The development of the model of satellite orbital motion

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Abstract. The article presents the results of the development of an imitation model allowing in real time to simulate the orbits of most satellite communication systems. The main feature of the model is the use of Kepler orbital elements presented in the TLE format as initial data.

1. Introduction

At present, there is an explosive interest growth of producers in the use of telecommunications equipment and telematics services based on the use of satellite technology and satellite data transmission channels.

In Russia, this is due to the massive use of GLONASS and GPS navigation systems, which are widely used in production, transport, etc. The ERA-GLONASS system and transponders of the Plato system are required for installation on the transport. There is an active development of autonomous vehicles that use satellite communication channels to transmit data to the control servers.

These features determine the relevance of studying the basics of constructing satellite communication systems and the effect of orbital motion satellites on the technical characteristics and parameters of satellite equipment installed at the end user and they must be taken into account when training specialists in the field of using telecommunications equipment.

In addition, the current stage in the development of information technologies determines the wide application of the model approach in the educational process, which makes it possible to form new knowledge within the framework of strict methodology [1], which allows reducing the time allocated for the study of complex systems with increasing the degree of mastering the training material, and forming the necessary set of competences in trainees [2, 3].

2. Statement of the problem

The main element of the satellite communication system is the satellite, which is moving in inertia around the Earth along a given orbit. The type of orbit depends on the purpose of the system and the types of services transmitted through it. For GLONASS and GPS navigation systems, the orbit is circular [4, 5] with a distance of about 20,000 km from the Earth to the satellite; to provide satellite TV services, the satellite is taken to the geostationary orbit (GSO) with an altitude of about 36,000 km; for systems of personal satellite communication, low-altitude circular orbits with a height of 700-1500 km are used.

The satellite motion along the orbit obeys Kepler’s laws of [6], the form and parameters of which are given by means of six variables, known as Kepler orbit elements.

While training specialists in radio engineering professions, a basic course of theoretical radio communication basics, including the propagation of radio waves, radio receivers, radio transmitting
and antenna devices, digital signal processing, etc. [7-8] precedes the study of the principles and features of the functioning of satellite communication systems and satellite navigation. However, for experts in the field of vehicle operation and transportation organization, detailed study of the features of satellite communication is not intended because of their training in another subject area.

A more rational method of studying the basics of satellite communication is the use of visual simulation models that allow demonstrating the motion of a satellite on orbit for given initial data.

The analysis of the subject area showed the lack of free access to adequate computer models that could be used in the educational process. At the same time, on the Internet one can find information resources that track in real time the movement of all spacecraft around the Earth, for example [10]. In these models, the spacecraft motion is modeled on the parameters of the satellite orbit elements represented in the two-line TLE (Two-Line Element set) data format compiled by NORAD [11] and freely distributed over the Internet.

Since the algorithms for modeling the motion of satellites used in models [10] are not available for studying, it is not possible to change them and correct them if necessary. Under these conditions, a scientific task was formulated, consisting in the development of a model of satellite orbital motion using available mathematical software available in the field.

3. Method of solution and results of modeling

By now, the features of the of satellites motion in outer space have been well studied and described in literature [6, 12].

The motion is carried out in a geocentric coordinate system, the center of reference of which coincides with the center of the Earth. The axis OX lies in the plane of the equator and passes through the zero meridian, the axis OZ is directed upwards, the axis OY, complements the system to the right-hand one. The position of any object in space is specified using three variables: longitude (λ), latitude (φ) and distance from the center of the Earth (d₀) (figure 1). The type of satellite orbit and its position in space are given by the following variables: the inclination of the orbit, the longitude of the ascending node, the argument of perigee, the size of the semi-major axis of the orbit, eccentricity. These variables are part of the TLE data and freely available for all satellites in orbit, which are tracked by the NORAD organization.

![Figure 1: Geocentric coordinate system.](image)

The development of the model of the satellite orbital motion was carried out in the mathematical environment of Matlab [13-15]. With the help of Matlab function “map” included in the standard functions of the environment, the Earth was added to the simulated orbits of the satellite.

The initial data used for modeling are given in tables 1 and 2. The results of modeling are shown in figures 2-5.
The simulation results shown in figures 2 and 3 allow concluding that, based on the parameters of the satellite communication system being developed and the tasks it solves, it is possible to create a given type of orbit.

**Table 1:** Initial data for modeling circular orbits.

| Orbit parameter          | Circular, oblique | Circular, polar |
|--------------------------|-------------------|-----------------|
| Number of satellites     | 6                 |                 |
| Earth Radius             | 6371 km           |                 |
| Size of the semiaxis     | 12000 km          |                 |
| Eccentricity             | 0                 |                 |
| Inclination              | 52°               | 90°             |
| Argument of perigee      | 0°, 60°, 120°, 150°, 270°, 90° | |
| Longitude of the ascending node | 35°              |                 |

For example, changing just one orbital parameter, for example, the inclination value, from 52 degrees (figure 2) to 90 degrees (figure 3) leads to a significant change in the position of the orbits from oblique to polar ones.

**Figure 2.** View of the circular oblique orbit of the satellite.

**Figure 3.** View of the circular polar orbit of the satellite.

To model the orbital grouping shown in figures 4 and 5, parameters of the currently used high-elliptic orbit of the “Molniya” (“Lightning”) with the four satellites of the “Meridian” No. 3, 4, 6 and 7 on it were the initial data presented in table 2. The simulation results show differences in the position of the satellite orbits relative to the Earth and each other, which is due to small differences in their eccentricity, inclination, perigee argument and longitude of the ascending node.

**Table 2:** Initial data for modeling the orbits of the “Molniya” (“Lightning”) type.

| Orbit parameter          | Type of orbit      |
|--------------------------|--------------------|
|                          | Oblique “Molniya” type (“Lightning”) |
The graphical editor of the Matlab environment allows changing the scale, position of the received drawings and graphs in the vertical and horizontal planes by 360 °, which increases their visibility, as well as comprehensively analyzing the results.

The size of the major semi-axis, km
Eccentricity
Inclination
Argument of perigee
Longitude of the ascending node

| Earth Radius, km | Satellite 3 | Satellite 4 | Satellite 6 | Satellite 7 |
|-----------------|-------------|-------------|-------------|-------------|
| 6371            | 26556       | 26558       | 26555       | 26555       |
| The size of the major semi-axis, km | 0.697 | 0.680 | 0.688 | 0.691 |
| Eccentricity | 63.3° | 64.5° | 65.4° | 62.8° |
| Inclination | 274.2° | 264.1° | 281° | 275.1° |
| Argument of perigee | 61.6° | 153.9° | 223.5° | 231.4° |
| Longitude of the ascending node | 61.6° | 153.9° | 223.5° | 231.4° |

Figure 4. Type of orbits of the satellite "Meridian" from Prime meridian.

Figure 5. View of orbits of the satellite “Meridian” from the side of the descending node.

4. Conclusion
Comparison of the results of orbital modeling of the existing orbital groupings (figure 4, 5) with the tested and widely used valid models [10] allows stating the high degree of adequacy of the developed model of the satellite orbital motion, and the use of TLE parameters as initial data gives an opportunity to model any type of orbits, including operating satellite communication systems, which indicates the reliability of the results obtained in real-time.

The developed model can be used in the educational process of training specialists whose future professional activity can be connected with modern satellite technologies. The use of the model of satellite orbiting motion in the training process allows the students to develop a logical imagination, which makes it easier for them to understand complex technical systems and the processes and phenomena occurring in them.
The developed model can be easily modernized and modified in order to further improve it, and the application of an accessible modeling environment expands the possibilities for its use in universities of the country.

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