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CONSTRAINED ADMISSIBLE REGION MULTI HYPOTHESIS FILTER FOR INITIAL ORBIT DETERMINATION USING OPTICAL OBSERVATIONS

Abstract

The problem of data association and track correlation is critical in the domain of Space Situational Awareness (SSA) and Space Surveillance and Tracking (SST), particularly when processing sparse, short-arc observational data from ground-based optical systems. These challenges are frequent in the context of Space Debris Events (SDEs), where systematic surveys of the sky are routinely performed to detect and characterise space debris fragments generated by in-orbit breakups. Similar challenges also occur with persistent monitoring wide Field-of-View (FoV) optical systems that simultaneously acquire observations of dozens of Resident Space Objects (RSOs). These observational scenarios often result in numerous uncorrelated or mistagged measurements, complicating initial orbit determination and introducing substantial uncertainty into trajectory estimation. To address these issues, a Constrained Admissible Region Multiple Hypothesis Filter (CAR-MHF) is proposed, specifically designed for processing multiple sets of uncorrelated optical observations without relying on any a priori state assumptions. The CAR-MHF utilises the concept of admissible regions to systematically generate and evaluate multiple orbit hypotheses from angles-only optical measurements. This filtering approach significantly enhances the data association process, enabling robust identification and accurate preliminary orbit determination. The method presented in this paper employs real observational data collected by the Sapienza Space System and Space Surveillance Laboratory (S5Lab) research team, rather than relying on synthetic datasets. Validation of the CAR-MHF was conducted using known calibration targets, whose precise ephemerides allowed a rigorous assessment of orbit determination accuracy. Results demonstrate that the CAR-MHF reliably associates measurements with the correct RSOs. Following successful validation, the methodology was applied to recent SDEs actively monitored by the S5Lab research group, with different observation campaigns aimed to search uncatalogued objects related to these events. During surveys, multiple uncatalogued and uncorrelated measurements are acquired and their correlation with observed SDEs is fundamental to characterise the event. These practical case studies highlight the effectiveness of CAR-MHF in complex, real-world scenarios involving newly detected debris fragments and ambiguous observational tracks. This advancement holds potential to substantially enhance capabilities in SSA, particularly in the accurate monitoring of emerging debris populations.