A METHOD FOR CATALOGUE CORRELATION OF SPACE OBJECTS

Shengxian Yu, Rongyu Sun, and Chen Zhang

Purple Mountain Observatory, Chinese Academy Sciences, Nanjing 210008, China., Email: {Shengxian Yu, yusx}@pmo.ac.cn

ABSTRACT

Survey of space objects is a very complicated procedure consisted of several interdependent steps. Every step plays an important role in seeking a perfect survey result. Catalogue correlation is very crucial during the whole course. There are mainly two correlation methods which are used frequently named orbit correlation algorithm and arc correlation algorithm simply. The first is to determine a six parameters orbit using a single tracklet by means of initial orbit determination, and then to correlate the tracklet by comparing the six parameters orbit and the orbits of catalogued space objects. The other method is independent of initial orbit determination. It transforms the orbits of catalogued space debris in celestial coordination to the topocentric astrometric positions in observation epoch when the tracklets happen. Hence the correlation is performed by comparing the observed tracklets and the computed tracklets. As we all know, the problem of initial orbit determination of short arcs is very difficult to solve. The general treatment is assuming the orbit is circular for the short tracklets. Obviously, it is not suitable for high eccentricity objects. The second method called arc correlation algorithm avoids the problem, hence it is applicable for space objects with different types of orbits. In the paper, a new method based on the second algorithm is proposed. The orbital errors of space objects are used in this method. Then the correlation results derived from these two algorithms are assessed. It is found that the algorithm with orbital errors is more reliable and efficient.

Keywords: Catalogue correlation; Dynamical criteria; Space object.

1. INTRODUCTION

Survey of space objects is a very complicated procedure consisted of several interdependent steps. Every step plays an important role in seeking a perfect survey result. In the first step, plenty of tracklets which are continual short series of astrometric positions are derived from the raw images. They will be correlated with the catalogued space objects then, usually called catalogue correlation. Once the tracklets are correlated with the known catalogued objects, the orbital information of these space objects can be updated. At the same time, the uncorrelated tracklets will be processed by the nest step called uncorrelated target (UCT) processing.

Obviously, catalogue correlation is very crucial during the whole course. To assess the results of catalogue correlation, correlation percentage is defined as the number of the correlated tracklets divided by the sum of tracklets. If the correlation percentage is smaller than expected magnitude, it means too many uncorrelated tracklets are left. This will increase the load of UCT processing, or even lead to abortion of the whole procedure. There are mainly two causes of the low correlation percentage. One is the bad weather which causes too many virtual tracklets which are not space object, the other cause is improper algorithm of catalogue correlation. The first cause is inevitable, and it happens accidentally. Therefore, a reasonable and suitable algorithm is of great importance. There are mainly two correlation methods which are used frequently named orbit correlation algorithm and arc correlation algorithm simply [1, 2]. The first is to determine a six parameters orbit using a single tracklet by means of initial orbit determination, and then to correlate the tracklet by comparing the six parameters orbit and the orbits of catalogued space objects. The other method is independent of initial orbit determination. It transforms the orbits of catalogued space debris in geocentric celestial coordination to the topocentric astrometric positions in observation epoch when the tracklets happen. Hence the correlation is performed by comparing the observed tracklets and the computed tracklets. As we all know, the problem of initial orbit determination of short arcs is very difficult to solve [3, 4]. The general treatment is assuming the orbit is circular for the short tracklets [1]. Obviously, it is not suitable for high eccentricity objects. The second method called arc correlation algorithm avoids the problem, hence it is applicable for space objects with different types of orbits.

2. CATALOGUE CORRELATION METHODS

Assuming that the observed tracklets (a series of right ascensions and declinations in geocentric celestial coordination of J2000.0) are as followed,

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$$\alpha_O^i(n),\ \delta_O^i(n),\ i=1,2,\cdots,K_n,\ n=1,2,\cdots,N. \quad (1)$$

where N is the number of tracklets obtained, K_n is the number of observed points in the n-th tracklet. The computed tracklets are derived from the orbit propagation of catalogued space objects and the transformation from the six parameters orbits to astrometric positions, as followed,

$$\alpha_C^i(n),\ \delta_C^i(n),\ i=1,2,\cdots,K_n,\ n=1,2,\cdots,N. \quad (2)$$

At the observed time, there are an observed tracklet and a computed tracklet. For each pair of tracklets, the velocities of the tracklets can be derived by using linear fitting, they can be expressed as

$$(V_{\alpha_O}, V_{\delta_O}),\ (V_{\alpha_C}, V_{\delta_C}). \quad (3)$$

Therefore, the in-track errors and the cross-track errors can be calculated using the following formula,

$$\begin{array}{l} ERR\,(in-track) = \left|\Delta\alpha^i V_{\alpha_O}\cos^2\delta_O^i + \Delta\delta^i V_{\delta_O}\right|/V_O, \\ ERR\,(cross-track) = \\ \left|\Delta\alpha^i V_{\delta_O} cos\delta_O^i - \Delta\delta^i V_{\alpha_O} cos\delta_O^i\right|/V_O, \\ V_O = \sqrt{\left(V_{\alpha_O}^2 cos^2\delta_O^i + V_{\delta_O}^2\right)},\ i=1,2,\cdots,K_n. \end{array} \quad (4)$$

