

Resident Space Object Proper Elements for Maneuver Detection^{*}

Aaron J. Rosengren¹[0000–0001–6301–1872], Di Wu¹[0000–0003–3544–2119], and
Lamberto Dell’Elce³

¹ UC San Diego, La Jolla, CA 92093, USA

ajrosengren@eng.ucsd.edu, d8wu@ucsd.edu

² Université Côte Azur and Inria Sophia Antipolis Méditerranée, 06902 Valbonne,
France

lamberto.dell-elce@inria.fr

Abstract. Asteroid families consist of swarms of fragments generated after energetic interasteroidal collisions in the distant past that result in the breakup of their progenitors. They are recognized by searching for clusters in the three-dimensional space of “proper elements”; parameters characterizing the asteroid orbits that are very close to fundamental invariants of motion, and thus keep a dynamical record of the initial proximity of the orbits generated by a catastrophic fragmentation event. In the circumterrestrial context, proper elements have recently been applied to the dynamical taxonomy of resident space objects (RSO) for the association of debris from breakup into its “parent” satellite. Here, we adapt and extend this fundamental concept to space situational awareness for on-orbit maneuver/anomaly detection. RSO proper elements, being linked to the underlying dynamical structure of orbits, can provide a more robust metric within existing maneuver-detection algorithms, through assessment of the induced changes in these quasi invariants of the motion. We highlight the deeper connection of proper elements to classical frozen orbits in Earth-satellite dynamics and showcase several techniques for their numerical computation.

Keywords: Space Debris · Maneuver Detection · Frozen Orbits · Dynamical Evolution and Stability.

1 Extended Abstract

As near-Earth space gets more and more congested, contested, and competitive, a rigorous classification scheme based upon scientific taxonomy is needed to properly identify, group, and discriminate resident space objects (RSOs). Any attempt to classify debris, say, into “families” cannot be based on the osculating elements, which, being in continual change as functions of time, do not clearly disclose any characteristic feature of the initial orbit or state vector. Mean orbital

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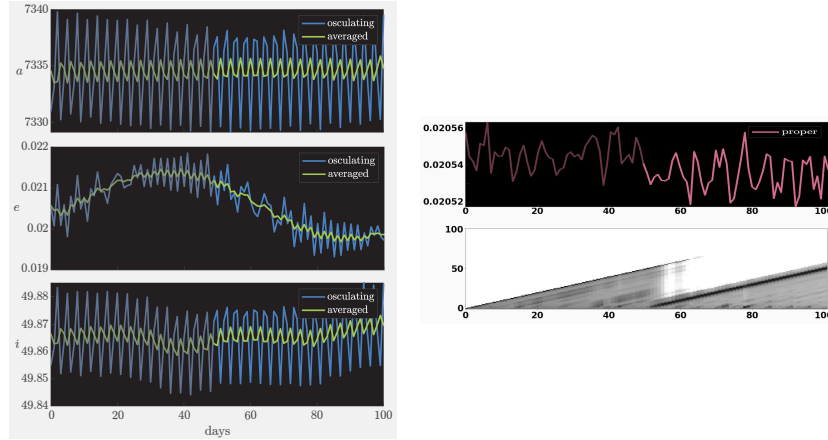


Fig. 1. Osculating and mean eccentricity (*left*) of a LEO satellite and proper eccentricity (*right*) computed from each data point using a heuristic synthetic theory. Bayesian online change point detection flags the maneuver in proper element space only.

elements, such as those provided by the two-line element sets (TLEs) of the space object catalog (SOC), also do not leave a dynamical fingerprint of the object’s inherent state, since they vary over longer (secular) timescales. Proper orbital elements, however, are obtained as a result of the elimination of short and long periodic perturbations from their instantaneous, osculating counterparts, and therefore represent a kind of average characteristic of motion [1]. Recently, using detailed Hamiltonian perturbation theory, Celletti et al. [2, 3] has shown the utility of proper elements for the association of space debris from a fragmentation event into its “parent” satellite. Here, we investigate how they may be applied to maneuver detection through induced changes in these fundamental invariants [4]. Figure 1 shows the orbital evolution of a hypothetical low-altitude Earth satellite, undergoing a maneuver in the along-track direction of 50 mm/s at day 50. While it is difficult to detect the maneuver from the osculating or mean eccentricity time histories, the mean values of the proper eccentricity for each segment differ; such discrete jumps are indicative of a maneuver.

References

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