Simulation of the Impacts of Single LEO Satellite Orbit Parameters on the Distribution and Number of Occultation Events

XU Xiaohua  LI Zhenghang  LUO Jia

ABSTRACT  Focusing on carrying out GPS occultation observations with a receiver set on LEO satellite, this paper develops the LEO orbit simulation system based on which the occultation events can be simulated taking into account the geometric relationship of the satellites and the field of view of the receiver antenna. In this paper, the impacts of 4 types of LEO orbit parameters including argument of latitude (AOL), right ascension of ascending node (RAAN), orbit height and orbit inclination on the distribution and number of occultation events observed with a single LEO satellite are discussed through simulation and some conclusions are drawn.

KEY WORDS  LEO satellite; GPS; occultation; orbit parameters

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Introduction

With GPS receivers mounted on LEO satellites, GPS occultation events can be observed. The observables are valuable for atmospheric monitoring and weather forecasting. When preparing to build up an LEO satellite occultation observation system, the evaluation, design and implementation of the system are based on effective simulations [1]. In this paper, with a LEO satellite orbit simulation system developed by the authors, the impacts of the orbit parameters of a single LEO satellite, such as argument of latitude (AOL), right ascension of ascending node (RAAN), orbit height and orbit inclination, on the distribution and number of occultation events are analyzed. In the simulation, when judging whether an occultation event will occur or not, two factors are taken into account, one is the geometric relationship between the LEO and GPS satellite and the other is the view field of the antenna of the GPS receiver.

1  Base for the simulation of occultation events

The simulation of the occultation events is based on a LEO satellite orbit simulation system developed by the authors. The real orbit of a LEO satellite is not the ideal Kepler orbit because of the impact of perturbing forces including gravitational force and non-gravitational force [2]. Only the gravitational force is taken into account in our simulation because the impact of non-gravitational force is negligible compared with that of the gravitational force.

In the simulation, two steps are followed when judging whether an occultation event will be observed or not [3].

1) To know whether an occultation event will occur is based on the geometric relationship between the LEO and the GPS satellite, we need to judge whether the line connecting the two satellites can
pass through certain layer of the earth’s atmosphere. This layer is defined as the range 0-80 km altitude above the surface of the earth because we focus attention on the inversion of the parameters of the neutrosphere in our research.

2) If the occultation event can be observed based on the geometric relationship, the field of view of the antenna is taken into consideration further more, which means that we need to know whether the direction of the line connecting the two satellites is in the view field of the antenna.

In the second step, we need to compute the angle formed by two vectors, the vector in the direction of the line connecting the two satellites and the vector of the antenna’s boresight direction. Through comparing the angle with the threshold power beam width (TPBW) of the antenna, which is the known parameter representing the view field of the GPS antenna, we can judge whether the ray path of the received GPS signal is in the view field of the antenna. So the computation of the angle is the key for the whole step and to achieve the aim, we should make the two vectors into the same coordinate system, which is decided to be the inertial system in our research. In the system the direction vector of the line connecting the two satellites in the inertial system can be got easily from the positions of the two satellites, the problem just lies in how to get the vector of the antenna’s boresight direction in the system. This problem can be solved if the transformation relationship between two coordinate systems, the spacecraft body-fixed system (sbf) and the inertial system, is known because the vector of the antenna’s boresight direction in sbf is fixed early in the satellite design stage. The attitude data of the satellite at any time is necessary to get that transformation relationship theoretically, but in our simulation, the problem is solved in a simple way. The LEO satellite is required to keep the designed attitude when orbiting around the earth and that the three axes of sbf are parallel with the three axes of RTN, it means the relationship between sbf and RTN is known. In this way, the vector of the antenna’s boresight direction in sbf, which is represented by the known azimuth and elevation of the antenna, can be transformed to the vector in the inertial system with two transformation relationships, the other between sbf and RTN and the one between RTN and the inertial system.

2 Parameters settings

Most of the LEO satellites in occultation missions are multi-use satellites. Take CHAMP and GRACE as examples, they are operating in near-circular orbits. The heights and the inclinations of the orbits are about 500 km and 90° respectively. In our simulation, the orbit parameters are set accordingly as in Table 1. The eccentricity of the orbit is set to be a small constant because of its near-circular property.

| Parameters settings | AOL/(°) | RAAN/(°) | Height/km | Inclination/(°) |
|---------------------|---------|----------|-----------|----------------|
| AOL/(°)             | 0–360   | 0        | 0         | 0              |
| RAAN/(°)            | 0       | 0–360    | 0         | 0              |
| Height/km           | 500     | 500      | 300–1500  | 500            |
| Inclination/(°)     | 90      | 90       | 0–90      | 0              |
| Eccentricity        | 0,002   | 0,002    | 0,002     | 0,002          |

In the simulation, it is assumed that 28 GPS satellites are in operation and two GPS receiver antennas are mounted on the LEO satellites, it means that rising and setting occultation events can both be observed. The parameters about the two antennas are set as listed in Table 2.

| Antenna type | Elevation/(°) | Azimuth/(°) | TPBW/(°) |
|--------------|---------------|-------------|----------|
| 1            | 27.0          | 180.0       | 45.0     |
| 2 Conical    | 27.0          | 0.0         | 45.0     |

3 Simulation results and analyses

3.1 Impact of AOL

Seeing that LEO satellites in occultation mis-
sions are mostly operating in orbits with small eccentricity, we can get the impacts of the argument of perigee and the true anomaly on the number and distribution of occultation events from the impact of AOL. The relationship between the three orbit parameters is as follows:

\[ \text{AOL} = \omega + f \]  

where \( \omega \) is the argument of perigee; \( f \) is the true anomaly.

