AI-Based Space Debris Tracking & Collision Avoidance System

A Detailed Technical Project Report

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Domain: Space Technology, Artificial Intelligence, Aerospace Engineering

Purpose: Academic, Research, and Competition Submission

Abstract

This report presents an AI-Based Space Debris Tracking and Collision Avoidance System designed to address the rapidly growing problem of orbital congestion and space debris. The system combines classical orbital mechanics with modern artificial intelligence techniques to predict debris trajectories, assess collision risks, and support safe space operations for satellites, startups, and future missions.

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Introduction

Space has become a critical infrastructure for humanity, supporting communication, navigation, weather forecasting, defense, and scientific exploration. However, the rapid increase in satellite launches has led to an alarming rise in space debris, making orbital safety one of the most serious challenges of modern space exploration.

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Problem Statement

Space debris consists of defunct satellites, rocket stages, fragments from explosions, and collision remnants. When two objects collide at orbital velocities, thousands of new fragments are generated, leading to a chain reaction known as the Kessler Syndrome. This phenomenon can render entire orbital regions unusable for decades.

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Why the Problem is Critical

Even small debris fragments can destroy operational satellites due to extremely high relative velocities. A single collision can compromise global communication systems, GPS services, and human spaceflight safety.

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Limitations of Existing Systems

Traditional space debris monitoring systems rely heavily on legacy physics models such as SGP4, manual analysis, and closed infrastructure. These systems are expensive, slow to adapt, and primarily accessible only to major space agencies.

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Need for an AI-Based Solution

The complexity and dynamic nature of orbital environments demand adaptive intelligence. Artificial intelligence enables learning from historical errors, handling uncertainties, and scaling analysis to thousands of objects simultaneously.

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System Overview

The proposed system functions as a mission-control-style platform that integrates real-time orbital data, AI-enhanced prediction models, and collision probability analysis.

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Data Sources

The system uses Two-Line Element (TLE) data obtained from publicly available sources such as CelesTrak and NORAD. These datasets provide orbital parameters for active satellites and debris.

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Orbital Mechanics Foundation

SGP4 (Simplified General Perturbations 4) serves as the physics-based backbone of the system, providing fast and reliable orbit propagation based on classical mechanics.

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AI Model Architecture

Long Short-Term Memory (LSTM) neural networks are employed to learn residual errors in SGP4 predictions. This hybrid approach preserves physical reliability while improving accuracy.

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Kalman Filtering

Kalman Filters are used for state estimation and uncertainty management, enabling the system to fuse predictions with noisy observational data.

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Collision Risk Assessment

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Visualization System

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Support for Startups

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How This Differs from Space Agencies

Unlike large agencies that focus on their own missions, this system is designed to be open, scalable, and accessible, democratizing space safety.

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Scalability and Modularity

The system architecture is modular, allowing components to be upgraded independently and scaled from academic demonstrations to real-world deployments.

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Ethical and Global Impact

Ensuring orbital safety is a shared responsibility. This project contributes toward sustainable and ethical use of outer space for future generations.

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Future Enhancements

Future work includes autonomous avoidance maneuvers using reinforcement learning, multi-sensor fusion, and cloud-based global deployment.

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Applications

Applications include satellite operations, space station safety, startup mission planning, research, and education.

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Conclusion

The AI-Based Space Debris Tracking and Collision Avoidance System demonstrates how modern AI can be combined with classical physics to solve one of the most pressing challenges in space exploration. The project aims to protect the future of space by preventing irreversible damage before it occurs.

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