through the visual channel of human perception. This imposes a requirement on the software in terms of applying visual modeling methods. This is a visual aspect of the creation of simulators and their operation.

When developing simulators, it is necessary to simulate the situations in which the spacecraft can be found. This is a situational aspect in the development of simulators.

A single situation does not solve the problems of flight and flight control. Therefore, it is necessary to create scenarios for the development of situations. This is a scenario aspect in the development of simulators.

All of these aspects are used in geoinformatics. Therefore, the use of geoinformatics is mandatory in the development of spatial models and scenarios for the simulator.

In addition to the listed aspects of the creation of simulators, it is necessary to apply the principles of: a systematic, anthropocentric approach; ergonomic approach, ergodic approach, resource principle.

The systemic principle (Tsvetkov, 2018) requires that the simulator as a technological system be complete and complete in terms of possible control situations. The principle of the anthropocentric approach requires that the interface of the simulator take into account the peculiarities of information reception (Nomokonova, 2015) and perception (Nomokonova, 2020) of information by the operator.

The principle of the ergonomic approach requires that the interface of the simulator be convenient to use. Did not cause temporary fatigue before.

The principle of the ergodic approach is that the simulator is considered as a human-machine or ergatic (Mordvinov, 2017) system. The features of such systems are informational cognitive aspects. Ergative systems have a number of advantages. For example, the possibility of application as fuzzy logic, the possibility of evolutionary development, the possibility of making decisions in non-standard situations. Other parameters of such systems are: aircraft control system, airport dispatch service, station dispatch service. Ergative systems are used in situations in which the operator's intervention in the operation of the object is a prerequisite for the reliable functioning of the object.

The resource principle requires the availability of a stock of information resources (Tsvetkov, 2016) (and information models) for the activities of the operator. At his disposal as a management resource should be information models, stereotypes, precedents, scenarios in order improve the efficiency of their activities.

Spatial analysis with remote control.

Simulators prepare operators for a set of possible actions. But practical flight control is based on the operator's ability to act in a real situation. Such management requires the ability to perform spatial and situational-spatial analysis.

When creating simulators, the principles of geoinformatics should be applied. Consequently, geoinformatics plays an important role in the formation of methodological support for simulators and even greater role in remote spatial control.

Spatial analysis is used in space research for control and spatial design, for navigation and orientation. The theoretical basis for statistical analysis in space research is space geoinformatics. Along with space geoinformatics, geodetic astronomy (Gospodinov, 2018), satellite geodesy, and space geodesy are used.

Spatial analysis is associated with situations in which management is carried out. This leads to the use of models of situational modeling (Buchkin, Potapov, 2020) and situational management. Spatial analysis is associated with the acquisition and use of spatial knowledge (Tsvetkov, 2015; Lin et al., 2020) and geoscience (Ozherel'eva, 2016; Tsvetkov, 2016; Raev, 2020). The basis of spatial analysis is a systematic approach. Spatial analysis in space exploration uses data integration, which brings it closer to geoinformatics.

3. Conclusion

Spacecraft mission control is a remote technology. The mission control circuit is the basis of the UCP. An important feature of the control is the decomposition of feedback channel models into information units. These information units serve as the basis for the formation of management decisions. The UCP is a complex technology that includes information and cognitive factors. Space flight control includes human factors that need to be reduced. ACS and geoinformatics methods act as a management support system. A number of specific features of the application of geoinformatics arise.

In mission control, it's not a single operator that works, but a group of operators, and they're the organizational component of the mission control systems, which includes the spacecraft automated control systems. The entire management system is a complex organizationally technical system. The board of space missions uses a channel of technical information and a channel of spatial information. The perception of information goes through the information and cognitive channels. The main information is transmitted through the information channel – visual information. The information load in the UCP falls on the operator's vision. The cognitive channel of perception and analysis uses paralinguistic information units. An important factor in the UCP is the simulator training of operators

The spacecraft model is partly invisible to the operator and located in a certain area. Therefore, the management is carried out using models of information spatial situations. About the peculiarity of the information situation in the UCP in the fact that it is formed as a cognitive model in the mind of the operator. Its objective part ends at the level of information units that describe the situation and are perceived by the operator. Hence, cognitive factors are most important in controlling the flight of a spacecraft. The model of the information situation is not static, but situationally dynamic. Electronic models take into account the dynamics of the development of the situation and the dynamics of the core of the situation – the object of control.

References

Bakhareva, 2016 – *Bakhareva, N.A.* (2016). Geodannye kak instrument upravleniya [Geodata as a management tool]. *Gosudarstvennyi sovetnik*. 2: 23-27. [in Russian]

Bondur, Tsvetkov, 2015 – *Bondur, V.G., Tsvetkov, V.Ya*. New Scientific Direction of Space Geoinformatics. *European Journal of Technology and Design*. 4(10): 118-126.

