Method for the design of a multi-satellite space system for global continuous monitoring of the Earth

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***Abstract*—The article considers approaches to the selection of design parameters of a multi-satellite space system for global continuous monitoring of the Earth. The objective of this research is to develop a method for determining the optimal parameters of a multi-satellite space system for global continuous monitoring of the Earth. Firstly, existing space-based observing systems of the Russian Federation and foreign multi-satellite space-based observing systems were analysed, secondly, the requirements for multi-satellite systems of global continuous monitoring of the Earth's surface were considered, thirdly, the main restrictions imposed by the technical capabilities of the ground segment and on-board equipment of the observing spacecraft were identified, and finally, a design problem for the synthesis of a multi-satellite space system for global continuous monitoring of the Earth's surface is formulated, taking into account the restrictions of the geographical location of ground receiving stations as well as the inter-satellite communications. As a result, a method of designing a multi-satellite space system for global continuous monitoring of the Earth was proposed.**

Keywords— small spacecraft, remote sensing space system, multi-satellite system, system design.

1. Introduction

Nowadays, a high level of informatization of many human fields stipulates higher requirements to space systems in terms of the globality and the periodicity of Earth surface observation, operability of obtaining and delivering information to consumers. Consequently, there is a need to create multi-satellite space systems of Earth remote sensing, providing continuous global monitoring and aimed at solving a wide range of tasks.

2. The current state of development of space-based remote sensing systems

The information obtained from Earth remote sensing space systems is widely used for solving problems in meteorology, emergency monitoring, environmental monitoring, agriculture, geology, cartography and many other areas of human activity [1].

Development of such technologies as "smart farming" and "big data" contributes to the fact that the demand for remote sensing data is constantly growing, therefore the market of remote sensing systems demonstrates 7...8 % annual growth and according to forecasts [1] will reach 3.5 billion USD by 2024. According to the European Association of Remote Sensing (EARSC) report the main consumption of remote sensing data is optical systems, 65 % of which are high spatial resolution satellite data. Fig. 1 shows statistics and forecasts of the number of remote sensing satellites launched into orbit.

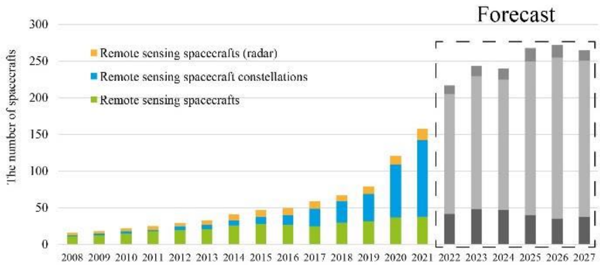

Fig. 1. Statistics and forecast of the number of remote sensing satellites launched into orbit

An analysis of existing space-based remote sensing systems has shown that in part of building modern remote sensing systems, there is a trend towards deploying multi-satellite constellations consisting of small satellites located on low circumferential sun-synchronous orbit with an altitude not exceeding 700 km [2]. The goal of such systems is to provide a global and uninterrupted view of the Earth.

Depending on the characteristics of sensors and orbital altitudes to ensure the globality and continuous overview (carrying out quasi-continuous imaging of the Earth's surface), a space surveillance system may include from several dozens to several hundreds of small satellites. A large number of spacecraft in an orbital constellation together with high-capacity sensors leads to an increase in volumes of information accumulated in the system. This problem can be solved by redistribution of information volumes between the satellites of a multi-satellite constellation through the organization of inter-satellite communication for prompt transfer of Earth remote sensing data to ground receiving stations.

In this regard, with the expected increase in the number of satellites in the orbital constellation, the urgent task is to develop a methodology for selecting design parameters of a multi-satellite space system providing global continuous monitoring of the Earth, taking into account the limited resources of onboard and ground data complexes, as well as technologies of inter-satellite communication.

3. A method for selecting design parameters for a multi-satellite space system for global continuous monitoring of the Earth

A. *Design problem formulation for a multi-satellite space system for global continuous monitoring of the Earth's surface*

The Earth remote sensing space system solving the tasks of global and continuous monitoring is a grouping of functionally interconnected spacecraft located on orbits so that any point of the Earth at any moment of time falls within the view area of at least one remote sensing satellite. At the same time, prompt data transfer to the Earth must be ensured.

