Common View Time Transfer by diffuse reflections from Space Debris Objects

Tong Liu[3], Ulrich Schreiber[1], Johann Eckl[2], Jan Kodet[1], Georg Kirchner[4], You Zhao[3]

[1]Technical University of Munich, GO Wettzell, Bad Koetzting, Germany,

[2]Federal Agency for Cartography and Geodesy, Bad Koetzting, Germany,

[3]National Astronomical Observatories, Chinese Academy of Sciences, Beijing, China,

[4]Space Research Institute, Department Satellite Geodesy, Austrian Academy of Sciences, Graz, Austria

Abstract: Optical two way time transfer between ground stations in common view can be achieved by diffuse laser pulse reflections from space debris items. These echo signals are detected by two stations individually from time of flight measurements of short laser pulses. Modeling the tumbling motion of the selected space debris target allows for a significant reduction of the return signal scatter. Uncertainties for the transfer of time appear to be reducible to less than 100 ps. This paper outlines the application of the Lomb-Scargle algorithm and illustrates it's application to accurate optical time transfer over larger distances.

1. Introduction

Satellite Laser Ranging provides the exact time of flight of ultra short laser pulses for a ground to space link. This allows time transfer between a single station on the ground and a suitable satellite, like the T2L2 (Time Transfer by Laser Link) and upcoming ACES (Atomic Clock Ensemble in Space) mission. A CCR (Corner Cube Reflector) is required for the measurement of the two-way path delay and a detector on the spacecraft times the satellite clock. The CCR reverses the direction of the laser beam. Hence it is impossible to have more than one station detecting the laser pulse, unless they are closely collocated systems. Space debris objects allow diffuse reflections and can be used to achieve high resolution time transfer between stations in common view on the ground with no extra delay involved. Thus, we aim to do laser time transfer over rocket body. Figure 1 depicts the setup for a laser time transfer experiment between two stations by diffuse reflections from rocket bodies.

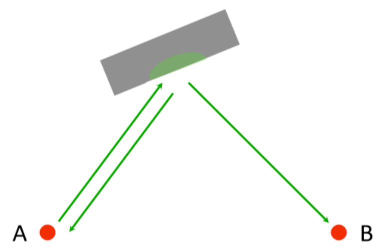

Fig. 1 laser time transfer between two stations by diffuse reflections from a rocket body. Each station performs two-way ranging to the rocket body. In addition to that, each station performs one-way detection of the laser pulses from the respective other stations. That is: 1 shot fired per station and 2 returns detected.

In order to reduce the scatter and calculate the offset between the center of mass and the surface panels with maximum surface radiance, we need to model the orbit and the tumbling motion of the rocket body.

2. Orbit and tumbling motion model

To simplify the problem, we make some reasonable assumptions for the rocket body and its tumbling motion.

1) The rocket body is a cylinder.
2) The rocket body is undergoing a uniform tumbling motion.
3) The mass is unevenly distributed along the symmetry axis and evenly distributed across the symmetry axis.
4) The right ascension and declination of the tumbling axis orientation are constant over a short time in an inertial frame of reference.
5) The true tumbling period is a constant over a short time.
6) For the rough surface of the rocket body, we use the diffuse reflection model from Oren and Nayar[1].

The surface of the cylinder is divided into many panels. The detection probability of each panel is proportional to its surface radiance. Apart from the coordinates of each panel in the body frame, this model also includes the tumbling motion of the cylinder, the orbital motion of its center of mass from TLE (Two Line Element), the position of the observatories in J2000 celestial reference frame, and the Earth's rotation.

3. Mono-static data analysis

Firstly, we use the fast Lomb-Scargle algorithm to calculate the observed tumbling period. The Lomb-Scargle algorithm was developed by Lomb and Scargle[2,3]. It is well set up for finding the significance of weak periodic signal in otherwise random, unevenly sampled data in astronomy. The computational burden of the Lomb-Scargle algorithm of a series of data with N points is about $10^2 \sim 10^3$ N^2 orders of magnitude. Press and Rybicki applied the Lagrange interpolation and fast Fourier transform to the Lomb-Scargle algorithm and proposed a faster algorithm [4]. Compared with the Lomb-Scargle algorithm, it needs less than one percent of the time to get the periodogram.

