REAL TIME IMPROVEMENT OF ORBITS OF SPACE DEBRIS BY FUSING SLR AND ASTROMETRIC DATA ACQUIRED BY A NIGHT-TRACKING CAMERA

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ABSTRACT

The precise knowledge of the trajectories of space debris objects and in particular of defunct satellites is fundamental for satellite operations. Several studies showed that it is possible to improve the accuracy of the orbit determination results by fusing different types of observables, i.e. classical astrometric positions and range measurements. Particularly promising in the space debris field are the ranges provided by a satellite laser ranging system. The factors which limit the applicability of the SLR techniques are the accuracy of the predicted ephemeris of the target, the energy of the laser pulse, and the laser field of view.

In this paper, we will show how the use of a night-tracking camera can overcome the challenges related to the quality of the predicted ephemerides providing both, real time correction to the pointing of the SLR system (active tracking), and simultaneously astrometric measurements which can be used to improve the orbits which will finally also allow studying the attitude of the target. After presenting the basic functionalities, the performance of the night-tracking camera, and the procedure to acquire the measurements, we will analyse the results of an orbit determination procedure when fusing the different observables. This study is carried out for defunct or recently decommissioned satellites. Only real angular/laser measurements provided by the sensors of the Swiss Optical Ground Station and Geodynamics Observatory Zimmerwald (SwissOGS) owned by the Astronomical Institute of the University of Bern (AIUB) are used to determine improved orbits in near real time.

1 INTRODUCTION

Space debris constitutes a serious danger for both, robotic and human missions. In order to deal with space debris objects the precise knowledge of their orbits is of fundamental importance. One way to improve the accuracy of orbit, especially for short observation arcs, is the fusion of angular and range measurements [1, 2]. The main challenge in the usage of laser ranging is due to the small field of view (FoV) of a laser system and the poor ephemeris accuracy of a generic space debris.

In this paper, we will show how to overcome this problem by using the newly implemented night-tracking camera into the SwissOGS laser system, and finally we will show the results obtained by orbit determination using the data acquired via the tracking camera.

2 THE TRACKING CAMERA

The main aim of the tracking camera is the improvement of satellite laser ranging (SLR) observations efficiency. The camera allows us, via the correction of the telescope pointing direction, to range also to those targets whose ephemeris are of poor accuracy. For details on the implementation, the characteristics, and of the performance of the camera please refer to [3]. Figure 1 reports a summary of the data acquired by the tracking camera for a cooperative spent satellite: ENVISAT. The first two graphs on the left show the range, and the de-trended range (to highlight the attitude contribution to the range) expressed as difference between expected (from

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ephemeris) and measured time of flight. On the bottom-left plot, we report the light curve extracted from the processing of the images stored by the camera, and on the right the angular directions of the satellite on the sky which can be used, together with the ranges, for the orbit improvement of the observed object.