Bronnikov i dr., 1983 – *Bronnikov, S.V., Koreshkov, V.P., Krivosheev, B.V.* (1983). Trenazher dlya operatorov, kontroliruyushchikh rabotu sistem letatel'nykh apparatov [Simulator for operators controlling the operation of aircraft systems]. *Raketno-kosmicheskaya tekhnika, Seriya 9*. 4: 50-52. [in Russian]

Bronnikov, 1987 – *Bronnikov, S.V.* (1987). Trenazhernaya sistema dlya nepreryvnogo kontrolya i upravleniya urovnem podgotovlennosti operatorov [A training system for continuous monitoring and control of the level of preparedness of operators]. Avtoreferat dissertatsii, spetsial'nost' 19.00.03. Moskva, NPO «Energiya», 18 p. [in Russian]

Bronnikov, Sudachenko, 1979 – *Bronnikov, S.V., Sudachenko, A.L.* (1979). Sistema dlya trenirovok personala operativnogo analiza sistem go apparata v polete [System for training personnel of the operational analysis of the systems of the first apparatus in flight]. A.S. 145150 SSSR, MKI2 V 64 G3/00. Zayavleno 23.08.79. [in Russian]

Buchkin, Potapov, 2020 – *Buchkin, V.A., Potapov, A.S.* (2020). Geoinformatsionnoe situatsionnoe modelirovanie [Geoinformation situational modeling]. *Slavic forum*. 2(28): 210-228. [in Russian]

Gospodinov, 2018 – *Gospodinov, S.G.* (2018). The Development of Geodesic Astronomy. *Russian Journal of Astrophysical Research. Series A*. 4(1): 9-33.

Hohensinn et al., 2021 – *Hohensinn, R., Stauffer, R., Raphael, S., Pinzon, I.D.H., Spannagel, R., Wolf, A., Rossi, Y., Rothacher, M.* (2021). Low-cost vs. Geodetic-grade GNSS Instrumentation: Geomonitoring with High-rate and Real-time PPP. *Proceedings of the 34th International Technical Meeting of the Satellite Division of The Institute of Navigation (ION GNSS+ 2021*). Pp. 3990-4001.

Kudzh, 2015 – *Kudzh, S.A.* (2015). Geomonitoring kak protsess poznaniya [Geomonitoring as a process of cognition]. *Perspektivy nauki i obrazovaniya*. 1(13): 24-29. [in Russian]

Lin et al., 2020 – *Lin, J., Cao, L., Li, N.* (2020). How the completeness of spatial knowledge influences the evacuation behavior of passengers in metro stations: A VR-based experimental study. *Automation in Construction*. 113: 103136.

Markelov, 2013 – *Markelov, V.M.* (2013). GIS kak sistemy upravleniya transportom [GIS as a transport management system]. *Izvestiya vysshikh uchebnykh zavedenii. Geodeziya i aerofotos"emka*. 2: 85-87. [in Russian]

Markelov, Tsvetkov, 2015 – *Markelov, V.M., Tsvetkov, V.Ya.* (2015). Geomonitoring [Geomonitoring]. *Slavic forum*. 2(8): 177-184. [in Russian]

Mordvinov, 2017 – *Mordvinov, V.A.* (2017). Informatsionnye potrebnosti ergaticheskikh sistem [Information needs of ergatic systems]. *Slavic forum*. 4(18): 42-49. [in Russian]

Mukhin i dr., 2018 – *Mukhin, I.E., Mukhin, A.I., Mikhailov, S.N., Koptev, D.S.* (2018). Metodologicheskie osnovy sinteza sistem diagnostiki tekhnicheskogo sostoyaniya kosmicheskikh i letatel'nykh apparatov [Methodological bases for the synthesis of systems for diagnosing the technical condition of space and aircraft]. Kursk, YuZGU, 211 p. [in Russian]

Nomokonova, 2015 – *Nomokonova, O.Yu.* (2015). Retseptsiya informatsii pri meditsinskoi diagnostike [Reception of information in medical diagnostics]. *Slavic forum*. 4(10): 238-243. [in Russian]

Nomokonova, 2020 – *Nomokonova, O.Yu.* (2020). Pertseptsiya informatsii v meditsinskoi diagnostike [Perception of information in medical diagnostics]. *Slavic forum*. 2(28): 75-83. [in Russian]

Ozhereleva, 2014 – *Ozhereleva, T.A.* (2014). Systematics for information units. *European Researcher*. 11/1(86): 1894-1900.

