A Comprehensive Machine Learning Paradigm for Space Debris Surveillance: An Integrated Triple Model Framework for Identification, Orbital Prediction, and Collision Risk Evaluation

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The growth of space debris in Low Earth Orbit (LEO) risks the current operation of satellites and spacecrafts. The Kessler Syndrome, in which debris is projected to grow at an exponential rate due to continuous collisions, has raised awareness and urgency about this subject. Current ground-based and machine learning approaches are subject to atmospheric distortions and are not able to track the smaller, faster pieces of debris capable of greater damage. Our research addresses this issue with three distinct, integrated machine learning models to perform debris detection, trajectory prediction, and collision risk assessment from a space-based perspective. The first model is a Convolutional Neural-Network trained on a dataset of over five-thousand images to identify and classify debris and defunct satellites at a 98% accuracy rate. The second model utilizes a Physics-Informed Neural Network incorporating a Long-Short Term Memory Model to predict the trajectories of space debris with 97% accuracy, taking into account various orbital parameters such as eccentricity and period. The third model, a Random Forest Regressor, evaluates the risk of collisions between debris and current satellites, yielding a 98% accuracy. The application of this framework is designed for space-based laser systems that reduces small debris lifespan in orbit using a technique known as ablation. This novel approach allows a space-based laser to provide precise and adaptive predictions unlike current ground based solutions. By integrating machine learning with space engineering, this study addresses a critical global issue, offering a cost and energy efficient way to mitigate the growing threat of space debris and ensure the safety of LEO operations.

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