The operability of the space system for global and continuous coverage should not be worse than t_{op}, which varies from a few minutes to a few hours. Such values of operability of information delivery can be provided in two ways, either by means of information transfer from satellite to satellite, with subsequent transfer to ground receiving stations, or by means of developed ground infrastructure, which would have a large number of receiving stations on the whole territory of the Earth. However, the economic and political situation in the world limits the possibilities of the Russian Federation to locate ground receiving stations outside the territory of the country, thus, this paper considers the existing ground infrastructure of ground receiving stations of Russia, as well as the transmission of accumulated remote sensing information via inter-satellite communication links. A number of requirements for a multi-satellite space system for global continuous monitoring of the Earth's surface are formulated:

- global coverage of the Earth's surface ($B_{obs} = \left\{ \varphi = \pm 90^\circ, \lambda = 0...360^\circ \right\}$);
- continuous coverage of the Earth's surface (periodicity - $t_{per} \approx 0$);
- imaging of the Earth's surface should be performed by optical-electronic sensors with a resolution of $R = 1...5\ m$;
- the orbit of each satellite should be circular;
- each spacecraft should be equipped with instruments for inter-satellite communication;
- operability of information delivery should be minimized ($t_{op} \to \min$);
- central Earth angle between the constellation satellites must satisfy the condition $\Theta_{\min} < \Theta < \Theta_{\max}$ that the satellites are in line of sight for inter-satellite communication;
- existing ground infrastructure of Russian receiving stations must be used.

The problem of selection of design parameters of space system of global continuous coverage is formulated as follows. It is necessary to provide a required level of efficiency E in the process of operation of the space system of global continuous coverage at a minimum cost of creation of the system C_{syst}. The design problem is to choose the parameters of the system F_{syst}^* from the condition:

$$F_{syst}^* = \arg\min\left\{ C_{syst} = f\left(X\right), E \le \bar{E} \right\}.$$

Considering the following restrictions:

$$B_{obs} \ge \left\{ \varphi = \pm 90^\circ, \lambda = 0...360^\circ \right\}$$
$$\Theta_{\min} < \Theta < \Theta_{\max}$$
$$t_{per} \le t_{per}^r$$
$$Q_{oe} \ge Q_{oe}^r$$

where - X is the parameters of the orbital structure providing the minimum number of satellites to solve global and continuous coverage tasks; Q_{oe} is the characteristics of the optical-electronic equipment.

Б. The proposed method

The proposed method is based on the selection of basic design parameters for a multi-satellite space system for global continuous coverage of the Earth from a variety of possible decisions satisfying a chosen criterion.

The proposed method includes:

- a model of the orbital structure of the space system providing the task of global and continuous monitoring of the Earth's surface;
- a model of information flows generated by Earth remote sensing equipment;
- a model of intervisibility of spacecraft, included into the orbital constellation;
- a model for information exchange between ground receiving station and spacecraft of the constellation;
- an algorithm for information stream control in a multi-satellite space system for global continuous monitoring of the Earth's surface operation
- an algorithm for choosing the optimum design parameters of a multi-satellite space system for global continuous monitoring of the Earth's surface from the set of solutions obtained by the selected criterion, taking into account the constraints on the design and ballistic characteristics.

4. Conclusion

A review of the present state of development of Earth remote sensing space systems is carried out. Requirements for multi-satellite systems of global continuous monitoring of the Earth's surface are considered. The main constraints imposed by technical capabilities of ground receiving stations and on-board equipment of observation spacecraft are defined. A statement of the design problem of synthesis of a multi-satellite space system for global continuous monitoring of the Earth's surface was formulated. A method for determining the design parameters of a multi-satellite space system for global continuous monitoring of the Earth is proposed.

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References

[1] Keith, A. Satellite-based Earth observation market prospects to 2027 / A. Keith, N. Larrea Brito. – Euroconsult, 2018.

[2] Baklanov, A.I. New Horizons of Space Systems of High Resolution Optical and Electronic Earth Observation / A.I. Baklanov // Rocket and Space Instrumentation and Information Systems. – 2018. – Vol. 5(4). – P. 14-27.