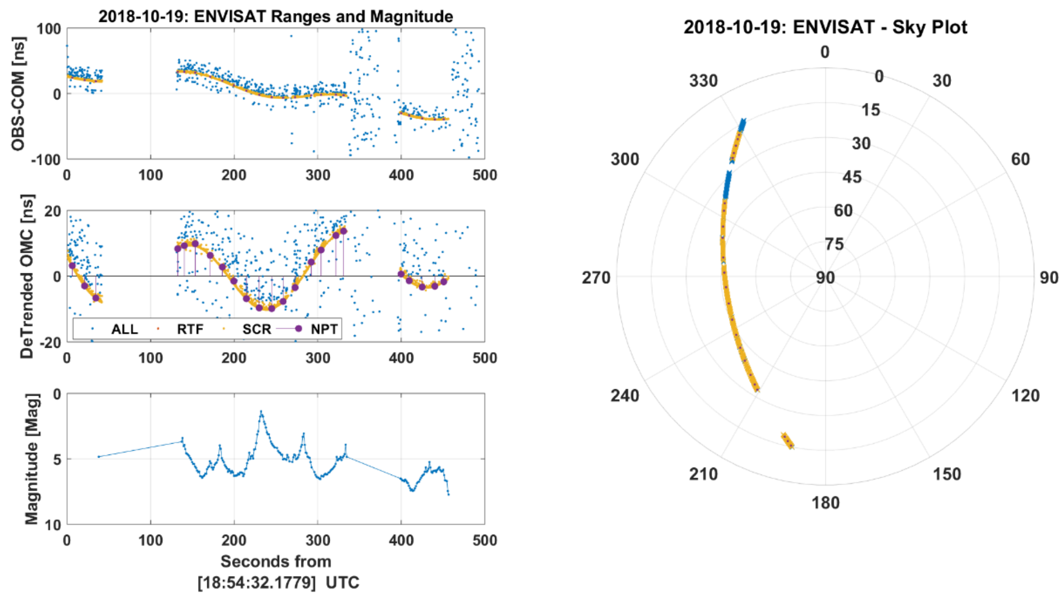

Figure 1 Summary of outputs provided by the night-tracking camera.

3 VALIDATION OF THE ORBIT DETERMINATION PROCESS

Before the regular employment of the data acquired by the camera, we wanted to validate the outcomes of the orbit determination process (OD). The validation was split in two main steps: in the first, we validated the measurements extracted from the camera and we evaluated their accuracy, in the second, we verified the goodness of the outcomes of an OD.

To calculate the accuracy of azimuth and elevation measurements, we compared the measured coordinates with those given by the ephemeris; this comparison was carried out on LAGEOS satellites, assuming that for them "perfect" ephemeris are available. Figure 2 shows the difference, in arcsec, between the measured angular position, recorded only when the SLR system got an echo from the satellite, and those provided by the ephemeris. Both azimuth and elevation discrepancies w.r.t. the ephemeris are within the 20 arcsec. These relatively big errors, especially if compared to the outcome of an astrometric data reduction process, are probably due to several reasons: the laser divergence which influences the effective FoV of the laser system, and the rough model of the laser pointing direction on the camera [3]. The average discrepancy, between measured angular position and the reference ones of this validation, is then used for the relative weighting of the measurements in the OD process.

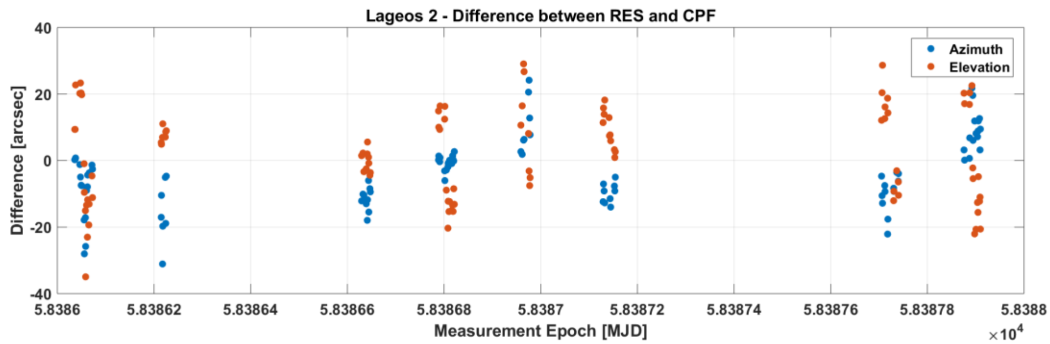

Figure 2 Difference between the measured Azimuth, Elevation coordinates and those obtained from ephemeris for Lageos 2.

The validation of the OD results was performed comparing the ephemeris generated by the propagation of the estimated orbit with the orbit predictions provided by the International Laser Ranging Service (ILRS) [4]. It must be said that the main aim of this study is not to obtain the best orbit but is the generation of an ephemeris that will allow the re-observation of the object as soon as possible. Figure 3 shows an example of the ephemeris comparison obtained for Jason 3 satellite. The comparison was done for different lengths of the observation arc, 1, 2, and 3 consecutive passes respectively, using only ranges, only angular, and merged measurements. It is very interesting to see how the ephemeris generated using only 3 passes of merged data acquired by a single station, do not exceed the 10 m error w.r.t. the reference ones over 3 days of propagation.

