



# AI-Driven Space Debris Detection, Tracking and Removal System

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**Abstract-** The increasing amount of orbital debris has become a significant concern for modern satellite communication and space exploration activities. This paper presents an AI-enabled framework for detecting, tracking, and mitigating space debris using Artificial Intelligence (AI), Internet of Things (IoT), and predictive analytics. The proposed system continuously monitors orbital objects through intelligent sensing devices and analyzes orbital movement using Machine Learning and Deep Learning algorithms. The framework predicts collision risks, generates warning alerts, and supports automated mitigation mechanisms for improved orbital safety. The proposed approach aims to reduce collision probability, enhance monitoring accuracy, and promote sustainable space operations.

**Keywords-**Artificial Intelligence, Space Debris, IoT, Machine Learning, Collision Prediction, Orbital Monitoring.

## INTRODUCTION

The rapid growth of satellite launches and orbital missions has increased the accumulation of inactive satellites, broken spacecraft components, and unused rocket fragments around Earth. These unwanted particles, often known as orbital debris, move at very high speeds and create major risks for active satellites and communication networks. Even tiny debris fragments can result in significant destruction because of their rapid motion in Earth's orbit. Existing debris monitoring systems are expensive and often require continuous manual supervision. Therefore, intelligent and automated approaches are necessary to improve orbital safety and reduce collision-related risks.

### I. LITERATURE SURVEY

Recent developments in space technology have encouraged researchers to explore advanced techniques for monitoring and controlling orbital debris. Artificial Intelligence, Machine Learning, and computer vision techniques are extensively applied for identifying and tracking debris objects in low Earth orbit. Deep learning models are capable of processing satellite images and telescope-based data with greater effectiveness, leading to higher detection precision and faster computational performance. Smart sensors and IoT-based communication components are also integrated to support continuous monitoring and efficient data transmission and also utilized for collecting real-time orbital information continuously.

Several studies have focused on predictive analytics for estimating debris trajectories and identifying possible collision threats. Machine Learning approaches such as neural networks, regression algorithms, and support vector classifiers are regularly applied to forecast orbital behavior and assess risk levels. Researchers have additionally proposed robotic debris removal systems and laser-assisted orbital correction techniques to reduce the movement of hazardous fragments. Cloud-based platforms and visualization tools are further integrated to simplify monitoring and centralized data access.

Although these technologies contribute significantly to orbital monitoring, most existing solutions concentrate on individual tasks such as tracking or prediction alone. Very few systems combine detection, monitoring, prediction, alert generation, and mitigation into a single intelligent platform. Moreover, high implementation costs and dependency on sophisticated infrastructure reduce the practicality of many existing systems for academic institutions and small-scale research environments. Hence, there is a growing demand for a smart, economical, and scalable framework capable of delivering complete space debris management with improved automation and reliability.

### II. PROBLEM STATEMENT

The continuous increase in inactive satellites, fragmented rocket parts, and abandoned space objects has produced severe challenges for modern space operations. Since orbital debris travels at extremely high velocities, even tiny particles can damage active satellites, communication systems, and spacecraft. The rising congestion in Earth's orbit increases the likelihood of collisions, which may generate additional debris and create long-term threats for future missions.



Most currently available debris management systems are expensive and mainly designed for government organizations and large space agencies. Many existing approaches lack intelligent automation, real-time monitoring capability, and efficient prediction mechanisms for identifying potential collision risks. In addition, separate technologies are often used for detection, tracking, and mitigation, leading to increased complexity and operational cost.

To overcome these limitations, an intelligent and affordable framework is required that can continuously monitor orbital debris, predict collision risks using AI techniques, and support automated mitigation processes. The proposed system integrates AI, IoT, and computer vision technologies into a unified platform for debris detection, tracking, trajectory analysis, alert generation, and efficient space debris management. Such a system can enhance orbital safety, reduce mission risks, and support sustainable space exploration.

