PDC2023
Vienna, Austria

NEO Characterization
Impact Effects & Consequences
Disaster Management & Impact Response

AN ALTERNATIVE PTOLEMAIC APPROACH FOR CONJUNCTION ANALYSIS IN LEO

An alternative Ptolemaic approach for conjunction analysis in LEO

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Keywords: *LEO, conjunction analysis, MOID, perturbations*

ABSTRACT

Low-Earth-Orbit (LEO) region congestion is a widely studied issue of the last decade. The main cause is the increasing rate of launches of small satellites but also huge constellations. Uncontrolled space debris originating from collision events are a huge threat for both present and upcoming missions, including planned crewed missions. In order to avoid issues arising from uncontrolled debris, now more than ever it is needed to enable systems for the autonomous monitoring of debris and for the forecasting of potential conjunctions between satellites.

An extensive literature is available covering the topics of orbital conjunction filtering techniques and computation of the Minimum Orbital Intersection Distance (MOID), with several algorithms providing trade-offs between precision and speed.

In general, the most common procedure for a wide conjunction analysis is to combine MOID algorithms with pre-filters. Since all LEO orbits comparisons are about hundreds of millions, pre-filters are employed for preliminary discrimination of the couples clearly not producing conjunctions. While MOID (computationally heavier) are applied for precise computation where needed.

This work investigates an alternative filtering technique that exploits the near-circularity of orbits (a condition often verified in LEO), to improve conjunction analysis performances.

Elliptical orbits are reshaped through an auxiliary 'deferent' model, inspired by C. Ptolemy's deferent and epicycle theory, replacing the real motion along conjunction analysis. The entire CelesTrack LEO catalogue was considered, and orbits were

propagated with SGP4 model. Over a one-day propagation, osculating ephemeris are converted into mean ones (focusing on the dominant J2 effect through the fast technique proposed by Servida, based on Ustinov and Kaula theories) and then an average value for each element is retained. Basing on averaged parameters, an off-centric circular orbit is considered instead of the elliptical one. While the resulting model is time-invariant, it can account for perturbations over the predefined time span. The resulting deferents (off-centric circles) are not far from osculating orbits thanks to LEO low eccentricities and become the basis for the conjunction analysis algorithm. The algorithm is structured as a sequence of pre-filters and a final MOID computation. Performances are inspected in an all-vs-all analysis over the catalogue, taking as reference a combination of Hoots' and Gronchi's algorithms. The method can exclude correctly and efficiently (average speed of approx. 0.1 MHz CPU per couple) about twenty percent more couples than Hoots' one.

The adoption of this approach would reduce the time needed for the preliminary conjunction inspections that take place during the first phases of a Collision Avoidance (CA) process especially in LEO, where pre-filtering aims to reduce the number of orbit couples where precise MOID computation is needed. Furthermore, the geometrical simplicity (not caring about eccentricity) of the final model employed suggests the possibility to employ this algorithm in experimental CA AI-based systems (e.g., machine learning routines for improving the monitoring of potential collisions).