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Selection of the best initial orbital elements of satellite based on fuzzy integration evaluation method*

Yang Yong'an[1,2], *Zhang Hongwei*[2], *Feng Zuren*[1] & *Luo Yongjin*[2]
1. Xi'an Jiaotong Univ., Xi'an 710049, P. R. China;
2. Xi'an Satellite Control Center, Xi'an 710043, P. R. China
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Abstract: The fuzzy integration evaluation method (FIEM) is studied in order to select the best orbital elements from the multi-group initial orbits determined by a satellite TT&C (Tracking, Telemetry and Control) center with all kinds of data sources. By employing FIEM together with the experience of TT&C experts, the index system to evaluate the selection of the best initial orbits is established after the data sources and orbit determination theories are studied. Besides, the concrete steps in employing the method are presented. Moreover, by taking the objects to be evaluated as evaluation experts, the problem of how to generate evaluation matrices is solved. Through practical application, the method to select the best initial orbital elements has been proved to be flexible and effective. The originality of the method is to find a new evaluation criterion (comparing the actually tracked orbits) replacing the traditional one (comparing the nominal orbits) for selecting the best orbital elements.

Keywords: system engineering, fuzzy integration evaluation method, satellite, initial orbit, TT&C system.

1. FOREWORD

At present, the data sources to be used by the satellite TT&C (Tracking, Telemetry and Control) center of China in determining initial orbits include the telemetry data and tracking data of rockets and satellites. In the telemetry data, there are data at seconds nodes and shutdown nodes of rockets, and the onboard GPS data of rockets and satellites. In TT&C missions, many TT&C stations with different TT&C equipment are often utilized during injection phases. Therefore, there are at least five groups of initial orbital elements determined by the satellite TT&C center each time, but only one group is used in the end. Then, there is a problem of how to select the only one group of initial orbital elements, which must be solved by the satellite TT&C center. The only one group to be selected for application must be the best to fit the actual conditions because the initial orbital elements are very important for the prediction of satellite tracking and the arrangement of TT&C schedules. In the contracts of TT&C supports to commercial launches for foreign customers, the index of differences of initial orbital elements is a very important requirement.

There are many factors involved in the selection of the best initial orbital elements. Some factors, such as the frequency of using tracking data and the influential degree of space environment, are abstract and fuzzy because it is hard to describe them exactly. The factors are influenced not only by the tracking equipment but also by the satellite and its space environment. Nevertheless, the factors can be compared with each other since all pieces of equipment are utilized to perform the same TT&C support to the same target. Therefore, it is feasible to employ the fuzzy integration evaluation method in selecting the best group of initial orbits.

2. DATA SOURCES AND THEORY TO DETERMINE INITIAL ORBITAL ELEMENTS

The initial orbital elements of a satellite are the coarse orbital elements determined by the satellite TT&C center with a small quantity of tracking data according to certain mathematical models. Theoretically speaking, in order to determine the ini-

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tial orbital elements of a satellite, the tracking data and telemetry data of rockets and satellites are utilized to compute the satellite state vectors of Position $\vec{r}_0$ and Velocity $\dot{\vec{r}}_0$ in the orbit coordinate system at a certain time t_0. And then, the two state vectors are converted into six orbital elements. Here, t_0 stands for the orbital epoch. The data sources and theory to be utilized by the satellite TT&C center for initial orbit determination during the injection phase are as follows.

Telemetry data at shutdown nodes of rockets

The telemetry data at shutdown nodes of rockets are divided into two kinds. One kind includes t_k, W_k, $\dot{W}_k$, $\ddot{W}_k$, $\dddot{W}_k$, which are time, velocity, simple integral of velocity, quadratic integral of velocity and cubic integral of velocity. The telemetry data of this kind with certain given coefficients are used to compute the velocity $\dot{\vec{r}}$ and the position $\vec{r}$ in the launch platform coordinate system, which are converted into orbital elements. The other kind includes velocity $\dot{\vec{r}}$ and position $\vec{r}$ in the launch platform inertial coordinate system, which are converted into orbital elements directly.

Telemetry data at seconds nodes of rockets

In every second, there is one group of flight position and velocity vectors, which are converted into orbital elements through coordinate conversion. Since there is one group of orbital elements generated in every second, there are many groups of orbital elements. First, the averages of each group of orbital elements are computed. Then, the group of orbital elements which average error is the biggest is eliminated each time. Finally, the only one group of orbital elements is got.

Tracking data of radar

In the Newtonian gravitational field, if the two position vectors $\vec{r}_1$ and $\vec{r}_2$ as well as the time interval from $\vec{r}_1$ to $\vec{r}_2$ are given, the conditions for boundary values which determine two-body movement differential equations are satisfied, and the movement equations are solvable. During the non-powered flight period from the final velocity correction shutdown of the rocket to the satellite-rocket separation, the radar can acquire related data for several dozens of seconds. The data can be used to determine the initial orbital elements of the satellite.

Onboard GPS data of satellites or rockets

The GPS data includes original data and resultant data. The original data contains the pseudo ranges and the pseudo ranging rates, which are used for orbit determination through difference; the resultant data contains time, position and velocity, which are used for orbit determination directly.

Tracking data of unified TT&C equipment

The types of the tracking data of unified TT&C equipment and their orbit determination theories are similar to those of the tracking data of radar. Therefore, it is not necessary to repeat them here.

3. SELECTION OF THE BEST INITIAL ORBITAL ELEMENTS BY USE OF FIEM[1]

3.1 Acquisition of Evaluation Data

The evaluation data contains the allowed differences of the rockets' orbital elements and the initial orbital elements determined by the TT&C center with various tracking data. All the evaluation data are required for selecting the best initial orbital elements, and they are provided by the TT&C center.

3.2 Determination of Evaluation Item Set

An item set is a common set composed of all the factors of the object to be evaluated, and it is expressed as $F=(f_1, f_2, \cdots, f_n)$. Here, $f_i (i=1,2, \cdots, n)$ is the i^{th} factor that affects the item F. According to the knowledge and experience of TT&C experts, the evaluation item for selecting the best orbital elements is composed of six orbital factors (i. e. orbital elements) for orbit determination. The evaluation item set is expressed as $F=(f_1, f_2, f_3, f_4, f_5, f_6)$, where, f_1 stands for the semi-major axis (A), f_2 stands for the eccentricity (E), f_3 stands for the orbit inclination (I), f_4 stands for the right ascension of ascending node (Ω), f_5 stands for the argument of perigee (ω), and f_6 stands for the mean anomaly (M). If a certain orbital element of a satellite has no accuracy requirement, the element is not taken as an evaluation element.