All vs. all conjunction detection

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Abstract. With the ever-growing number of space debris in orbit around the Earth and the plans for mega-constellations, the interest in fast methods to detect possible conjunctions between objects has grown [5]. The latest figures provided by the ESA Space Debris Office estimate that more than 36000 objects greater than 10 cm are currently in orbit, and about 32000 of these are regularly tracked. For the all vs. all problem, detecting conjunctions by simply propagating the orbits would require too much time. Indeed, the number of pairs of objects is very high. In addition, the propagation step size would have to be very small and the procedure should be repeated often in order to give accurate results. Starting with [1], one proposed solution to this problem has been to implement a sequence of filters that is able to quickly rule out the possibility of conjunctions for a high number of pairs, thus reducing the computational time. This first sequence of filters consisted of two geometrical filters that took into account the shape and orientation of the orbits and a third filter that considered the actual position of the bodies on their orbits to look for conjunctions. The filter sequence approach has then been used by others, including [2] and [3], where the sequence has been modified to try and make it faster and more accurate. Following these ideas, the goal of this work is to continue improving the sequence of filters and the way it is implemented so that the detection of conjunctions in the all vs. all problem becomes achievable with reasonable computational time. Using a multistep algorithm and regularized formulations of the dynamics, we are able to perform a more accurate numerical integration. Following [3], we use direct access files to store the objects' ephemerides so that they are quickly accessible during the filter sequence. In the first filter, pairs of objects are examined by considering the maximum and minimum values of the distance of each object from the Earth during the entire timespan under examination. The second filter is based on the computation of the MOID between two orbits as in [3], but it is improved in two ways. First, a new implementation to compute the MOID is applied following results from Gronchi, Baù, Grassi (in preparation, 2022), based on refinements of the results of [4]. Second, pairs of objects with low eccentricities and high enough mutual inclinations are managed with a simplified MOID computation using Newton's method. Finally, in the third filter we select relevant time-windows for the remaining pairs where we look for possible conjunctions. We then apply a one-dimensional Newton's method by assuming Keplerian motions inside each time-window and find the minimum distance and the time of conjunction between the objects. Because

of the high computational cost of the process, we employ parallelization techniques that allow us to significantly reduce the computational time. Considering all this, daily screenings for conjunction detection in the all vs. all problem become feasible. We applied the whole procedure to the approximately 23000 objects currently available in the Space-Track TLE catalogue to detect conjunctions at less than 10 km during a five-day time span. Using a hundred Intel Xeon processors with base clock 2.2 GHz, the entire computation was completed in a few hours.

References

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