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AN ANALYTIC METHOD OF THE DENSITY EVOLUTION OF LARGE CONSTELLATIONS AND COLLISION PROBABILITY EVALUATION

Abstract

Commercial remote sensing constellations in low Earth orbit (LEO), such as "Dove Flock", "Lemur" and "SkySat", have developed rapidly and realized large-scale commercial deployment since 2010. SpaceX's "Starlink" has been approved by America in 2018, which aims to launch nearly 12000 satellites into LEO. Therefore, it is of great significance to calculate the effects of large constellations on current and future space missions. In this work, we propose a long-term density evolution method for large constellations in LEO and calculate the collision probability based on the density evolution model.

One way of establishing the density evolution model is to integrate all satellites trajectories, and then extract statistical information through Monte Carlo simulations, so that the spatial density of the constellation can be obtained. However, it is inapplicable for a large constellation which consists of thousands of satellites. Thus, we focus on the analytic method to propagate the density of a large constellation. The assumption that any satellites within the constellation are working in normal operation mode which means the deposition and failure of satellites are neglected, is introduced to simplify the evolution model. Inspired by the traditional method for hydrodynamics, where the continuum equation is used to associate the fluid density with its velocity, the central idea of this work is to model the constellation as a fluid with continuous properties. Regarding the probability density function as the dependent variable, a Partial Differential Equation (PDE) is derived in the first step. Afterwards, the method of characteristics is applied to solve the PDE, which transforms the PDE into a set of Ordinary Differential Equations. Therefore, the density evolution can be analytically computed in the presence of the well-selected initial density. Based on the density evolution model, the collision probability between a constellation and target satellites can be analyzed and computed. We also investigate the influences of the parameters on the collision probability, such as the orbit of target satellites and the initial density of the constellation.

The simulation results show that the proposed method is feasible and more time efficient compared with numerical method. And it reveals the relationship between collision probability and the predefined parameters. This work makes contributions in the density evolution of a large constellation, provides great support in the safety evaluation of the near-earth environment, and offers valuable reference for constellation design.