Ozherel'eva, 2016a – *Ozherel'eva, T.A.* (2016). Informatsionnaya situatsiya kak instrument upravleniya [Information situation as a management tool]. *Slavic forum*. 4(14): 176-181. [in Russian]

Ozherel'eva, 2016b – *Ozherel'eva, T.A.* (2016). Geoznaniya [Geoscience]. *Mezhdunarodnyi zhurnal prikladnykh i fundamental'nykh issledovanii*. 5—4: 669-669. [in Russian]

Pavlov, 2016 – *Pavlov, A.I.* (2016). Prostranstvennaya informatsionnaya situatsiya [Spatial information situation]. *Slavic forum*. 4(14): 198-203. [in Russian]

Potapov, 2020 – *Potapov, A.S.* (2020). Subsidiarnost' i komplementarnost' intellektual'nykh sistem [Subsidiarity and complementarity of intelligent]. *Slavic forum*. 1(27): 77-86. [in Russian]

Raev, 2020 – *Raev, V.K.* (2020). Izvlechenie geoznanii [Geoknowledge extraction]. *Slavic forum*. 4(30): 95-104. [in Russian]

Rozenberg i dr., 2009 – *Rozenberg, I.N., Savinykh, V.P., Tsvetkov, V.Ya.* (2009). Prakticheskoe primenenie GLONASS [Practical application of GLONASS]. *Rossiiskii kosmos*. 2: 24-27. [in Russian]

Rozenberg, Tsvetkov, 2010 – *Rozenberg, I.N., Tsvetkov, V.Ya.* (2010). Avtomatizirovannye informatsionnye sistemy upravleniya [Automated information management systems]. M.: Moskovskii gosudarstvennyi universitet putei soobshcheniya, 80 p. [in Russian]

Savelyev, 2019 – *Savelyev, D.O., Gudim, A.S., Solovev, D.B.* (2019). Stabilizing the transients in the objects and systems controlling the compensation of nonlinear ACS (Automatic Control System) elements. *2019 International Science and Technology Conference" EastConf". – IEEE.* Pp. 1-4.

Savinykh, Tsvetkov, 2014 – *Savinykh, V.P., Tsvetkov, V.Ya.* (2014). Geodata As a Systemic Information Resource. *Herald of the Russian Academy of Sciences*. 84(5): 365-368. DOI: 10.1134/S1019331614050049

Soloviev i dr., 2006 – *Soloviev, V.A., Lysenko, L.N., Liubinskii, V.E. i dr.* (2006). Space flight control: Tutorial: 2 parts, Moscow: Publishing house of Bauman State Technical University. [in Russian]

Titov, Tsvetkov, 2020 – *Titov, E.K., Tsvetkov, V.Ya.* Accumulated reliability of information hardware and software systems, 2020. IOP *Conf. Series: Materials Science and Engineering,* 919 022055. DOI: 10.1088/1757-899X/919/6/022055

Tsvetkov, 2001 – *Tsvetkov, V.Ya.* (2001). Primenenie geoinformatsionnykh tekhnologii dlya podderzhki prinyatiya reshenii [Application of geoinformation technologies for decision support]. *Izvestiya vysshikh uchebnykh zavedenii. Geodeziya i aerofotos"emka*. 4: 128-138. [in Russian]

Tsvetkov, 2012 – *Tsvetkov, V.Ya.* (2012). Information Situation and Information Position as a Management Tool. *European researcher*. 12-1 (36): 2166-2170.

Tsvetkov, 2013 – *Tsvetkov, V.Ya.* (2013). Paralingvisticheskie informatsionnye edinitsy v obrazovanii [Paralinguistic information units in education]. *Perspektivy nauki i obrazovaniya*. 4(4): 30-38. [in Russian]

Tsvetkov, 2014 – *Tsvetkov, V.Ya.* (2014). Informatsionnye edinitsy kak sredstvo postroeniya kartiny mira [Information units as a means of building a picture of the world]. *Mezhdunarodnyi zhurnal prikladnykh i fundamental'nykh issledovanii.* 8(4): 36-40. [in Russian]

Tsvetkov, 2015 – *Tsvetkov, V.Ya.* (2015). Formirovanie prostranstvennykh znanii [Formation of spatial knowledge]: Monografiya. M.: MAKS Press, 68 p. [in Russian]

Tsvetkov, 2016 – *Tsvetkov, V.Ya.* (2016). Geoknowledge. *European Journal of Technology and Design*. 3(13): 122-132.

Tsvetkov, 2016 – *Tsvetkov, V.Ya.* (2016). Information Models and Information Resources. *European Journal of Technology and Design*. 2(12): 79-86.

Tsvetkov, 2016 – *Tsvetkov, V.Ya.* (2016). Sistematika informatsionnykh situatsii [Systematics of information situations]. *Perspektivy nauki i obrazovaniya*. 5(23): 64-68. [in Russian]

Tsvetkov, 2018 – *Tsvetkov, V.Ya.* (2018). Teoriya system [Theory of systems]. M.: MAKS Press, 88 p. [in Russian]