Besides the two errors of in-track and cross-track, there is another parameter which is feasible and effective in catalogue correlation. It is defined as the angle between the velocity of the observed tracklet and the velocity of the computed tracklet. It also reveals the error of the orbital plane of space object when the orbital inclination is actually unknown. The defined angle can be derived as below,

$$\begin{array}{l} A = cos^{-1} \\ \left[(V_{\alpha_O}V_{\alpha_C}cos\delta_O^i cos\delta_C^i + V_{\delta_O}V_{\delta_C}),/(V_O V_C)\right], \\ V_C = \sqrt{\left(V_{\alpha_C}^2 cos^2\delta_C^i + V_{\delta_C}^2\right)},\ i=1,2,\cdots,K_n. \end{array} \quad (5)$$

In general, the three parameters $ERR\,(in-track)$, $ERR\,(cross-track)$ and A in Eq. (4)-(5) are combined to perform the catalogue correlation. A tracklet is regarded as correlated when all the following conditions are satisfied,

$$\begin{array}{l} ERR(in-track) < R_1,\ ERR(cross-track) < R_2, \\ A < R_3. \end{array} \quad (6)$$

Usually, the thresholds R_1, R_2 and R_3 are set to be constant, or set to be different constants according to the type of orbits of space objects [1]. However, it is not reasonable to use the same thresholds for all the space objects, even for the space objects with the same type of orbits. As we all known, the orbital errors of the catalogued space objects are different for all kinds of reasons. The orbital errors are often ranged from no more than 1 kilometer to several hundreds kilometers. If the thresholds are too small, most of the tracklets will be identified as UCTs. On the contrary, the tracklets will be correlated to multiple space objects when the thresholds are large. Therefore, it is difficult to determine the thresholds.

In the paper, a new method is proposed to overcome these disadvantages and difficulties mentioned above. In this method, the basic equations (4)-(6) are also used. Differently, the orbital errors are introduced to determine the threshold. So each catalogued space object corresponds to a different threshold. In fact, the method depends on the orbital errors strongly. Therefore the catalogued space objects should contain not only the orbital elements but also the orbital errors. However, currant official catalogues do not provide any covariance information, including the two line element (TLE) data from space-track internet [7]. Fortunately, for most of space objects, there is enough data that is updated continuously for about one set of orbit elements a day for TLE data. In this study, the catalogued TLE data are adopted to correlate the tracklets. At the same time, there are some studies about the orbital errors of TLEs [5, 6]. Xu [6] used statistical method to derive the orbital errors in orbit tangential direction, normal direction inside orbital plane and normal direction out of orbital plane. It can be used in this study to derive the orbital errors of catalogued space objects for catalogue correlation. The vectors of the three directions are defined below,

$$\begin{array}{l} \mathbf{U} = \mathbf{V}, \\ \mathbf{W} = \mathbf{P} \times \mathbf{U}, \\ \mathbf{N} = \mathbf{W} \times \mathbf{U}. \end{array} \quad (7)$$

where $\mathbf{P}$ and $\mathbf{V}$ are the unit vectors of position and velocity of the space object in J2000.0 geocentric celestial coordination.

The statistical results contains the mean errors and the root-mean-square errors in the above mentioned three directions. They are expressed as $U_{ave}(t)$, $N_{ave}(t)$, $W_{ave}(t)$, $U_{rms}(t)$, $N_{rms}(t)$ and $W_{rms}(t)$ which are all conic function of the time span t since the initial time corresponding to initial orbit of space object [6].

In the paper, the 6-σ rule is adopted although the probability of the errors larger than 3-σ is only 0.27%. However, the statistical results derived from the TLE data is not always the ideal normal distribution due to the limited TLE data, hence the more strict rule 6-σ is adopted.

The errors in U, N and W directions are converted to the errors in the direction of in-track, out-track and the defined angle A then.

3. COMPARISON OF CATALOGUE CORRELATION RESULTS

In this section, the dynamical criteria proposed in previous section is adopted to correlate the measured data observed from January 24, 2018 to January 26, 2018 by an optical telescope located in Yaoan with 4.4 square degree. As a comparison, the static criteria is also used to make the catalogue correlations. The two correlation results will be compared to each other to assess the feasibility of the catalogue correlation method with the dynamical criteria.

