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Achievable debris orbit prediction accuracy using laser ranging data from a single station

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Abstract

Earlier studies have shown that an orbit prediction accuracy of 20 arc sec ground station pointing error for 1–2 day predictions was achievable for low Earth orbit (LEO) debris using two passes of debris laser ranging (DLR) data from a single station, separated by about 24 h. The accuracy was determined by comparing the predicted orbits with subsequent tracking data from the same station. This accuracy statement might be over-optimistic for other parts of orbit far away from the station. This paper presents the achievable orbit prediction accuracy using satellite laser ranging (SLR) data of Starlette and Larets under a similar data scenario as that of DLR. The SLR data is corrupted with random errors of 1 m standard deviation so that its accuracy is similar to that of DLR data. The accurate ILRS Consolidated Prediction Format orbits are used as reference to compute the orbit prediction errors. The study demonstrates that accuracy of 20 arc sec for 1–2 day predictions is achievable.

Keywords: Satellite laser ranging; Debris laser ranging; Orbit prediction performance

1. Introduction

Laser ranging to low Earth orbit (LEO) debris (Greene, 2002; Smith, 2007; Zhang et al., 2012; Kirchner et al., 2013) provides range data with about 1 m accuracy mainly due to the targets being uncooperative, i.e. there are no retroreflectors for precision laser ranging. Currently, debris laser ranging (DLR) operates only during the terminator time periods because of the low accuracy of the debris orbit predictions that are delivered to the laser system. The prediction has to be improved using real-time angular tracking data and hence requires the debris to be sun-lit. As well as overcoming other technical challenges, extending the DLR capability to non-terminator periods requires accurate orbit predictions. Accurate orbit predictions are also required for debris orbital maneuver using ground-based lasers (Mason et al., 2011; Phipps et al., 2012) and reliable orbit conjunction assessments.

The DLR data makes accurate debris orbit determination (OD) and prediction (OP) possible (Sang and Smith, 2011; Bennett et al., 2013; Sang et al., 2013a,b) even if the data is from a single station. Earlier studies showed that a 1-day orbit prediction ground station pointing error of 20 arc sec was achievable for LEO debris below 800 km altitude using 2 passes of laser ranging data separated by about 24 h from the EOS Space Debris Tracking System (SDTS) at Mt Stromlo, Australia. The accuracy was obtained by comparing the predicted orbits with the tracking data from the same station.

It has been suspected that this accuracy might be over-optimistic for other parts of the orbit because the generated

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orbit is only constrained over the tracking station. A verification of this orbit prediction accuracy is necessary to obtain a more convincing conclusion. However, the lack of accurate debris tracking data from other stations prevents this verification.

SLR data and accurate orbit predictions in consolidated laser ranging prediction format (CPF) are available from the ILRS network (Pearlman et al., 2002). Therefore, it is feasible to perform the verification using the satellite laser ranging (SLR) data from a single station in similar data availability scenarios as faced with debris objects, i.e., only SLR data of two passes separated by about 24 h is used in the orbit determinations. Two satellites, Starlette and Larets, whose perigee altitudes are 815 km and 690 km, respectively, are chosen for this verification study.

In what follows, the problem of debris OD and OP and the procedure to perform the verification are described first. Then, the results are presented from processing the Starlette and Larets SLR data from the first 6 months of 2012. Finally some conclusions are given.

2. Debris orbit determination and prediction

The condition that the debris object has to be sun-lit so it is visible to the camera system at the laser tracking ground station makes the debris laser tracking only possible during terminator periods. There are only a few stations with DLR capability. No coordinated DLR campaign has been organized. Also, the weather and tracking schedule compromise tracking operations. Therefore, the available DLR data for each individual object is usually sparse. For example, most of the DLR passes for each object at the EOS SDTS are separated by at least 24 h. It would be much easier if three or more DLR passes within about 48 h are available for the orbit determinations.

For the orbit determination and prediction, another significant problem with a debris object is the unavailability of the critical ballistic coefficient, defined here as $C_D \frac{A}{m}$, where C_D is the drag coefficient, A the cross-sectional area in the direction of object motion relative to the atmosphere, and m the object mass. A nominal value of 2.2 for C_D may be used but its true value could be much larger. The mass is unknown for most debris objects, and the cross-sectional area, A, may be estimated with very low accuracy from the radar cross sectional area given in the NORAD catalog. Without this parameter, it is unlikely that the drag effect will be properly accounted for in the LEO orbit prediction. Experiments have shown that if only two passes of DLR data are available and the ballistic coefficient is treated as a fitting parameter, the orbit determination will most likely fail to converge, or the subsequent orbit prediction contains large errors (Bennett et al., 2013; Sang et al., 2013a).

If tracking data of an object is dense and well distributed, the ballistic coefficient can be estimated as a fitting parameter in the OD computations. Bowman (2002) presented the “true” ballistic coefficient values of some High Accurate Satellite Drag Model (HASDM) objects. For each individual object, the “true” value was obtained as the average of nearly 3200 ballistic coefficient values between 1970 and 2001, each of which was estimated as a fitting parameter in the differential OD process using tracking data over a 3-day fit span.

The debris ballistic coefficient can be estimated from archived long-term two-line element (TLE) data (Saunders et al., 2012; Sang et al., 2013a). It has been shown in Sang et al. (2013a) that the ballistic coefficients of debris objects below 650 km in altitude could be estimated with accuracy better than 10% using over 30 years of TLE data. The tests with 4 SLR satellites at about 800 km in altitude also showed better than 10% ballistic coefficient estimation accuracy (Bennett et al., 2013).

When only two passes of DLR data is available, the problem of failed OD convergence or large prediction errors from a converged OD is greatly eased if the TLE-derived ballistic coefficient is fixed in the orbit determination. Numerous orbit determination and prediction experiments using the EOS SDTS DLR data have confirmed this (Bennett et al., 2013; Sang et al., 2013a,b). In this way, 1-day ground-station pointing orbit prediction errors of less than 20 arc sec are achieved. The error is obtained by the comparison between the predicted orbit and the tracking data from the same station. The uncertainty in other parts of the object’s orbit away from the tracking station cannot be verified due to the lack of accurate data from other tracking stations, and may be much larger.

This verification is performed below using the SLR data for Starlette and Larets with the procedure and results given in the next section.

3. Assessment results

3.1. Ballistic coefficients of Starlette and Larets

It has been stressed that the ballistic coefficient has to be fixed when processing ranging data of two passes to obtain good results. For Starlette, the ballistic coefficient value is 0.002292 m^2/kg obtained from Bennett et al. (2013) which was estimated using TLE data from 1980 to 2012. It has a relative error of 3.5% against the “true” value.

Larets was launched in November 2003 so the TLE data from December 2003 to October 2013 are available for ballistic coefficient estimation using the method outlined in Sang et al. (2013a). The estimated value is 0.004681 m^2/kg. The mass and the diameter of Larets are 23.28 kg and 24.5 cm, respectively (refer to Table 1 in Kucharski et al., 2013). Assuming $C_D = 2.3$, then the “true” ballistic coefficient is 0.004658. The difference between the TLE-derived and “true” ballistic coefficient values is less than 1%.

The TLE-derived ballistic coefficient values of 0.002292 m^2/kg and 0.004681 m^2/kg for Starlette and Larets, respectively, are used in all of the OD and OP computations presented in this paper.

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