Efficiency assessment of a multi-satellite Earth remote sensing space systems

Maksim Ivanushkin
Samara National Research University
Samara, Russian Federation
ivanushkin.mks@gmail.com

Ivan Tkachenko
Samara National Research University
Samara, Russian Federation
innovatore@mail.ru

***Abstract*— This article considers multi-satellite Earth remote sensing space systems providing a global coverage. The purpose of the study is to provide a comprehensive model for assessing the effectiveness of multi-satellite Earth observation space systems. As a result, modelling and performance assessment of three space systems providing a global overview of the Earth's surface with a revisit time for any point at least one time per day has been carried out.**

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

I. Introduction

Multi-satellite space systems consist of hundreds and even thousands of satellites in low orbit with altitudes from 500 to 1600 km. At present their widespread development is related to the increased requirements for globality, speed and volume of information exchange. These systems make it possible to effectively solve the problems of remote sensing, broadband Internet access, navigation, meteorology, TV and radio broadcasting, etc. About 20 such systems are being created or are being worked on in different countries of the world.

The purpose of this work is to develop a comprehensive model to assess the effectiveness of multi-satellite space monitoring systems.

II. Models for assessing the effectiveness of Earth remote sensing space systems

Models have been developed to estimate performance indicators, taking into account the viewing area of the satellite's target equipment, the geographical location of receiving stations, and such parameters of the remote sensing spacecraft as the capacity of the on-board storage device and delays in the operation of the transmitting equipment.

A. Model for estimating the coverage of a spacecraft

The observation equipment is characterised by an angle of view γ_O, and in a nadir survey, it views a spherical segment of the Earth's surface. In this case, the dimensions of the surveyed surface are characterised by the central angle φ_E (Fig. 1):

$$\varphi_E = \frac{\pi}{2} - \arcsin\left(\frac{R_E + H}{R_E}\sin\gamma_O\right) - \gamma_O,$$

where R_E - Earth radius, H - height of orbit, γ_O - viewing angle of sensors, φ_E - centre angle.

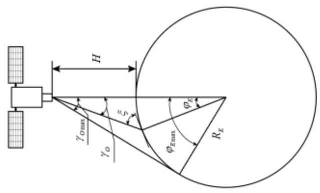


Fig. 1. Coverage area of the remote sensing spacecraft

The maximum area of Earth that can be observed by a spacecraft is characterised by the maximum observation angle $\varphi_{E\max}$:

$$\varphi_{E\max} = \arccos\left(\frac{R_E}{R_E + H}\right).$$

In turn, the coverage area can be calculated as the surface area of the sphere segment:

$$S = 2\pi R_E^2\left(1 - \cos\varphi_E\right).$$

Using the above mentioned uncomplicated ratios while simulating the orbital motion of the space system, it becomes possible to detect whether an object is in the footprint of the sensor, to estimate the duration of the communication session with the ground receiving stations, as well as the area covered by the captured area.

B. Models for assessing operability and periodicity

The operability t_{op} is estimated for each object of observation and is made up of several components:

- the time required to survey a given area - t_O;
- time required to record and wait for information in the onboard data storage device - t_{mem};
- time required to transmit information from on-board spacecraft to ground receiving point - t_{trans}.

The periodicity is estimated for each observation object and represents the time that passes between the imagery of a given object by the spacecraft of the constellation. At the same time, each fact that an observation object enters the spacecraft's field of view is recorded, which makes it possible to obtain the minimum, average and maximum values of the periodicity.

C. Restrictions

This paper proposes to take into account the following constraints in the operation of the satellite: the delay between capturing two consecutive objects; the delay before capturing after data transmission; delay before sending data after capturing; delay between shooting the same object; delay between data transmissions.

III. Modelling the operation of multi-satellite space monitoring systems

One of the most abundant space monitoring systems is the Planet constellation. Currently, it consists of 195 spacecraft: 21 SkySats and 174 Dove spacecraft [1]. The Planet constellation provides frequency of visiting any point on the Earth up to 10 times a day.

As input data for modelling, the data on target equipment [2], information on orbital motion [1] of spacecraft, and coordinates of ground receiving network [3] were used.

Also, a simulation of the operation of two multi-satellite space systems, which are expected to be able to view almost the entire surface of the Earth at least once a day, was performed. A sun-synchronous orbit with an altitude of 490 km was taken as the initial orbit. It was assumed that the spacecraft were evenly distributed over the planes, which in turn were evenly distributed over the longitude of the ascending node. The characteristics of the space systems are given in Table 1.