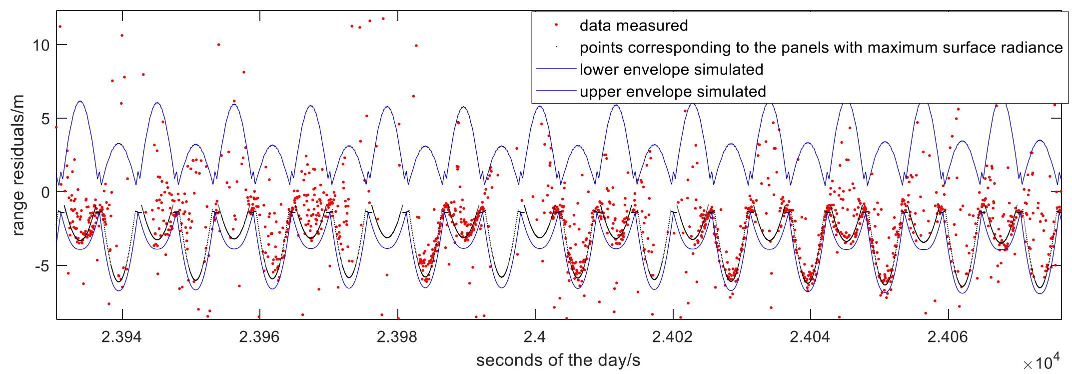

Fig. 2 Data measured on December 29th of 2015 by Wettzell station

Using the above model and the observed tumbling period, we estimate the tumbling attitude and calculate the residuals of the panels with maximum surface radiance from the mono-static data. The analysis result of 39679 (NORAD ID) is given in figure 2. The tumbling motion and signature effects are removed by using our tumbling motion model and we obtain almost flat residuals in figure 3. Figure 4 shows the Allan deviation of the flat residuals.

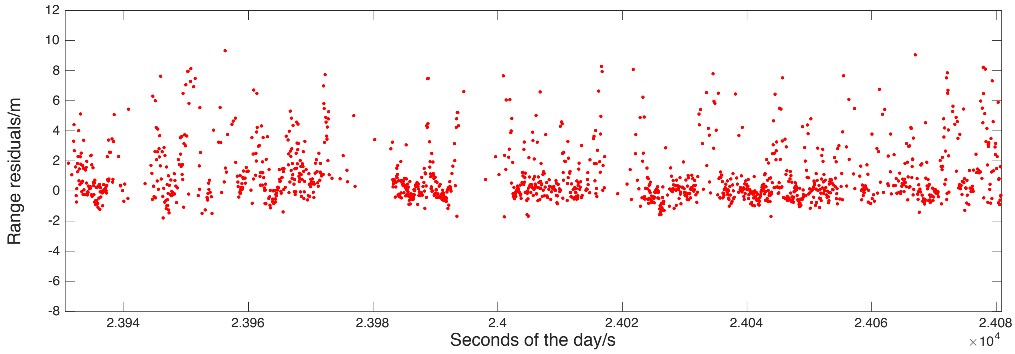

Fig. 3 The flat residuals of 39679

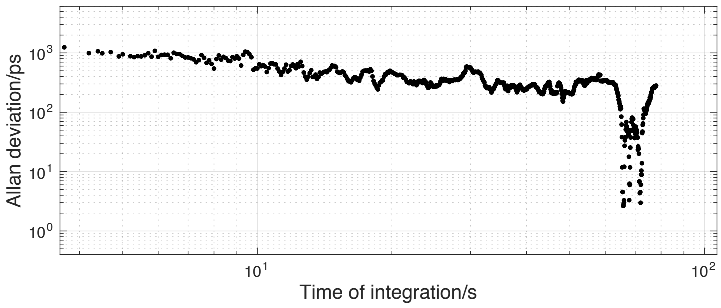

Fig. 4 The Allan deviation of the flat residuals

We also performed this analysis on other rocket bodies with similar results and the process indicates that a time transfer via a rocket body at the level of 100 ps appears feasible.

4. Conclusion and future work

We have shown that time transfer by diffuse reflections from space debris object can be a viable albeit involved technique for accurate time transfer between two locations on the ground. The analysis results of mono-static ranging data show time transfer via suitable space debris at the level of 100 ps appears feasible. Our future work includes the combination of the Debris Laser Ranging data and photometry to get a more accurate tumbling attitude of the target, bi-static time transfer experiment (two-systems in one location) in Graz and our final goal is the bi-static time transfer between the Borowiec station, the Graz station and the Wettzell station.

References

[1] Oren, M., Nayar, S.K.. Generalization of the Lambertian model and Implications for Machine Vision, International Journal of Computer Vision. Vol,14(3), 1996.

[2] Lomb, N.R., Least-squares frequency analysis of unequally spaced data. Astrophysics and Space Science, 1976, 39:447-462.

[3] Scargle, J.D., Studies in astronomical time series analysis(2): Statistical aspects of spectral analysis of unevenly spaced data. The Astrophysical Journal, 1982,263:835-853.
[4] Press, W. H., Rybicki, G. B. Fast algorithm for spectral analysis of unevenly sampled data. The Astrophysical Journal, 1989, 338:277-280.