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LARGE-SCALE RAPID EVALUATION FOR THE COLLISION RISK OF MEGA CONSTELLATIONS

Abstract

In recent years, low Earth orbit (LEO) mega constellations, composed of hundreds to thousands of satellites, have been proposed by commercial aerospace companies, such as OneWeb and SpaceX. The mega constellation can provide global broadband even covering rural areas. With so many satellites launched into space for constructing mega constellations, however, one of the most significant threats to the operation is the collision between the constellation and other objects such as satellites, rocket bodies, debris, etc. Such collisions may result in catastrophic damage to the spacecraft's operating environment. To ensure the safe operation of constellations, it is essential to rapidly monitor and foresee collision risks in real time. However, the current collision warning analysis mainly focuses on individual targets by calculating collision risks through methods such as minimum distance or collision probability. This approach would lead to a computational debacle when dealing with a large number of satellites in mega-constellations. Hence, a new method of calculating the satellite density is proposed based on the continuity equation (CE) to assess space collision risks over a large area quickly. The proposed method can eliminate the individual differences between space objects and provide an overall perspective of multiple satellites and orbits. Compared with a determined satellite orbit model, this method significantly reduces calculation time. The contributions of this paper mainly focus on two aspects. The proposed method constructs a density calculation model in the solution space of latitude and time. Different from existing methods which often express density as a function of other variables, such as true anomaly and time, distance and time, the satellite number density is more sensitive to the latitude which can describe the congestion more clearly. On the other hand, the proposed method considers $J2$ perturbation and atmospheric drag perturbation, which ascends the accuracy of the evolutionary analysis model. A high-precision and efficient long-term space object density evolution analysis model is constructed using differential algebra (DA) and semi-analytical mean orbital dynamics (SAMOD). Finally, the proposed method sets a satellite density threshold quantification indicator, enabling it to provide a large-scale rapid warning capability under limited computing resources. The simulation results validate the effectiveness of the algorithm.