DETERMINATION OF THE LIGHT CURVE OF THE ARTIFICIAL SATELLITE BY ITS ROTATION PATH AS PREPARATION TO THE INVERSE PROBLEM SOLUTION

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ABSTRACT. Developing the algorithm of estimation of the rotational parameters of the artificial satellite by its light curve, we face the necessity to compute test light curves for various initially given types of rotation and specific features of lighting of the satellite. In the present study the algorithm of creation of such light curves with the simulation method and the obtained result are described.

Introduction

In addition to the rotation that is consciously imparted to the artificial satellite and whose parameters are defined, the unplanned rotation can occur. And generally, the type of that rotation is not defined, and the attendant problems arisen in that case, such as impossibility to receive or to send signals and shortage of energy due to the satellite's inability to position itself by the Sun, do not allow of estimating the parameters of such rotation using the satellite's capabilities only. And that, in its turn, may lead to the loss of the expensive or unique satellite. But it is possible to support such abnormal satellite from the Earth by chasing changes in its light curve and interpreting them in the terms of the rotational parameters. It is possible to determine the rotational frequency by the periodicity of the brightness changes; and the orientation in space can be defined by the non-uniformity in reflection. Of course, it is not so easy, and there is great number of problems. For instance, before the launching, it is necessary to create the chart of specific features of the light reflection from the satellite, taking into account all possible positions of the satellite and the angle of the light reflection. And it is natural that those charts can turn out to be useless when the specific characteristics of the brightness change later in space, for example, due to the damages caused by micrometeorites or incomplete unfolding of the solar panels. Besides, one can not forget about errors both in the brightness charts and in the measuring of the satellite's brightness on orbit. Considering that, the determined rotational parameters will often look not as unique result, but as some range of solutions with different probability. Nevertheless, in most cases such investigation can provide useful and topical information on the rotational parameters of the satellite not using proper communication capabilities of the satellite.

Problem statement

When solving the problem of determination of the rotational motion of the artificial satellite by its brightness [1], one of the issues is the absence of real light curves for different types of rotation. Usually, the light curves are determined either for slowly rotating "active" satellites or for the satellites with undefined rotational parameters – the disabled satellites. Besides, real light curves do not allow of solving the problem "from easy to difficult", i.e. to conduct a gradual increase of the problem's complexity and similar gradual solving of the problems arisen during that process. In view of that, it is necessary to simulate the assumed light curves for the satellites with the given specific features of reflection, rotational velocity and path. In so doing, it is possible to progressively change the accuracy, duration and other characteristics of the obtained assumed light curves, as well as to find events important for the solution by continuous changing of the essential factors. By analogy with the "inverse problem", the task of which is to determine the body's rotation by its brightness, the simulation of the light curve itself based on different factors is to be hereinafter called the "direct problem".

Steps of the direct model problem solution

1. The construction of the brightness charts, i.e. correlation between the brightness of the satellite model and its orientation in space relative to the position of the light source and the observer. The data array is four-dimensional, but as the applied model of the body is axisymmetric [2] the obtained array of the brightness charts is three-dimensional. Its coordinates are the angles, defining the position of the

body's axis of symmetry relative to the Sun and the scattering plane, and the angle between the Sun and the observer – the phase angle. The step width for the chart angles is 1 degree. The example of the brightness chart of the applied model is shown in Figure 1.

2. The determination of the position of the satellite (whose orbit is a prototype for the model), observer and the Sun in the global coordinates in the given moments. The current position of the satellite is computed with algorithm SGP4 by its orbital data in the TLE format [3]. The coordinate system is geocentric equatorial.

3. Successive transfer of the position and orientation of the satellite in space, its direction by the Sun and the observer's location from the geocentric coordinate system (axis OZ – the Earth's axis of rotation) to the satellite-centric coordinate system (axis OZ – the axis of symmetry of the satellite) and then to the spherical coordinate system of the brightness charts using the translation and the rotation matrix.

4. The polar angle *"p"* and the longitude *"A"* of the longitudinal axis (the axis of symmetry) in the brightness charts' system, as well as the phase angle *"Φ"*, make possible to obtain the brightness of the model for the nearest by values nodal points in the brightness charts. The linear interpolation of data by points enables to determine the satellite's brightness for the specific values of those angles.

5. The construction of the light curve of the satellite's model.

Testing of the direct problem

Positions of the light source α=0°, δ=90° (p=0°) and the observer α=0°, δ=45°; the axis of rotation in space: α=0°, δ=60° (*p*=30°); the axis of rotation within the body: α=0°, δ=45°.

