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Space Debris Ranging Data Orbit Determination

Zhipeng LIANG, Chengzhi LIU, Cunbo FAN, Xingwei HAN
Changchun Observatory, National Observatories, CAS.
liangzp@cho.ac.cn

Abstract. *We analyzed Changchun SDLRS data statistics, and proposed hybrid orbit determination method for fitting on single pass laser ranging data. Method demos on Starlette data exhibited perfect improvement in both single-station and multi-station cases. The accuracy of initial and fitted debris orbits were assessed against real data. The improvement of debris orbits was acceptable.*

Introduction

Space debris problem has attracted global concern. The foundation of all space debris coping methods require highly accurate orbits, therefore precise orbit measurement facilities are built, such as laser ranging systems dedicated to precise tracking of space debris. Laser ranging is the most promising technique in space debris orbit improvement. Inside ILRS network, the first publicly reported case of space debris laser ranging was by EOS technologies [Greene2002]. Asian and European stations were also successful in acquiring ranging data [Zhang2012, Kirchner2013]. Research in debris ranging data analysis and orbit determination began in the same period [Liang2012], and in recent years great progress had been achieved [Bennett2015, Sang2014a, Sang2014b]. Changchun Observatory had been continually upgrading its laser ranging system, and acquired debris ranging data successfully in February 2014.

Changchun Space Debris Laser Ranging System

The Changchun SDLRS system was dedicated to commit space debris laser ranging mission. Its pulsed NdYAG laser works at wavelength 532nm, with 60mJ pulses. The repetition rate is 500 Hz and adjustable. Pulse width is less than 10ns. The beam divergence is 0.4mrad from laser, and 22 microradian exiting the system. The beam quality has M-square factor of less than 1.5 .

System Performance

Single shot precision of the system was 1.5m in average, while most data achieved better precision. The system tracked 466 passes from 233 different debris objects during 23 nights in Feb-May 2014 campaign. The system acquired 4890 normal points from 412,882 full rate data points. Data duration distributes from 2s to 271s, averaging to 1 minute. Measured laser range data has minimum of 400km and maximum of 1717km, with an average about one thousand kilometer.

Orbit and Assessment Method

To make use of single station laser ranging data, we have two questions to ask:
1) Is it possible for single station range data to improve space debris orbit accuracy?
2) Would this improvement benefit other stations?
These two questions are important because space debris laser ranging is difficult in the present time, and respective global network might not be available. Be single station orbit improvement possible,

existing stations could work rather independently. If such independent improvement can be shared with other tracking stations, the acquisition of follow-up observations will be easier. Both facilitate smooth transition from stand-alone stations to globally coordinated network.
As will be shown below, the answers to the above questions are both confirmative.

Method of Orbit Determination

To determine orbit from single station laser ranging data, special method is required. The method is called ‘hybrid orbit determination’ (HOD for short) or ‘TLE-aided orbit determination’. First generate initial orbit from TLE, which should have been done before tracking operations. Then simulate observation data for presumed globally distributed network stations from that initial orbit. Finally, proper weight is assigned to both real data and simulated data. The rest is same as ordinary orbit determination process, applying proper perturbation models: earth gravitation model, solar radiation pressure, atmospheric drag, etc.. The word ‘hybrid’ means that real data and simulated data are mixed up as input for orbit determination. Data weight is assigned to reflect data precision, that we assume one meter for real data and 600 meters for TLE-simulated data. The presumed station network need not be real coordinates, but can be fake ones. In our case, 12 fake stations evenly distributed on earth ellipsoid are sufficient.
With determined orbit, prediction may be generated for 5-day span from observation epoch. The orbit assessment is described below.

Method of Orbit Assessment

Reliable assessment is as important as stable orbit determination. In most of the literature, orbit assessment for space debris is done during orbit determination process, which is ‘self assessment’. The assessment we use, however, is based on real data and thus more valid. To assess the orbit we determined in last section, an extra data pass is required to compare with the orbit prediction.
For one space debris object, the steps to assess its orbit are:
Step 0: First, make the TLE orbit for initial tracking, getting orbit T.
Step 1: Get two passes of data during tracking campaign.
Step 2: Do HOD fitting on the first pass of data, getting orbit H.
Step 3: Compare the second pass with both orbits, getting error T and error H.
Now if error H is less than error T, then we assert orbit H is better than orbit T in predicting future observations, and thus the orbit H is improved from orbit T.

