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A STATISTICAL APPROACH TO ESTIMATE THE FRAGMENTATION EPOCH FROM A SINGLE FRAGMENT SURVEILLANCE RADAR OBSERVATION

Abstract

In the last decades, the growing in-orbit population of resident objects has become one of the main concerns for space agencies and institutions worldwide. In this context, fragmentations further contribute to increase the number of space debris and, operationally, it is fundamental to identify the event epoch as soon as possible, even when just a single fragment orbital state, resulting from an Initial Orbit Determination (IOD) process, is available.

This work illustrates the Fragmentation Epoch Detector (FRED) algorithm, which deals with the problem through a statistical approach. The process starts by populating the fragment ephemerides space (expressed through mean state and covariance) with a multivariate normal distribution and, for each sample, the Minimum Orbital Intersection Distances (MOIDs) with respect to the parent object trajectory (assumed as deterministic) are computed on a time. This operation is conducted by SGP4 propagator and on a specified time window, which is limited by the epoch of the last available ephemerides of the parent object and the one of the first fragmentation alert. In this way, multiple MOIDs (and related epochs of transit) are attributed to each sample, resulting in a new distribution of MOID with respect to time.

After a filtering phase aiming at removing unfeasible solutions, all the evaluations are clustered in time and expressed in terms of the MOID value and of the related epoch of transit, resulting in two-dimensional samples. Then, for each cluster, a Gaussian distribution of the content is computed, and the algorithm evaluates the correlation (based on Mahalanobis Distance) between each two-dimensional sample of the cluster and the mean value. A second filtering phase removes those two-dimensional samples that do not satisfy a correlation threshold, and the Gaussian distribution is refined accordingly. After these steps have been repeated for all clusters, the fragmentation epoch candidates (provided with their uncertainty) are returned, together with a statistical representation of both the MOID and the impulse magnitude associated to the fragment. The algorithm can converge either to a single or to multiple epoch candidates and, in the latter case, the best solution can be identified by comparing their statistics.

A sensitivity analysis shows that the fragmentation epoch identification right after the event is robust to IOD accuracy deterioration. Furthermore, additional observations of the same fragment can be used to refine the result and to mitigate possible failures of the FRED algorithm. Finally, the computational demand is discussed.