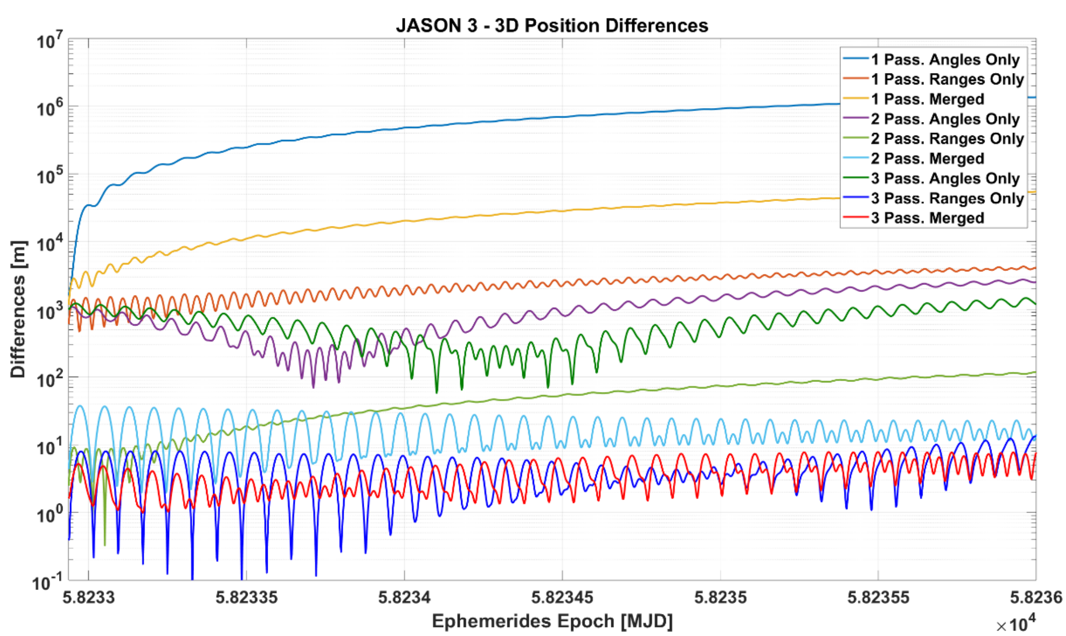

Figure 3 Ephemeris comparison for Jason 3 satellite.

4 ORBIT DETERMINATION RESULTS

The camera was finally tested on defunct satellites for which only poorly accurate ephemeris were available. We will show the results obtained for TOPEX (LEO) and an old GLONASS (MEO), whose cospar-ids are 92052A and 91025B, respectively.

To better show the re-observation capability, we decided to report two examples where first, a set of data is used to perform an OD, and then secondly, the determined orbit is used to predict the angular position and the ranges expected at the second set of data. These computed measurements are then compared with those really measured by the SLR system.

Figure 4 shows the observations acquired for Topex during its first pass over the SwissOGS station, while Figure 5 shows the obtained residuals during its second pass. Focusing especially on the angular residuals (left plot of Figure 5), it is easy to see how the OD performed using separately the two sets of measurements (ranges and angular) would not allow us to reobserve the object in the second pass; this is due to the relatively small FoV of the tracking camera (~7 arcmin). While processing simultaneously the angular and the range measurement, we have an improvement of one order of magnitude in the OD accuracy (error between 1-2 arcmin) allowing the re-observation of the object in the following pass.