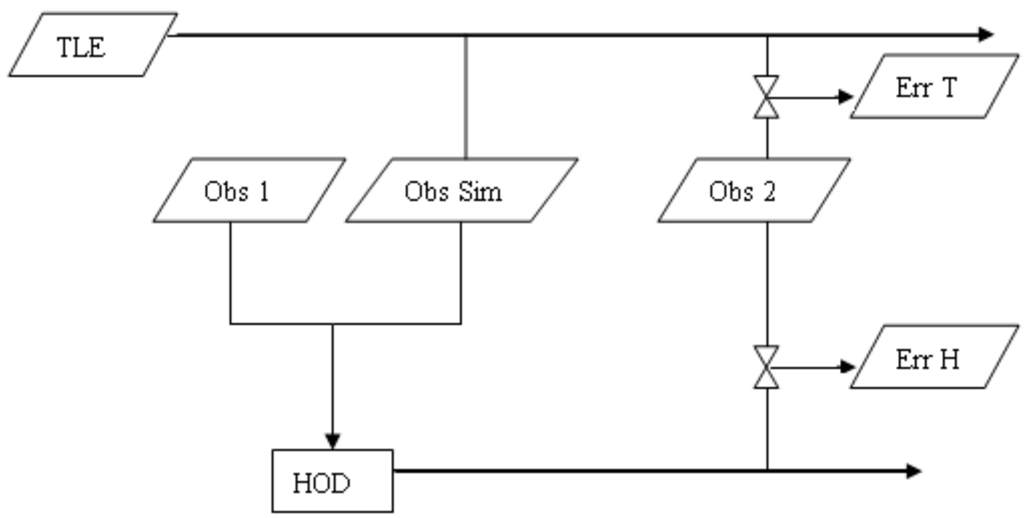

Figure 1. Flow Chart for the orbit determination and assessment process --- TLE and HOD stand for space debris orbits, while Obs-1 and Obs-2 represent observation data in separated passes.

Demo with Starlette data

To test the above orbit determination and assessment method, we chose the satellite Starlette as example. Seven Starlette passes in three days were extracted from Changchun's data repository, and corresponding TLEs were retrieved from space-track website. HOD fit was done for every single pass, and the resulting orbits were compared with later passes, making 21 pairs. All these pairs gave positive results, i.e. HOD orbits were improved upon TLE orbits.

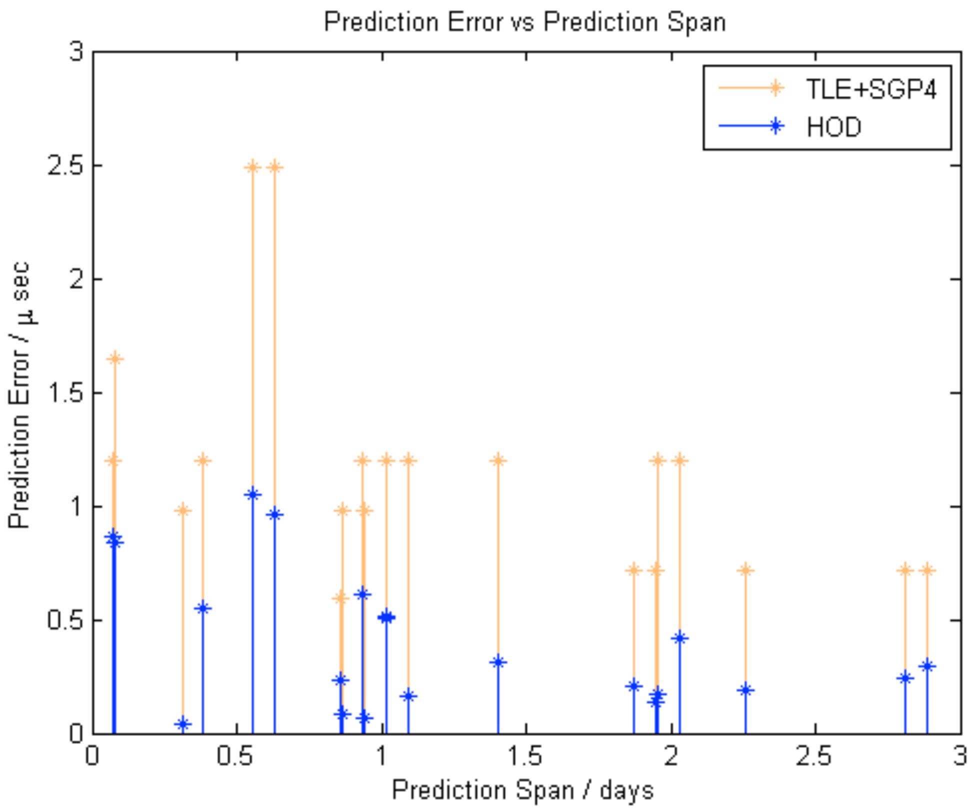

Figure 2. Prediction error vs. prediction span for Starlette single station demo --- The Horizontal axis is prediction span in days, and vertical axis is prediction error in microseconds. Prediction span is the time between earlier and later passes in a pair. Predictions were generated in single-pass manner, and were considered to be done when the earlier pass was acquired. Prediction error is the difference between predicted range fitted from earlier pass of data and the observed range extracted from later pass of data, in each pair of compared passes. For each comparison pair, HOD error and TLE error are plotted on one stem. HOD errors are less than TLE errors, as can be seen from the plot.

Space Debris Results

For space debris objects, adjacent pass pairs are few. We selected objects with five or more passes and got 13 objects with total 77 passes, where 48 pass pairs with gap less than 5 days were matched. HOD fit was done for every single pass, and the resulting orbits were compared with later passes. Of all 48 pairs, 26 pairs gave positive results, that HOD orbits were improved upon TLE orbits, while for the rest 22 pairs, TLE orbits were better. See Table 1.

