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Author: Mr. Aidan Correa
Australia

PREDICTIVE FRAMEWORK FOR SPACE DEBRIS TRAJECTORY FORECASTING AND COLLISION AVOIDANCE

Abstract

This study aims to develop a predictive framework for forecasting the movement of space debris in Earth's orbit, addressing the significant risks posed to active satellites, crewed missions, and future space exploration. Effective prediction and tracking of space debris are critical for collision avoidance and long-term space sustainability. The framework utilises Two-Line Element (TLE) data and the SGP4 orbital propagation model, combining physics-based modelling with real-time data assimilation to accurately predict debris motion.

The system uses the SGP4 model to simulate debris trajectories, accounting for Keplerian orbital mechanics and perturbation factors like atmospheric drag and gravitational anomalies. A Python-based simulation tool is employed to visualise the propagation of debris over time and identify potential conjunction risks with operational satellites. Additionally, an adaptive prediction model is incorporated, refining debris trajectory estimates iteratively through data updates to improve accuracy continuously.

Initial results demonstrate the framework's ability to track debris motion with high precision. The system successfully predicts potential collision risks with satellites and visualizes debris propagation over time. The adaptive prediction model shows significant improvements in trajectory forecasting by refining its estimates through real-time data assimilation. These results suggest that the framework can effectively support satellite collision avoidance, mission planning, and active debris removal strategies, contributing to space debris mitigation efforts.

This research highlights the importance of scalable, autonomous space debris tracking systems for ensuring the long-term sustainability of the orbital environment. The developed framework offers a reliable method for forecasting space debris trajectories, enabling better risk assessment and informed decision-making in debris mitigation. Future work will focus on optimising computational efficiency, incorporating machine learning techniques for anomaly detection, and expanding the model to include multi-body gravitational effects. This work represents a critical step toward addressing the growing issue of space debris and securing the future of space exploration.