Application of density-based propagation to fragment clouds using the Starling suite

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ABSTRACT

The Starling suite, being developed at Politecnico di Milano and funded by the COMPASS European Research Council project and the European Space Agency, estimates the non-linear evolution of densities in orbit. These densities can be probability density functions describing uncertainties about states or distributions of particle clouds modelled as continua. The name is inspired by the murmurations of starlings, a spectacle of nature where millions of these birds fly together in perfect synchrony, seemingly as one ever-changing continuum.

Conventional tools to integrate uncertainties over time rely on Monte Carlo sampling and require many propagations to give an accurate estimate of the evolved density. The underlying technique used in Starling, instead, gives an exact measure of the density along each characteristic line of the dynamics. If the continua describe maneuverable objects, such as constellations of active satellites, feedback control based on the local density can be implemented. To estimate the density over the whole domain, a Gaussian mixture model is fitted to the scattered cloud of characteristics. Given such an analytical approximation of the density facilitates the computation of subsequent products, such as for example the collision risk computation. An iterative algorithm of forward and backward propagation allows to further reduce the number of propagations required by improving the knowledge of the density where it is largest. The iterative approach also deals with the problem that non-linear dynamics lead to curved distributions by forcing the fitting function to model voids, or near-empty parts of the domain, adequately. The suite is based on the semi-analytical theory of orbit propagation, making it ideal for – but not restricting it to – long-term propagation in a perturbed environment.

In this work, the Starling suite is applied to the case of a satellite fragmentation in a highly eccentric orbit around Earth and the propagation of the resulting debris fragment cloud. This case is challenging, as previous work showed, for two reasons. First, the distribution remains dependent on the node and argument of perigee. Simplifications assuming the density to be uniform in these variables do not hold. Secondly, the evolution of the high area-to-mass ratio fragments is perturbed by atmospheric drag and solar radiation pressure, third-body and an oblate main attracting body effect. Estimating the consequences of fragmentations is important as it can be used to rate planned space missions in terms of risks towards the future space environment.