Development of tools for computer-aided engineering and simulation of the remote sensing satellite systems, taking into account the requirements and limitations on customer resources

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Abstract. This article examines approaches to the selection of design parameters and modelling the functioning of the remote sensing satellite systems, taking into account the requirements and restrictions on customer resources. The objective of this research is to increase the efficiency of the use of space systems to solve urgent tasks of monitoring the earth's surface. Firstly, an analysis of the requirements for space imagery materials and consumer information support for solving regional problems was carried out, secondly, mathematical models of remote sensing equipment and onboard systems of small spacecraft, as well as the ground-based complex for receiving and processing information, were developed, and finally, a database with the technical characteristics of the onboard systems and remote sensing equipment of spacecraft, launch vehicles and ground-based reception and processing information facilities was created. As a result, software to determine main design parameters and modelling the functioning of cost-effective remote sensing satellite systems was developed.

1. Introduction

Nowadays, steady increase of the number of remote sensing satellites and surveillance systems, based on them, is characteristic for Earth observation. In [1,2] it is noted that from year to year the role of remote sensing of the Earth is constantly increasing. Experts believe that by 2026 there will be more than 1100 new remote sensing satellites in orbit. In addition, a market of space information consumers has been formed, which is constantly expanding. The number of consumers grows, their composition changes, the level of tasks they solve increases. In conditions of serious competition on the market of commercial Earth observation systems the problem of obtaining profit from its functioning becomes urgent. The purpose of this research is to develop means of automated designing and modeling of target functioning of space monitoring system taking into account the requirements and limitations on the customer's resources.

2. Analysis of requirements to space imagery materials and consumer information support aimed to solve regional problems

Earth surface monitoring results are now being applied in many industries around the world. These include: agriculture; environmental management; forestry; water management; environmental monitoring; oil and gas; housing and communal services; construction; transport and logistics;

cartography and state registration; regional spatial data infrastructure; emergencies, etc. Each of the sectors corresponds to one or several consumers (regional executive authority, subordinate structures and organizations, commercial contractors), which set requirements to the information product of remote sensing.

In this study, the requirements to remote sensing information that can be used to solve problems in the above-mentioned domains have been analyzed. Thus, a link was established between the thematic tasks solved by the space monitoring system and the required characteristics of the information product: required image level and scale, spatial resolution and spectral range. Based on these data, it becomes possible to proceed to the determination of the design characteristics of the spacecraft sensing payloads.

3. Development of mathematical models of platforms and payloads for a remote sensing satellite

Development of models of satellite platforms and payloads is necessary to determine the composition of on-board systems of the spacecraft and their design characteristics, taking into account cost and time constraints. To model the characteristics of the power supply system, the thermal control system and the system for transmitting the target information, mathematical models proposed in [3,4] were used to determine the mass, size and cost of supporting systems of small spacecraft.

To determine the mass characteristics of the opto-electronic telescopic complex, the following mathematical model is proposed, linking its mass with the performance characteristics:

$$m_{sensor} = k_{spec} \cdot \pi \cdot k_D \cdot k_{MM} \frac{\Delta l_p}{\Delta L} B \left(\frac{k_D}{2} k_{MM} \frac{\Delta l_p B}{\Delta L} + \frac{\Delta l_p H}{k_f \Delta L} \right) =$$

$$= k_{spec} \cdot \pi \cdot k_D \cdot k_{MM} \cdot \Delta l_p \cdot \left[\frac{k_D \cdot k_{MM}}{2} \Delta l_p \cdot \left(\frac{B}{\Delta L} \right)^2 + \frac{\Delta l_p}{k_f} \cdot \frac{B}{\Delta L} \cdot \frac{H}{\Delta L} \right],$$

where k_{spec} – specific surface weight of the payload, k_D – overshoot ratio of the payload body diameter over the diameter of the main mirror, k_{MM} – overshoot ratio of the payload main mirror diameter over the photoreceiver, k_f – overshoot factor of the payload over its length, ΔL – linear resolution on the ground, Δl_p – characteristic size of a photoreceiver element (linear pixel size), B – swath width, H – spacecraft altitude.

