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AI Model Development

Personal Research Portal | Phase 1: Framing Brief

ML Systems for Space Debris Tracking and Collision Avoidance

Domain

Machine learning applications for space debris tracking and spacecraft collision avoidance in Low Earth Orbit (LEO).

Research Question

What are the key failure modes and limitations of machine learning systems for space debris tracking and conjunction assessment?

The threat orbital debris poses to current and future space infrastructure is a significant problem that continues to grow as we expand our presence in space. While machine learning (ML) offers potential solutions, there are a number of challenges impeding implementation. Understanding where and why ML approaches fail is essential for guiding future research and informing deployment decisions.

Sub-Questions

1. What ML approaches are currently being used or researched for debris tracking and conjunction assessment?.
2. How do data limitations—catalog incompleteness, measurement noise, sparse observations—affect ML model performance?
3. Where do ML models fail to generalize—across orbit regimes, debris types, or novel conjunction scenarios?
4. How well do current ML approaches quantify and communicate uncertainty in their predictions?
5. What are the failure modes when ML predictions are integrated into operational decision-making?
6. How can ML models for conjunction assessment be validated when actual collisions are extremely rare events?

Scope

This research focuses on the technical barriers to deploying ML systems for debris tracking and collision detection/avoidance in Low Earth Orbit (LEO), where the majority of operational space activity and research is concentrated. The scope emphasizes ML-specific limitations (e.g. data quality, generalization, uncertainty, validation, and human-system integration) rather than broader policy or environmental modeling questions.

In Scope

- ML methods for debris detection, tracking, orbit prediction, and collision avoidance in LEO

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- Both agency (ESA, NASA, US Space Force) and commercial operator applications
- Technical limitations and failure modes specific to ML approaches
- Human-system integration issues affecting ML deployment (alert fatigue, trust calibration)
- Work from approximately 2015–present (coincides with modern deep learning era and ESA CDM dataset availability)

Out of Scope

- Active debris removal mission planning and logistics
- Long-term debris environment modeling and Kessler syndrome projections (except when directly informing ML performance evaluation)
- Policy, governance, and international data-sharing frameworks
- Sensor hardware development (unless directly evaluating ML pipeline performance)
- Non-LEO regimes (GEO, MEO, cislunar) unless directly compared to LEO
- Pre-deep learning approaches (traditional Kalman filters, SGP4 alone) except as baselines for comparison