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GRAPH NEURAL NETWORKS FOR ORBITAL DEBRIS: TRACKING, PREDICTION, CLASSIFICATION, AND MITIGATION

Abstract

With the beginning of the Space Race, humankind started preparing metals for space travel and developed various instruments to support exploration. However, to avoid extra weight, some of these pieces were left in space. Over time, we also had to abandon instruments that became outdated or non-functional. This has resulted in a growing challenge: orbital debris ,a significant threat to active satellites, space missions, and the future of space exploration.

This paper will focus on advancing space debris monitoring and mitigation through AI-driven solutions. It will explore innovative approaches in Space Surveillance and Tracking (SST), including advanced measurement techniques, data processing methods, and space debris characterization.

Currently, traditional debris tracking systems—such as ground-based radars, optical telescopes, and space based sensors face limitations in accurately predicting debris trajectories, classifying objects, and enabling real time collision avoidance. To enhance these efforts, we propose an AI-driven approach that integrates Graph Neural Networks (GNNs) and Reinforcement Learning (RL) for improved detection, classification, and mitigation of space debris.

GNNs help model the relationships between debris objects, treating them as interconnected nodes based on factors like gravitational influence, orbital proximity, and collision risk. This allows for more precise classification of debris, distinguishing between functional satellites, defunct spacecraft, and hazardous fragments. Meanwhile, RL enables AI systems to optimize satellite maneuvers and develop intelligent debris removal strategies, using historical space traffic data and real-time tracking inputs to predict high-risk collisions and recommend evasive actions.

As satellite constellations like Starlink, OneWeb, and Kuiper continue to grow, integrating AI into debris management will be crucial for maintaining a safe and sustainable orbital environment.

This is an important topic, not just from a technological standpoint but also for the long term sustainability of space activities. By combining machine learning with real-time orbital surveillance, we can move toward autonomous space traffic management and more effective debris mitigation strategies.