It means that the phase angle *Φ* is to be constant and equal to 45, and the angle between the axis of rotation and the axis of symmetry of the body is to be also always 45 degrees.

Figure 2 shows the change in the polar and azimuth angles *A* and *p*, defining the orientation of the longitudinal axis, from the angle of rotation of the model in degrees for the complete revolution.

The light curve is plotted in the same figure in certain relative values. The position of the axis of symmetry in space defines the value of brightness. As seen, the light curve is symmetrical, and it has two not significant peaks; angle *A* is gradually increasing from 0 to 360 degrees, the curve of changes *p* – a sinusoid with its maximum of 75 degrees in the initial point and the minimum of 15 degrees. The "selected" observations are marked with vertical lines.

As the whole light curve is obtained at the same constant phase angle (45°), then the trajectory of the longitudinal axis can be represented in single "brightness chart" in coordinates *A* and *p* (Figure 3).

As seen, the brightness chart is symmetrical in that section where the trajectory of the axis of symmetry of the body passes. The trajectory is also symmetrical, and that is the reason for the symmetry of the light curve. A narrow stripe of high brightness, which is twice intersected by the trajectory of the model's axis during its one revolution, can be seen in the brightness chart; that explains the positions and values of two peaks in the light curve. Within the range of change of *A* from 100 to 260° a significant fall of the brightness in the chart can be retraced (with angle *p* changing within 15÷25°), that corresponds to the minimum of the light curve.

On having compared the coordinates for the selected observation in the curve and in the chart, it is possible to make sure that the brightness in the curve corresponds to the brightness in the chart. For example, the coordinates of the first of the selected observations are A~25, p~75, and in the brightness scale it is somewhere between 140 and 160. That orientation corresponds to the point where the light curve value is 150.

In the context of the inverse problem solution, i.e. determination of the position of the axis of symmetry by the data on the brightness in that moment, let us consider how many points in the brightness chart correspond to one of the given brightness values, and how those points are located. The results for the second and the third selected points in the light curve are shown in Figure 4 below.

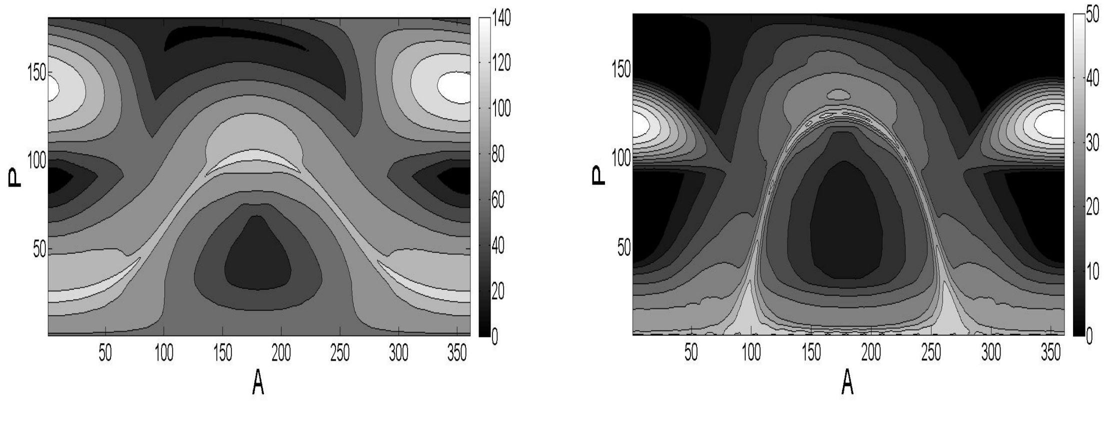

Figure 1. The brightness distribution of the model depending on the position of the longitudinal axis of the model for the phase angles 80 and 124 degrees. The axes show the longitude *A* and the polar angle *p* of the longitudinal axis.