For the static criteria, it is troublesome to determine the criteria. If the criteria is too small, some tracklets will miss the correlations. Conversely, it will result in too many incorrect correlations. Hence, to ensure more track-lets are correlated, the larger constant criteria $U = 80km, N = 40km$, and $W = 40km$ are adopted for all of the space objects in this paper.

In the paper, the catalogued TLE data are adopted to correlate the tracklets. There are 28 space objects whose orbital elements are updated continuously are picked to make the correlations. As we all know, the orbital error is relevant to the duration of orbital propagation. In the process of catalogue correlation, the durations of the orbital propagation of the space objects used are always different from one another. Hence, two different durations 5 days and 10 days are used to access the correlation results. For example, the catalogued orbital elements in January 19 and in January 14 are adopted when correlating the observation data of January 24, 2018.

After catalogue correlations are made, precision orbit determination is used to verify whether the correlation is right. In the process of precision orbit determination, the tracklets of the same space object will be dealt together, and the 3-sigma criterion is used, so that the tracklets beyond 3-sigma are thought to be miscorrelation. All of the tracklets will be recognized as mis-correlated when the precision orbital determination is failed or the root-mean-square error is larger than 10 arc-seconds. This criterion of 10 arc-seconds is mainly a rough estimation according to the precision of the observation data which is about 1-3 arc-seconds. The other reason is that sometimes the precision of the observation data is affected by the stars when the space object is very close to a star. And it is very rare that there are two space objects are nearer than 10 arc-seconds. Hence, the criterion of 10 arc-second is thought to be appropriate.

Table 1 Number of correlated space objects.

	Dynamical criteria		Static criteria	
Data	5d	10d	5d	10d
2018-01-24	20	19	16	10
2018-01-25	19	18	16	12
2018-01-26	17	16	16	11

Table 2 Number of correlated tracklets.

	Dynamical criteria		Static criteria	
Data	5d	10d	5d	10d
2018-01-24	133	123	110	55
2018-01-25	126	123	115	73
2018-01-26	113	107	98	59

Using the above methods, the processed results are listed in table 1 and table 2. Table 1 presents the numbers of correlated space objects using the two catalogue correlation methods for propagation durations of 5 days and 10 days, and it is the corresponding numbers of tracklets in table 2. Due to the reason that the orbital error of 10 days' propagation is obviously larger than that of 5 days' propagation, the number of the correlated space objects for 10 days case is obviously no more than the number for 5 days case using static criteria. In fact, there are far less space objects correlated for the 10 days case than the results of other cases. At the same time, the number of the tracklets correlated in 10 days case are also very less.

For the dynamical criteria, the number of correlated space objects is obviously larger than the results in static criteria case. As shown in table 1. The 10 days case only miss one space object compared with the 5 days case in each of the three days. The number of correlated tracklets in 10 days case decreases by 10 tracklets at most.

From the results, it can be concluded that the dynamical criteria performs well compared with the static criteria. Due to the reason that the orbital error is relevant with the propagation time. Hence it is undoubted that the orbital errors in 10 days case are larger than that in 5 days case. under the circumstances, the orbital errors of some space objects are larger than the static static criteria in 10 days case, and then it results in the failure of correlation for these space objects. For the dynamical criteria, it uses the criteria which is relevant with the propagation time. Hence, most of the space objects are also can be correlated even for the 10 days' propagation. However, the orbital errors we used are only a statistical results based on the historical catalogued data. The reliability of the propagation of the orbital error is dependent on several reasons including the density of the historical catalogued data, the orbital type and the dynamical propagation model used. Hence, when the propagation time is larger, there are still some space objects can not be correlated. In a word, dynamical criteria method can correlated most of the mis-correlated space objects while using static criteria method. It is effective in performing catalogue correlation.

4. CONCLUSIONS AND DISCUSSIONS

In the paper, two catalogue correlation methods are performed using the observation data from January 24 to January 26. In order to assess the feasibilities and efficiencies of the two methods, the catalogue orbits with two different propagation durations are adopted to correlate the observation data, that is, the catalogue orbits of 5 days ago and 10 days ago are used. It is found that the static criteria is not so effective especially for the 10 days' case. On the contrary, the dynamical criteria works well even for the longer propagation duration. In the three days' test, only one space object is failed to be correlated for each day. It can be concluded that the dynamical methods is feasible and efficient when performing catalogue correlation. However, it requests that the catalogued space objects have the information of orbital errors, so that it can be used for the calculation of dynamical criteria. Therefore, a reliable and updated consistently catalogue data library with orbital errors is necessary. However, most of the public catalogue data libraries have no information of orbital errors, so that it is a crucial problem that how to derive the reliable information of orbital errors. It needs to be studied further.

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