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POTENTIAL ERROR ELLIPSOID ENVELOPE BASED MULTI-OBJECT OPTIMAL COLLISION AVOIDANCE MANEUVER FOR MEGA-CONSTELLATION

Abstract

Because of the springing up of mega-constellations, space objects and dangerous rendezvous witness a conspicuous rise in number recently. In this context, Collision Avoidance Maneuver(CAM) for risk mitigation is becoming increasingly important. For CAM design, one of the difficulties to be faced with is that there may be various types of unexpected potential collision objects with uncertainties in the close proximity, such as other spacecraft, satellite formations, debris clouds, etc. The complexity of multi-object collision avoidance constraints makes the onboard calculation process time-consuming. To deal with the complex constraints due to the multi-object CAM design, the concept of potential error ellipsoid envelope method is introduced. By setting risk areas of the potential collision space objects based on orbit determination error ellipsoids, and combining geometrical adjacent ones of them, suboptimal CAM trajectory can be solved considering fuel cost and collision probability as the performance index. Thus calculation efficiency can be significantly improved. As far as the knowledge of authors, the state-of-the-art CAM algorithm does not consider the complex constraints caused by multi-object, which leads to the CAM trajectory invalid to the avoidance of the emerging risks because of the increasingly crowded space environment with mega-constellations. The proposed potential error ellipsoid envelope method considers trackable objects in vicinity as collision avoidance constraints. Risk areas are delineated and envelope are used to simplify the shape and lessen the number of constraints, so that the complexity of the multi-object CAM problem is greatly reduced and the real-time performance is enhanced. First of all, the potential collision space objects in certain range are detected and selected and error ellipsoids of different sizes are modeled according to the tracking precision. Peripheral constraint regions are connected to form a boundary of maneuver in simple shapes. Error ellipsoid envelope are used to integrate the regions in close distance and eliminate the redundant constraints. A multi-object constraint optimization problem is later solved to determine the optimal CAM. While mitigating the risk of collision, complex constraints are satisfied so that new rendezvous is avoided as much as possible. In addition, the multi-object optimal collision avoidance maneuver based on potential error ellipsoid envelope method does not lead to complex onboard calculation, and enables our target to return to its nominal orbit in a timely manner. The effectiveness of the proposed method is verified by numerical simulation.