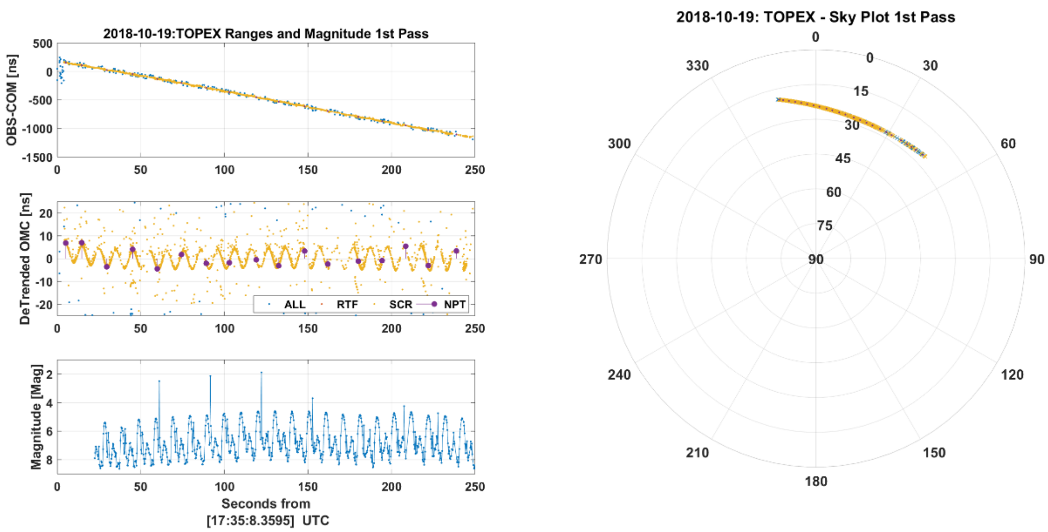

Figure 4 Topex observation used in the OD process.

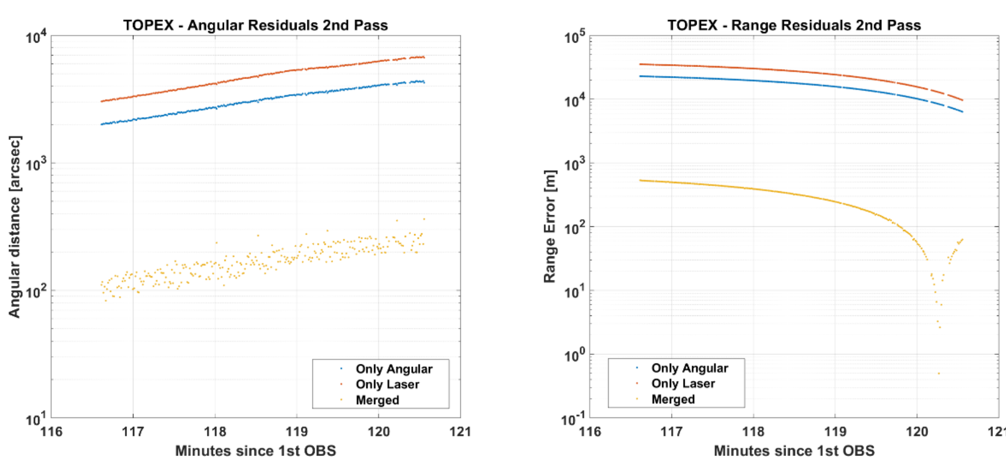

Figure 5 Topex residuals at the second pass obtained by propagating the OD results based on observations acquired in the first pass.

Figure 6 and Figure 7 show the analogous results obtained for the Glonass satellite. Due to the length of the pass, we could perform the same experiment using two different segments of the same pass. The first ~12 minutes of observations were used for the OD, the obtained results are then compared with the measurements acquired ~20 minutes later.

