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PROBABILISTIC TRACKLET CLUSTERING AND INITIAL ORBIT DETERMINATION

Abstract

Space Situational Awareness (SSA) is critical for monitoring the increasing number of space objects. A key component of SSA is tracklet clustering, which involves integrating fragmented observation data from multiple sensors to construct continuous trajectories. Effective tracklet clustering facilitates object identification and initial orbit determination (IOD), thereby enhancing collision avoidance and space traffic management.

The primary challenge in tracklet clustering is managing the vast volume of observation data. Deploying mega-constellations has significantly expanded the number of observable space objects. Traditional approaches struggle to establish accurate correlations within such large datasets, particularly in the case of constellation satellites. Moreover, optical tracklets frequently arise from short observation arcs, leading to significant uncertainty in angular velocity, which further complicates the association of multiple tracklets with a single object.

To overcome these challenges, this paper develops a probabilistic tracklet clustering method and a robust IOD method based on clustering. The process begins with an initial association executed via the Boundary Value Problem Constrained Admissible Region (BVPCAR). The association probability between two tracklets is assessed through the Mahalanobis distance between the measured and estimated angular-rate information. The tracklet clustering is formulated as an optimization problem. The optimization objective is to maximize the likelihood of the association matrix, which is calculated based on the association probabilities obtained through the BVPCAR method. This progress achieves efficient and accurate tracklet clustering by solving the optimal association matrix, avoiding the exhaustive enumeration of all hypotheses. Once the clusters are determined, the weighted hypothetical orbits are generated by the BVPCAR according to their corresponding association probabilities. These weighted hypothetical orbits are subsequently approximated as a Gaussian mixture model, yielding the initial orbit. Incorporating weighting factors significantly reduces the relative influence of the assumed orbits on error estimation, thereby ensuring a stable and consistent initial orbit.

To evaluate the performance of the developed method, two simulation scenarios were employed and compared with Markov clustering techniques. Optical observation data were generated from 10 space-based sensors. In the first scenario, tracklet clustering was applied to 100 randomly selected space objects

from the 18th Space Defense Squadron public catalog. The new approach demonstrates a consistent tracklet clustering accuracy with Markov clustering while offering a faster computation speed, affirming its effectiveness in typical scenarios. In the second scenario, the method was applied to constellation targets, and the experimental results validated that the proposed approach yielded higher accuracy than Markov clustering.