Analysis of CelesTrak's SOCRATES Results for Conjunctions with Two Line Elements

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Abstract

The Celestrak.org website offers the filtered results of the so-called SOCRATES service (Satellite Orbital Conjunction Reports Assessing Threatening Encounters in Space). Three times each day, CelesTrak runs a list of all satellite payloads in orbit against a list of all objects in orbit to look for satellite conjunctions of less than 5 kilometers over the next seven days. This paper focuses on the analysis of the results registered during January 2023 (92 runs, 11.228.976 conjunctions). The aim is to compare the mentioned results with the ones obtained by means of the data provided by the TLE and the propagation tackled with the SGP4 propagator, and to assess whether it is feasible to compute conjunctions with this method.

1 Introduction

Provided all the conjunctions computed by SOCRATES during January 2023 and for the sake of simplicity, this paper concentrates on the analysis of the data registered on 29 January 2023 (the only day in which not three but two calculations were made, resulting in 224.115 conjunctions). However, the code has been developed to be extrapolated to any day.

Figure 1 displays the number of times that a particular type of satellite appears in the conjunctions, representing the potential risk with regard to the orbital environment. It is evident that Starlink, the most populated constellation, is the main contributor to the conjunction events.

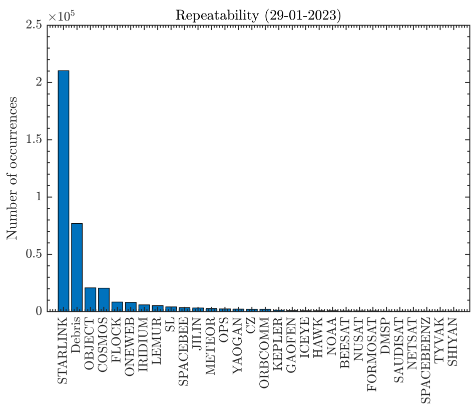

Figure 1

Nevertheless, the Starlink constellation is accurately localized and the individual satellites have the capability of maneuvering in case of probable collision. Thus, their encounters may not describe a significant risk. For now on and for the sake of simplicity, conjunctions in which both objects are Starlink satellites will not be considered. Figure 2 presents different interpretations of the resulting data regarding repeatability, minimum range, and maximum probability.

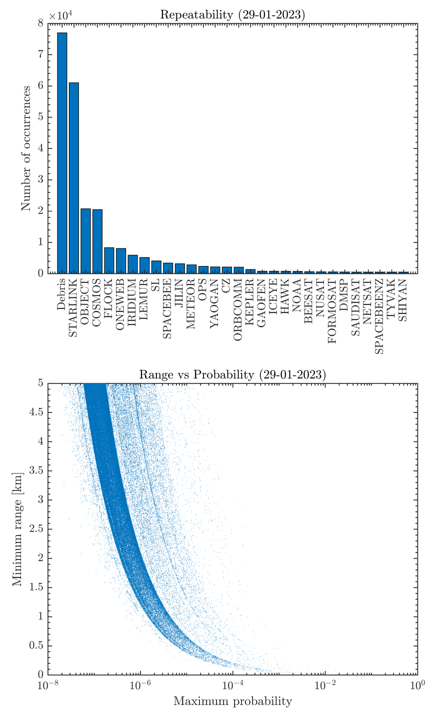

Figure 2

2 Analysis of conjunctions with TLE

The information contained in each report includes the catalog number and the name of each object, the maximum probability, the minimum range, and the time of closest approach (TCA), as well as the relative velocity between both objects at this time. Besides, it includes the days since epoch (DSE) of each object, that is, the time from the epoch of the TLE used to generate the prediction until the TCA. Making use of the DSE and the TCA data, it is possible to generate an alternative prediction with the aim of comparing the result with the prediction made by SOCRATES.

Once the conjunction to be analyzed is selected, the corresponding TCA together with the catalog number and the DSE of each object is used to get the TLE data of both satellites. This is made via requests to the Space-Track.org's API. However, Space-Track throttles the API use in order to maintain consistent performance for all users, so the code performance is constrained by the query frequency restrictions of the website.

Having the TLE data of the objects of the conjunction, the last step is to propagate (using the SGP4 propagator) both orbits until the TCA given by the SOCRATES prediction and compare the results in terms of distance and relative velocity. On the face of it, it seems clear that the higher the DSE, the higher the error induced in the propagation with respect to the SOCRATES result. To study the influence of the number of days since epoch on the final error, several ranges of DSE are considered, with each range encompassing the intermediate times between two integer numbers of days. Furthermore, numerous conjunctions are computed within every range. The number of ranges and samples is a trade-off solution that accounts for representativeness, time consumption, and the API access rate limitations.

Figure 3 shows the errors of the propagation regarding minimum range and relative velocity with respect to SOCRATES calculations, for 8 ranges and 5 samples in each range.

The results manifest the high accuracy of the propagation. The error produced in the position is lower than one meter in most of the cases and the error produced in the relative velocity is lower than one meter per second in all of the cases. In addition, the increment in DSE does not affect the results.

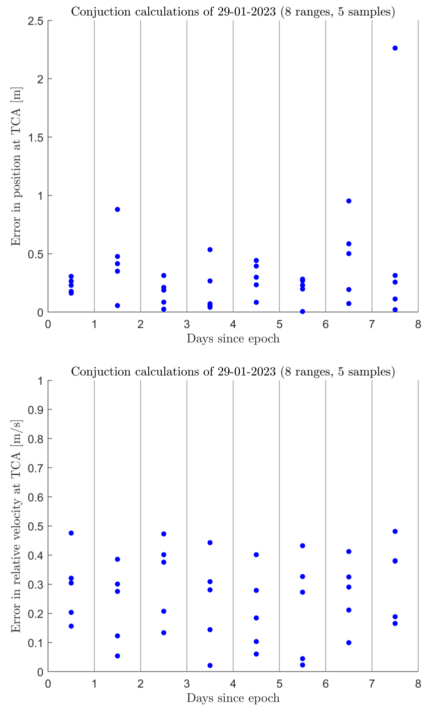

Figure 3

The TLE data only allows for propagating the state of the satellite, that is, the position and the velocity. The maximum probability of collision is computed by sizing and orienting the projected covariance ellipse at the time of closest approach. Since the covariance is not given in the TLE, the maximum probability cannot be propagated. An extremely simplified approach can be derived from figure 2. Given the minimum range of the conjunction, the maximum probability can be extracted as an interval of values within the region of high data concentration. Figure 4 shows the lines that delimit this region (datasets obtained from WebPlotDigitizer, so that new values can be interpolated).

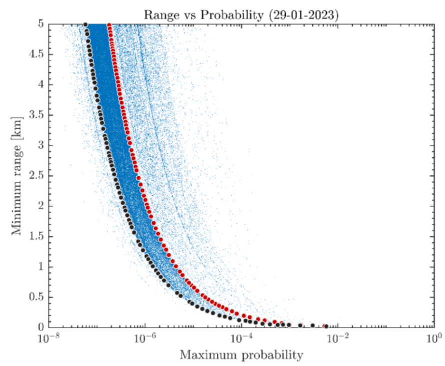

Figure 4

References

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