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SMALL/MINI SATELLITE SUBSYSTEM HIGH-LEVEL ANALYSES FOR DEBRIS REMOVAL BETWEEN 30 CM – 1M

Abstract

The growing population of space debris in low Earth orbit (LEO) poses an existential risk to the long-term sustainability of space. Medium-sized debris (30 cm – 1 m) is especially concerning, as it is large enough to catastrophically damage active satellites but too small for conventional removal methods. This study presents a holistic debris removal subsystem for 200–500 kg small satellites integrating some of the cutting-edge technologies to facilitate Active Debris Removal (ADR), Just-in-Time Collision Avoidance (JCA), and Large Debris Traffic Management (LDTM).

The system is multimodal with the incorporation of electromagnetic nets or coils for repelling or attracting charged debris in a selective manner, facilitating dynamic collision risk mitigation. Meanwhile, laser-induced plasma waves create controlled momentum transfers in debris, slowly changing its orbit to enable deorbiting or avoidance maneuvers. The system also incorporates electrodynamic tethers, which electrostatically capture and steer debris into controlled descent by interacting with the Earth's magnetic field. By combining these three methods in one platform, this solution presents a low-propellant and flexible option to traditional debris removal approaches.

This research integrates mathematical modeling and graphical simulation to determine the feasibility, performance, and operational constraints of the system. Computational models analyze the interactions between debris within different orbital environments by mass, charge state, velocity, and atmospheric effects. At the same time, graphical representations and visual simulations give insight into the dynamical interaction between debris and the mitigation technologies integrated, presenting an exhaustive analysis of realistic deployment.

The study also investigates performance trade-offs, power constraints, mission life, and deployment scenarios with operational integration into future space traffic management systems. Through a small satellite-based, multi-technological approach, this study proposes a cost-effective and scalable solution relative to traditional single-method missions for space debris removal.

The findings guide post-mission disposal practices with data-driven direction toward sustainable space operations and global space debris remediation. Through the use of quantitative modeling and graphical representation, the study aims to demonstrate the potential of future debris management systems to mitigate collision risks and protect LEO's long-term usability.