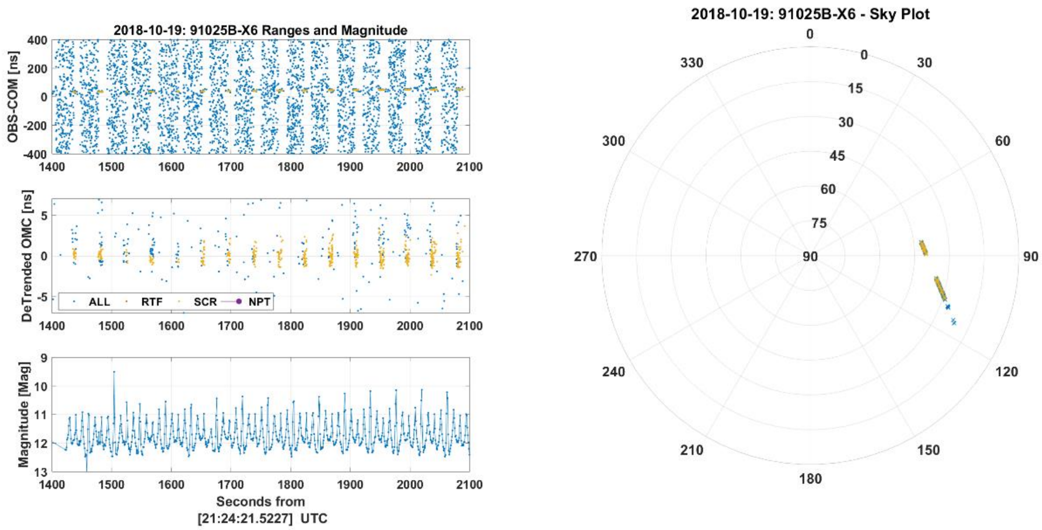

Figure 6 Glonass observation used in the OD process.

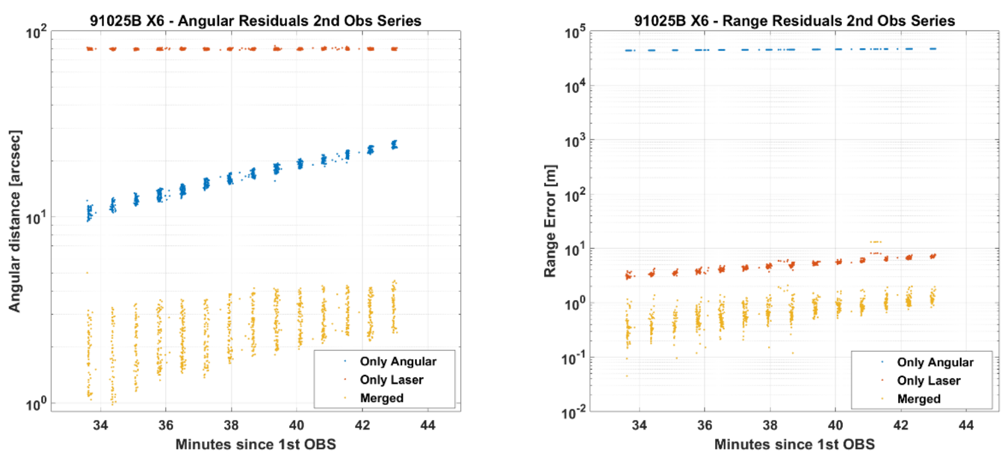

Figure 7 Glonass residuals at the second segment of the pass obtained by propagating the OD results based on observations acquired in the first segment.

Due to the orbital dynamics of the Glonass, and the short time distance between the two sets of measurements, the re-observation of the object would be possible also using separately either the angular measurements or the. As in the previous case, the worst solution, when looking at angular residuals, is given by the range only solution. This is not surprising since the length of the observation arc does not provide enough information to estimate correctly the orbital plane of the observed object.

Finally, for the aim of attitude studies, it is interesting to look at the middle and bottom graph of Figure 6. Comparing the obtained light curve with the range measurements, one is able to disambiguate the symmetries in the light curve and understand the orientation of the satellite since, it is possible to get laser measurements only when its nadir face, equipped with retroreflector, is pointing towards the observer.

5 CONCLUSION

In this paper, we have shown the results obtained by the usage of a tracking camera for space debris observations with the SwissOGS laser system. The tracking camera, being able to correct in real time the offset in the ephemeris, allows us to range to LEO and MEO objects, extract their angular position, and measure their brightness all at the same time with the timing accuracy provided by the laser system. All this data can be used for orbit and attitude determination studies. In fact, the range and the angular data, which can be extracted without the need of an astrometric data reduction, are used to perform an orbit determination whose results are used to generate new ephemeris of the object that allow its re-observation during subsequent passes.

These preliminary results confirmed the expected advantage of the usage of the tracking camera. Therefore the next step we would like to perform is the full automatization of the camera. After the improvement of the pointing model, we will implement the automatic recognition of the object in the image and the consequent ephemeris correction. The final goal of the project is the active real time tracking of objects with poorly known or unknown orbits. The final interesting aspect to be investigated is the possible application of the camera for daylight observation.

6 REFERENCES

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