The occultation events are simulated according to the set orbit parameters listed in Table 1 and AOL varies in the range \( 0° - 350° \) with \( 10° \) as the increasing step. It is found that the variation of AOL has little impact on the longitudinal distribution of the occultation events but as to the number of occultation events, the impact of the variation of RAAN is obviously greater than that of the variation of AOL. As shown in Fig. 3, when RAAN varies in the range \( 0° - 350° \), the number of occultation events varies regularly with 680 as the average and the variation is not larger than \( \pm 55° \).

### 3.2 Impact of RAAN

According to the parameters settings in Table 1, the impact of RAAN on the number and distribution of occultation events is studied through simulation. It is found that the variation of this parameter has little impact on the longitudinal and latitudinal distribution of occultation events but as to the number of occultation events, the impact of the variation of RAAN is obviously greater than that of the variation of AOL. As shown in Fig. 3, when RAAN varies in the range \( 0° - 350° \), the number of occultation events varies regularly with 680 as the average and the variation is not larger than \( \pm 55° \).

Furthermore, the number of occultation events varies with \( 180° \) RAAN as the period approxi-
mately. Table 3 shows that RAANs in the range 0°–180° corresponding to the largest and smallest number of occultation events, when plus 180°, get the largest and smallest number of occultation events as well.

| RAAN      | RAAN       |
|-----------|------------|
| 30° largest | 210° largest |
| 60° smallest | 240° smallest |
| 90° largest  | 270° largest |
| 120° smallest | 300° smallest |
| 150° largest  | 330° largest |
| 180° smallest | 360° smallest |

3.3 Impact of orbit height

Orbit height is an important parameter in satellite orbit design. The mission characteristics and the operating life span of the satellite both need to be concerned about in the determination of this parameter. According to the settings listed in Table 1, the occultation events are simulated while orbit height varies in the range 300–1 500 km with 100 km as the increasing step. It is found that the variation of the orbit height has little impact on the space distribution of occultation events. As shown in Fig. 4, the number of the occultation events decreases near linearly while the orbit height increases in the range 300–1 200 km, and at around 1 200 km, there is an obvious decreasing jump of about 30. It can be concluded that to get more occultation events, the height of the LEO satellite should not be too great.

Fig. 4 Impact of orbit height on the number of occultation events

3.4 Impact of orbit inclination

From Fig. 5(a)–5(f), we can get the variation of the longitudinal and latitudinal distribution of occultation events with the variation of the orbit inclination. It is found that inclination has great impact on the latitudinal distribution of occultation events. When inclination is about 10°, although the number of occultation events is large, most of the events occur over the area between latitude −30°–30°, which is not good for the global observation mission. The latitudinal distribution of occultation events becomes even when the inclination increases gradually. It is also found that when the inclination increases, the number of occultation events occur over areas of large latitude increases as well, which is beneficial for us to study the global and polar atmosphere with this technology. It is shown in Fig. 6 that the number of occultation events increases rapidly from 595 to 645 while the inclination changes from 60° to 80°. It can be concluded that the inclination of the LEO satellite should not be designed too small to get good number and distribution of occultation events.

With a LEO satellite whose inclination is larger than 90°, more occultation events may be observed because the inclination of occulting GPS satellite is smaller than 90°. But on such occasions, the relative speed between the two satellites is too large and the quality of the occultation events may be bad. That is why in all occultation missions carried through nowadays, the inclinations of LEO satellites are all designed to be smaller than 90°.

4 Conclusions

For the purpose of atmospheric and meteorological research and application, the orbit design of the LEO satellite should satisfy the requirement that there are as many even-distributed occultation events as possible. By use of the LEO satellite orbit simulation system developed by us, the impacts of orbit parameters such as AOL, RAAN, orbit height and inclination on the number and distribution of occultation events are studied in this paper. When analyzing the impact of one parameter, other orbit parameters and GPS antenna parameters are set as fixed.
Fig. 5 Impact of orbit inclination on the distribution of occultation events

Fig. 6 Impact of orbit inclination on the number of occultation events

Some improvements will be made in this future work because two factors have not been taken into consideration in the simulation. Firstly, in an occultation event, whether the GPS signals can be received by the antennas on the LEO satellite or not will be affected by the antenna gain and the signal intensity. In this study, the impact of the property of the antennas on the quality of the received signals has not been taken into account. Secondly, the study of occultation events observed by a LEO constellation composed of multi-satellites is necessary on that the space-time distribution of occultation events observed by a single LEO satellite is not good enough for the application purpose. It is believed that these problems will be solved in the near future.

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