23rd IAA SYMPOSIUM ON SPACE DEBRIS (A6)
Interactive Presentations - 23rd IAA SYMPOSIUM ON SPACE DEBRIS (IP)

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A SYSTEM FRAMEWORK FOR ENHANCED SPACE SITUATIONAL AWARENESS AND COLLISION AVOIDANCE LEVERAGING ON-BOARD AUTONOMY

Abstract

The deployment of mega-constellations has exponentially increased the number of Low Earth Orbit (LEO) satellites, raising significant concerns about the safety of space operations. Historic events such as the 2009 Iridium-Cosmos collision and the deliberate testing of Anti-Satellite (ASAT) systems have contributed to space debris proliferation, escalating collision risks and necessitating urgent mitigation strategies. While ground-based sensors play a crucial role in space debris tracking, smaller debris segments remain largely unmonitored, highlighting the need for enhanced Space Situational Awareness (SSA) to ensure efficient Space Traffic Management (STM).

This paper presents a high-level system framework aimed at advancing SSA, assuming a one-on-one conjunction model for risk assessment and mitigation. While current efforts rely on ground- and space-based Space Surveillance and Tracking (SST) networks to monitor Resident Space Objects (RSOs), this study explores equipping individual satellites with on-board tracking and surveillance capabilities to enhance autonomy. Building on existing Collision Avoidance Maneuver (CAM) practices, this research proposes automation-driven improvements to enhance autonomous decision-making. It examines the division of tasks between ground and on-board systems, complementing ground computational power with on-board resources for near real-time data acquisition to refine maneuver planning. Additionally, it explores optimizing data volume contained in Conjunction Data Messages (CDMs) to reduce communication and processing overhead, leveraging on-board systems to plan maneuvers with more recent data and execute them closer to the Time of Closest Approach (TCA).

With growing concerns over Signal Intelligence (SIGINT) activities, this framework also incorporates Space Domain Awareness (SDA) to enhance monitoring of close-proximity operations, addressing threats such as jamming and spoofing. The study further evaluates the advancements and innovation in space-based sensor technologies through a trade-off analysis against defined criteria, considering various operational principles and emerging variants with enhanced processing capabilities, particularly considering the challenges of high relative velocities in LEO and limited observation windows.

The analysis considers onboard resource constraints, aligning well with the small satellite population in LEO. It examines the challenges associated with each sensor technology, assessing their maturity and effectiveness in enabling efficient STM, and concludes with recommendations for sensors that best meet system requirements.