TABLE I. THE CHARACTERISTICS OF THE SPACE SYSTEMS

Parameter name	Case 1	Case 2
Total number of satellites in the space system	48	24
Number of planes	6	3
Distribution of planes by longitude of ascending node ($\Delta\Omega$), °	30	60
Orbital altitude, km	490	490
Inclination,°	97,3	97,3
Maximal time of survey per revolution, s	400	400
Minimum height of the Sun above the horizon, °	10	10
Maximum allowable angle of deviation during survey, °	30	30
Time of image preparation for sending, s	1800	1800
Orbital altitude, km	30,0	30,0

Case №1 represents the constellation with the largest number of spacecraft, with a total of 48 spacecraft, distributed evenly over six orbital planes, which in turn are distributed throughout the Earth's sphere by shifting the longitude of the ascending node of the orbit. The orbital structure of case 2 is half that of case 1, the distribution of orbits by longitude of the ascending node being 60 degrees.

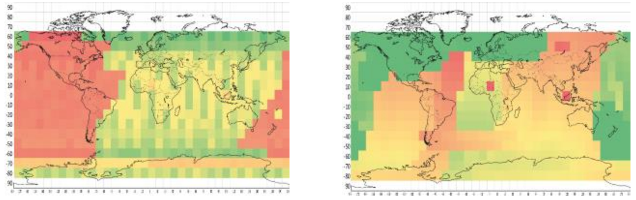
A. General considerations for modelling

For the space monitoring systems, it was assumed that surveys are taken only on the illuminated part of the turn, there are no inter-satellite communication lines, the accumulated information is transmitted to the first ground station after the survey, if the constraints are fulfilled.

Coordinates of crossing longitudes and latitudes in increments of 10 degrees were used as observation objects, this arrangement will allow to assess the global coverage of the constellation, as well as to evaluate the effectiveness of one or another location of ground stations.

B. Modelling results

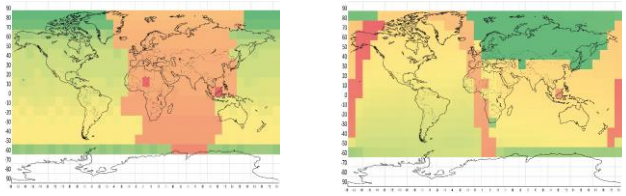
In order to identify those areas of the Earth's surface that are surveyed less frequently, as well as those areas from which it takes the longest to deliver information to ground stations, thermal maps of the frequency and timeliness distribution have been plotted. Fig. 2a,b show heatmaps of the frequency and responsiveness of Planet constellation information delivery. The areas with maximum periodicity and operability, respectively, are marked in red.



a) b)

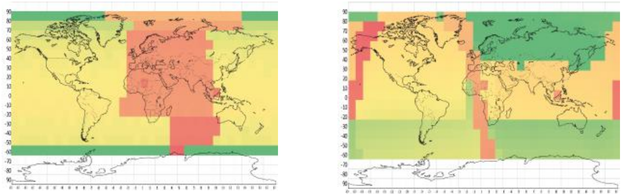
Fig. 2. Heatmaps of the periodicity and operability of information delivery of the Planet constellation

Fig. 3, 4 below show heat maps of periodicity and operability for the two proposed constellation alternatives.



a) b)

Fig. 3. Heatmaps of periodicity and operability of constellation information delivery (case №1)



a) b)

Fig. 4. Heatmaps of periodicity and operability of constellation information delivery (case №2)

Fig. 3, 4 show that cases №1 and №2 satisfy the criterion of globality of the Earth surface view during one day of flight. Case 1 (Fig. 3a) allows observation of almost the entire territory of Eurasia and North America with an average revisit time not exceeding 385 minutes. Case 2 (Fig. 4a) allows observation of the territory of Eurasia and North and South America with an average revisit time not exceeding 410 minutes. In both variants, using ground stations located on the territory of Eurasia, it is possible to achieve an average information delivery rate of 50-60 minutes (Fig. 3b, 4b).

IV. CONCLUSION

Models for assessing the performance of multispectral space-based observing systems are considered. These include: a model for the assessment of spacecraft coverage, models for the assessment of operability and periodicity, and the limitations imposed on the Earth remote sensing space system model are also described. Modelling of three space systems providing a global overview of the Earth's surface with a revisit time of at least once a day has been carried out.

REFERENCES

[1] Planet labs public orbital ephemerides [Electronic resource]. — Access mode: https://ephemerides.planet-labs.com (13.12.2022).

[2] Marshall, W. Planet Labs' Remote Sensing Satellite System / W. Marshall, C. Boshuizen // Proc. Of 27 Annual AIAA/USU Conference on Small Satellites. – 2013.

[3] Colton, K. Supporting the Flock: Building a Ground Station Network for Autonomy and Reliability / K. Colton, B. Klofas // Proc. Of 30 Annual AIAA/USU Conference on Small Satellites. – 2016.