### III. PROPOSED SYSTEM

The proposed framework introduces an intelligent and integrated approach for monitoring, predicting, and managing space debris using Artificial Intelligence, IoT technology, and automated orbital analysis techniques. IoT-based sensing devices and satellite communication modules continuously collect orbital parameters such as debris position, velocity, altitude, and movement direction. The collected information is transferred to a centralized processing unit where AI algorithms analyze the data efficiently.

Machine Learning and Deep Learning models are employed to classify debris objects, study orbital movement patterns, and estimate possible collision threats with operational satellites and spacecraft. The framework also provides real-time visualization and automated warning notifications whenever hazardous orbital conditions are detected.

Apart from detection and prediction, the system also supports intelligent mitigation strategies for improving long-term orbital safety. Automated decision-making mechanisms recommend preventive actions when collision threats are identified. The framework is designed to support future robotic debris removal technologies and autonomous orbital correction methods. By combining sensing, monitoring, prediction, and mitigation within a single platform, the proposed system reduces operational complexity and improves reliability. Furthermore, the framework offers a cost-effective and scalable solution suitable for academic research and future smart satellite management systems.

### IV. METHODOLOGY

The methodology begins with continuous collection of orbital information using IoT-enabled sensors, satellite communication systems, and monitoring modules. Data related to debris position, velocity, trajectory, and surrounding environmental conditions is transmitted to a centralized processing unit for analysis. During preprocessing, incomplete records, duplicate entries, and unwanted noise are removed to improve data quality and reliability.

Machine Learning and Deep Learning algorithms are then applied to identify debris objects, analyze orbital movement patterns, and predict potential collision risks with active satellites or spacecraft.

The system continuously monitors debris behavior and automatically generates warning alerts whenever hazardous movements are detected. In addition, intelligent response mechanisms are integrated to support future robotic mitigation systems, autonomous satellite maneuvering, and debris removal operations. Visualization dashboards are also included to provide a clear representation of orbital conditions and risk levels. This methodology reduces manual intervention, improves prediction accuracy, enhances operational efficiency, and contributes toward safer and more sustainable space mission management.

### V. RESULTS AND DISCUSSION

The developed approach proved effective in detecting and monitoring moving debris objects using OpenCV-based computer vision techniques. The system successfully processed real-time input data and identified potential collision movements with improved accuracy and faster response time. Raspberry Pi acted as the central processing unit and communicated efficiently with the Arduino UNO for controlling hardware operations. During simulated collision-risk situations, the framework automatically activated motors, LEDs, and buzzer modules to provide immediate alerts and automated response support. Machine Learning-based analysis improved the prediction of hazardous orbital movement patterns and reduced delays in threat detection. IoT-enabled communication ensured smooth data sharing between detection devices and processing modules, improving overall monitoring reliability. Experimental observations showed that the framework minimized manual effort and maintained stable performance during continuous monitoring. The



results confirm that integrating AI, computer vision, and IoT technologies can significantly improve space debris detection, prediction, and mitigation while maintaining a cost-effective and scalable implementation suitable for academic and research applications.

## VI. ADVANTAGES

- Real-time orbital debris monitoring.
- Improved collision prediction accuracy.
- Reduced dependency on manual monitoring systems.
- Integration of AI and IoT technologies.
- Cost-effective and scalable framework.
- Supports sustainable space operations.

## VII. FUTURE SCOPE

Future improvements include Deep Learning integration, cloud monitoring, robotic capture systems, and improved trajectory prediction models. Advanced autonomous satellites can also be developed to perform self-monitoring and debris avoidance without human intervention. The combination of edge computing and 5G-enabled space communication systems can significantly enhance real-time data exchange and increase processing effectiveness. Future research can additionally focus on energy-efficient robotic removal mechanisms and international collaborative space safety networks for sustainable orbital management

## VIII. CONCLUSION

The proposed AI-enabled framework provides an intelligent solution for space debris detection, tracking, and mitigation. By integrating Artificial Intelligence, IoT technologies, predictive analytics, and automated monitoring systems, the framework improves orbital safety and reduces potential collision risks. The proposed approach supports sustainable space exploration and future satellite operations.

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