Table 1. Paired Comparison Results per Object

NORAD #	Pass Pairs	Error H < Error T	Comment
11267	1	1	GOOD
13028	4	4	GOOD
14373	1	1	GOOD
24298	4	4	GOOD
25400	3	3	GOOD
25732	2	2	GOOD
28480	3	3	GOOD
28499	3	3	GOOD
05118	6	3	BAD
25723	4	0	BAD
28222	9	0	BAD
28738	1	0	BAD
37363	7	2	BAD

Since the above Starlette demo exhibited perfect improvement, we believe that the HOD method is effective in orbit improving. However, the space debris case did not show improvement for all passes. For 8 of 13 objects, the method gave good results, but for the rest 5 of 13 objects, the results were bad. It is a reasonable guess that the difference is due to imperfect perturbation modeling, especially atmospheric drag, because Starlette's area-to-mass ratio is far smaller than space debris objects.

Inter-station Improvement: Demo with Starlette
When one station tracks an object, gets a pass of data and improves its orbit, the prediction of next pass over this station is improved, as the above sections show. If the improved orbit were provided to other stations, would their predictions improve? The following demo with Starlette data will give the answer.

We chose stations A, B, respectively CHAL and YARL, and retrieved Starlette pass data on these two stations, during 6 days. For days 0-3, five passes of Starlette data on A was selected, while for days 4-6, 5 passes of Starlette data on B was selected. HOD fit was done on every single pass, and all passes were included in the pairwise comparison.
The comparison shows perfect orbit improvement, similar to the above Starlette single station demo.

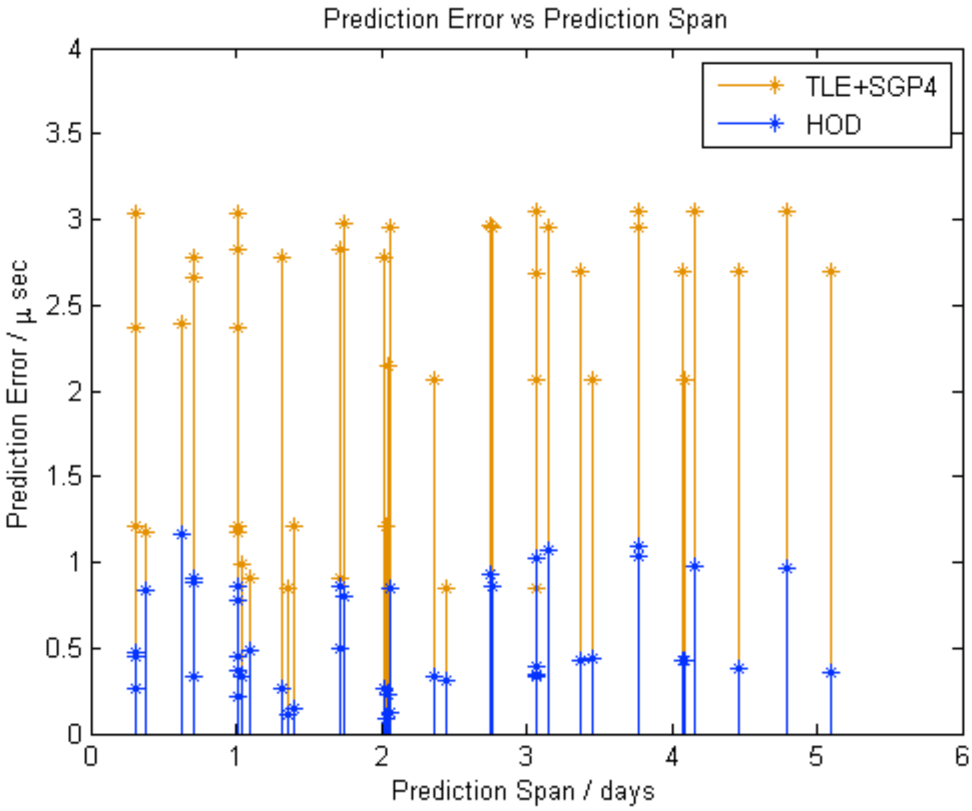

Figure 3. Prediction error vs. prediction span for Starlette dual station demo --- The Horizontal axis is prediction span in days, and vertical axis is prediction error in microseconds. For each comparison pair, HOD error and TLE error are plotted on one stem.

Those comparison results with prediction span greater than three are pairs with earlier pass (or fit pass) from A and later pass (or test pass) from B, as highlighted in Fig 3. Since the whole comparison shows perfect improvement, all 'A-B' results are positive. That means A's single pass determination improves the prediction, and B benefits from the improvement.

Conclusion

The Starlette single-station and inter-station demos both exhibited perfect improvement. Space debris orbit improvement exhibited acceptable results. The results were imperfect due to imperfect perturbation modeling of space debris. The questions that we concerned in above section were answered, that it is possible for single station range data to improve space debris orbit accuracy, and such improvement would benefit other tracking stations. The HOD method mentioned above has thus provided a way to track space debris in a more effective manner, whether with single station or with multi-station network. More work on debris object modeling is required.

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