Ground complexes of reception and processing of the sensing information (GCC) represent set of hardware-software complexes and the personnel, in a most basic variant comprised from an antenna and reception-recording subsystems, control workstations with corresponding software and staff of operators. The GCC model includes the following models:

- radio visibility condition model GCC → satellite;
- ground infrastructure model GCC;
- temporal communication session sequence model GCC;
- information processing complex model.

4. Results

As a result, an algorithm was developed that allows to determine the main design parameters and to perform modeling of the target functioning of the space monitoring system, taking into account the requirements and limitations of the customer's resources. The algorithm includes the following stages.

First, the characteristics of the opto-electronic telescopic complex (hereinafter referred to as payload) of the spacecraft are determined by successive selection of the thematic area of the problem, section, topic, name of the problem, thematic map (scheme), mapped layers and level of observation detail. As a result, a list of characteristics of suitable payloads that meet the requirements of the problem in terms of characteristics of scale, resolution and composition of spectral bands is formed.

Secondly, the composition of spacecraft on-board systems is being formed. For each block of on-board equipment parameters are either calculated using the developed mathematical models, or selected from the appropriate databases of already developed products with known characteristics. For each block of on-board equipment and on-board system the following parameters are transferred to the module for calculating the characteristics of the spacecraft: mass, density, volume, moment of inertia, production cost, production time, as well as characteristic parameters such as memory capacity, swath width, resolution, etc.

Thirdly, the main characteristics of the designed spacecraft are calculated, including mass, dimensions, volume, moment of inertia, energy consumption, cost and time of its production. In case of emerging discrepancy of the obtained characteristics to the required (set by the customer), there is a possibility of change of composition of onboard systems of the spacecraft and parameters of onboard equipment, and the subsequent iterative recalculation of characteristics of the spacecraft. After each calculation iteration a protocol is formed that reflects all the calculated and given characteristics of the on-board systems.

On the fourth step, the basic parameters of the space monitoring system are set, which include the number of spacecraft in the system, their active lifetime, the duration of payload operation on a single orbit pass, the minimum altitude of the Sun above the horizon during the sensing, the maximum allowable angle of deviation of the spacecraft during the operation, the time of image preparation for sending to the ground control complex and the required level of processing of the received images.

On the fifth step, the launch vehicle is automatically selected according to the number of spacecraft, their mass and volume. The selection of the launch vehicle is performed with simultaneous calculation of the number of required launches and their cost.

On the sixth step, geographic coordinates, equipment and cost of creation of ground complexes for receiving information from the space monitoring system are specified.

On the seventh step, geographic coordinates and names of observation objects of the space monitoring system are determined.

On the eighth step, the spacecraft orbit is selected from the list of available orbits or a new orbit is created for which the following parameters should be specified: perigee altitude, apogee altitude, inclination, ascending node longitude, perigee argument and launch date.

Then, a simulation of the space monitoring system functioning is performed, as a result of which the following parameters are calculated: average period of surveying of the selected objects, average speed of information delivery to the ground point, total captured area of the Earth's surface, number of transmitted images and time of the spacecraft stay in orbit.

Finally, the discount rate is set and the economic performance of the space monitoring system is calculated. The internal rate of return, discounted net income, payback period and cash flow are calculated. The cost of creation and/or lease of ground complexes of information reception, characteristics of the cost and time of spacecraft production, parameters of the system deployment are used as initial data for calculation of the system economic efficiency indicators. In case of detection of inconsistency of the calculated economic indicators with the required ones (set by the customer), there is an opportunity to return to any of the stages of selecting a thematic task, setting the characteristics of on-board systems of the spacecraft, selecting the parameters of the monitoring space system, the spacecraft orbit, and repeat the simulation modeling. After each stage of calculation of economic indicators of the space monitoring system, it is possible to form a protocol of results of calculation of system characteristics. The resulting protocol serves as the basis for the tactical and technical specifications for the space monitoring system being created.

The algorithm presented above is the basis for software and mathematical software for computer-aided design and simulation of the operation of a space monitoring system.

5. Conclusion

Approaches to the selection of design parameters and modeling of the target functioning of the space monitoring system, as well as the software system developed on their basis, differs from the well-known complexes of foreign and Russian companies by the presence of financial and economic model, allowing to determine the most advantageous option of organization, creation, launching into orbit and operation of the Earth surface monitoring space system on the basis of business modeling.

6. References

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