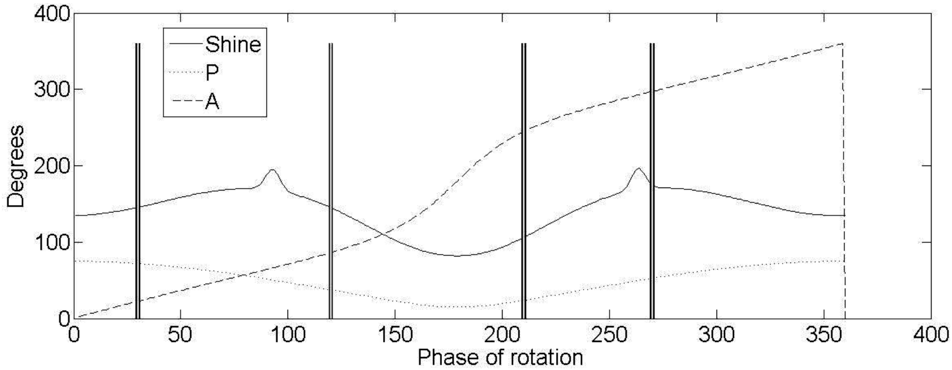

Figure 2. The change in the polar angles *p* (the dotted line) and longitude angles *A* (the dashed line) that define the orientation of the longitudinal axis and the corresponding light curve (the solid line).

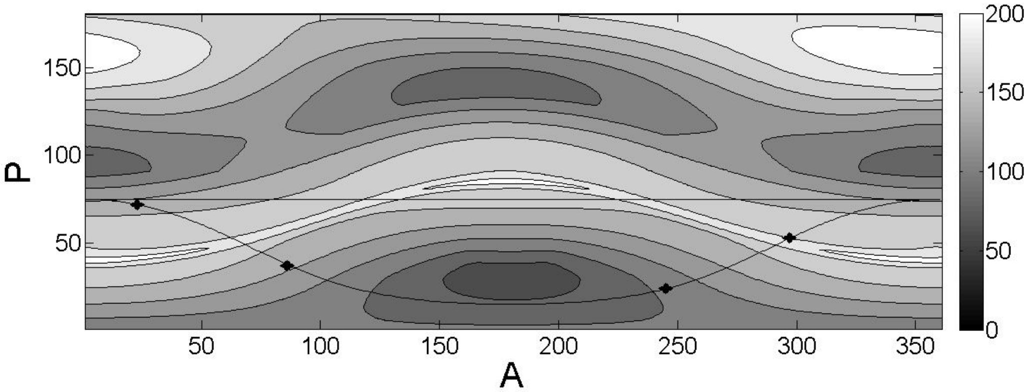

Figure 3. The brightness chart (renormalized) for Φ = 45° with the plotted motion path of the model's axis of symmetry (marked as the solid line); the selected observations are marked as crosses.

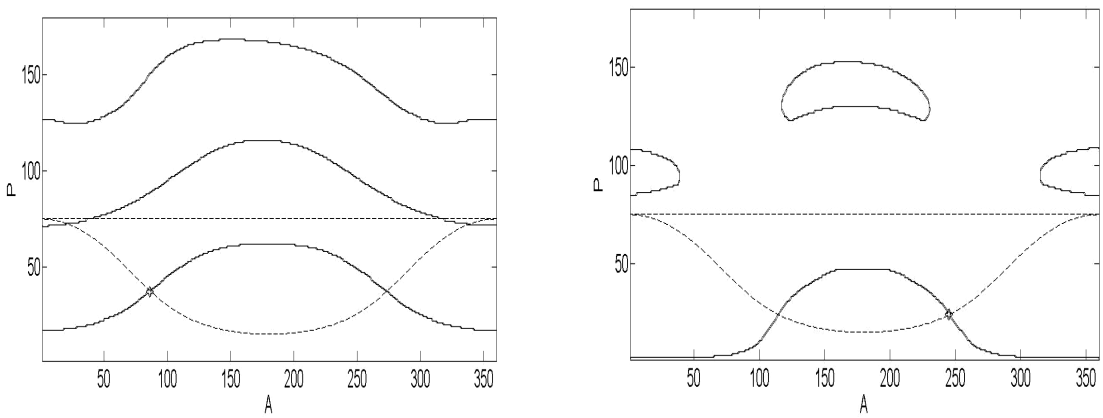

Figure 4. Isophots in the brightness chart (Φ = 45°) for two values of the model brightness with the rotation phase 120° and 210°.

Conclusion and the study to conduct

The devised algorithms allow of estimating theoretical light curves of the satellite model by the given parameters of its motion and rotation for certain lighting and observation conditions. Thereby to solve the inverse problem, it is necessary to restore the kinematic parameters of the model on the basis of the "model" light curve data by available brightness charts.

References

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3. http://www.celestrak.com/NORAD/elements/