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PHYSICS-INFORMED MACHINE LEARNING FOR SPACE DEBRIS RISK ASSESSMENT BASED ON PUBLICLY AVAILABLE DATA

Abstract

The growing accumulation of space debris poses a significant threat to operational satellites and future space missions. According to the ESA, space surveillance networks track approximately 35,000 objects, of which only 9,100 are active payloads, while the remainder consists of debris larger than 10 cm. The increasing density of these objects rises the risk of collisions, potentially triggering the Kessler effect. To mitigate this issue, various approaches have been proposed, including active debris removal missions, such as the future mission ClearSpace-1, and predictive modeling for collision avoidance. One promising approach involves the use of Two-Line Element data and radar observations to develop real-time conjunction alert systems. However, existing solutions are often limited by high false alarm rates and restricted accessibility, as many are proprietary commercial products. In this context, this work presents an open-source, Python-based predictive analytics tool that integrates deep learning and physics-informed machine learning approaches. By combining publicly available data with custom loss functions that incorporate orbital mechanics and physics-based constraints, our system delivers risk assessments of space debris across various orbital regimes. Validation against historical collision data, including publicly available satellite conjunction records, demonstrates that our approach significantly reduces false alarms compared to conventional methods while improving accessibility to advanced predictive tools. This work aims to provide a scalable, interpretable, and cost-effective alternative for advancing space situational awareness and debris mitigation strategies.