Acceleron Aerospace Journal || AAJ.11.2106-2305
Volume 1, Issue 1, pp (23-27)
Conceptual Paper
ISSN- 2583-9942 || DOI: 10.61359/11.2106-2305

Conceptual Design of Artificial Intelligence Powered Automated Space Debris Remover (ASDR)

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Abstract: The focus of this research article is the application of AI technology for space debris removal. With the increasing number of non-functional artificial objects orbiting Earth, commonly known as space debris or junk, the need to address this issue has become crucial. Currently, there are over 200,000 such objects posing a significant threat to operational satellites and space missions. To mitigate this risk, we propose the utilization of AI-trained robotic systems to safely de-orbit space debris, thereby reducing the probability of collisions and potential damage. This research paper introduces the concept of employing AI and robotics technology to achieve this objective, with a specific emphasis on targeting Point Nemo as a designated disposal location. By harnessing the capabilities of AI, we can effectively identify and track space debris, enabling the robotic system to navigate and remove debris from critical orbital paths safely. Furthermore, the re-entry trajectory directed towards Point Nemo ensures that approximately 95% of the debris will burn up upon atmospheric re-entry, thus minimizing any potential risks to human life and property.

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1. Introduction

The rapid increase in the number of rocket launches has brought about a pressing concern regarding the proper disposal of rocket parts and the subsequent accumulation of space debris. While certain rockets are designed for controlled re-entry, a substantial portion of rocket stages and other components strands in Earth's orbit, posing a significant and growing threat to operational satellites and exacerbating the risk of the Kessler syndrome becoming a reality **[1-6]**. In response to this formidable challenge, numerous ideas have been proposed to tackle the issue of space debris accumulation and the methodology to eradicate it. These proposals encompass a range of innovative approaches, including debris removal systems employing capturing mechanisms with flexible or stiff connections, re-entry strategies involving descent to lower orbits, utilization of space lasers for targeted debris elimination, implementation of electrified wires to drag objects out of orbit, deployment of robotic arms for precise maneuvering, and the use of nets and other sophisticated techniques for debris manipulation and removal. These ideas hold immense potential in mitigating the risks associated with space debris, ensuring the sustainability and safety of future space activities.

The aforementioned methods encompass various approaches to remove or destroy space debris, either by eliminating them in orbit or by maneuvering them to lower orbits where their re-entry time is substantially reduced. Among these methods, the utilization of AI-Trained robotics emerges as a significant advancement, presenting clear and compelling advantages. This innovative solution focuses on the detection and retrieval of space debris, followed by its controlled navigation towards a designated remote location known as Point Nemo for secure disposal **[7]**. The present research article delves into an in-depth exploration of the potential benefits and advantages associated with the implementation of an AI-Trained robotic system for the efficient and cost-

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**Received: 01-July-2023 || Revised: 15-July-2023 || Accepted: 18-July-2023 || Published Online: 30-July-2023

effective management of space debris. By harnessing the power of artificial intelligence and robotics, this cutting-edge solution holds the promise of revolutionizing the way we address the complex challenges posed by space debris, ensuring a safer and more sustainable future for space exploration and satellite operations.

2. Literature Review & Prospect

Space debris, characterized as non-cooperative objects in Earth's orbit, presents a significant challenge for effective removal. The traditional methods used for on-orbit servicing missions, which involve cooperative targets, do not directly apply to the capture and removal of space debris. This review explores various approaches and technologies, including the integration of AI, to address the complexities associated with space debris management.

One significant challenge in space debris removal is reliably capturing and removing non-cooperative targets without exacerbating the debris issue. Traditional on-orbit servicing missions, which involve cooperative targets, do not directly apply to space debris. Proposed methods for active debris removal (ADR) include the use of robotic arms, nets, harpoons, and other capture mechanisms. AI can play a vital role in guiding these ADR systems, enabling autonomous identification and minimal human intervention. This not only reduces the risk of human error but also enhances the efficiency and cost-effectiveness of debris removal operations.

The looming threat of the Kessler Syndrome, in which the density of space debris reaches a critical point, necessitates prompt action. It is crucial to track and predict space debris to prevent collisions and the creation of more debris. AI can contribute to developing new technologies for debris removal and improving the accuracy of tracking systems. Investing in AI-driven solutions for space debris management is not only crucial for the space industry but also for governments and private companies involved in satellite operations.

The economic benefits of AI-driven space debris management solutions are significant. The global space economy is predicted to experience substantial growth, and by embracing AI-powered technologies, organizations can position themselves for success. Governments and companies involved in space activities can tap into the lucrative market and drive innovation while mitigating the risks associated with space debris incidents.

Research efforts are being made to address the challenges of space debris removal. For example, a team at Sapienza University of Rome developed a machine learning algorithm to track the rotational motion of space debris, enhancing the understanding of debris behavior. The European Space Agency (ESA) has partnered with ClearSpace to launch a debris removal project that utilizes AI-enabled cameras and robotic arms for debris collection and disposal. These initiatives showcase the potential of AI in advancing space debris management.

However, caution must be exercised in relying too heavily on AI-based solutions. The dynamic and evolving nature of the space environment presents uncertainties that can limit the accuracy of predictions. Factors like atmospheric density and other unknowns' impact debris behavior, necessitating real-time information updates and continuous adaptation of AI models to the changing spatial environment.

Finally, addressing the space debris challenge requires innovative solutions, and the integration of AI technologies holds promise. By leveraging AI for tracking, identification, and removal of space debris, we can improve the efficiency, safety, and sustainability of space operations. Continued research and development in this field will contribute to a cleaner and more secure space environment for future generations **[8-11]**.

3. Research Methodology

The research article provides a comprehensive examination of the diverse approaches employed for space debris removal, thoroughly evaluating their respective strengths and weaknesses, and highlighting the comparative advantages of specific systems over others. The analysis underscores the pivotal role of AI technology as a significant leap forward in addressing this critical issue. In light of the escalating number of satellites being launched, coupled with the emergence of large-scale constellation projects, the need for effective measures to avert collisional and catastrophic accidents in low Earth orbit (LEO) becomes paramount. Consequently, this article delves into a meticulous exploration of the intricate steps involved in the utilization of AI technology for the detection, capturing, and safe disposal of space debris. By employing AI algorithms and advanced robotic systems, the proposed solution aims to mitigate the risks associated with LEO collisions, thereby safeguarding the integrity of both existing and upcoming satellite constellations. The study recognizes the imperative of this technological advancement amidst the intensifying demands of an ever-expanding satellite deployment landscape.

4. Mission Phases

4.1. Detecting and Tracking Space-Debris

The initial phase in effectively managing space debris involves the development of an AI Trained robotic system equipped with cutting-edge sensors, including high-resolution optical cameras, radar systems, and LiDAR technology **[12]**. These advanced sensors enable precise detection and tracking of space debris by capturing detailed information about the size, position, trajectory, and composition of the objects. The AI Trained robots are trained using sophisticated machine learning algorithms, such as convolutional neural networks (CNNs) and recurrent neural networks (RNNs), to analyze the sensor data and accurately identify and classify space debris **[13-14]**. The training process involves feeding the algorithms with a vast dataset of labeled debris samples, enabling the robots to learn patterns and characteristics associated with different types of debris. This training enables the robots to autonomously detect and track debris objects in real-time, even in complex and cluttered orbital environments.

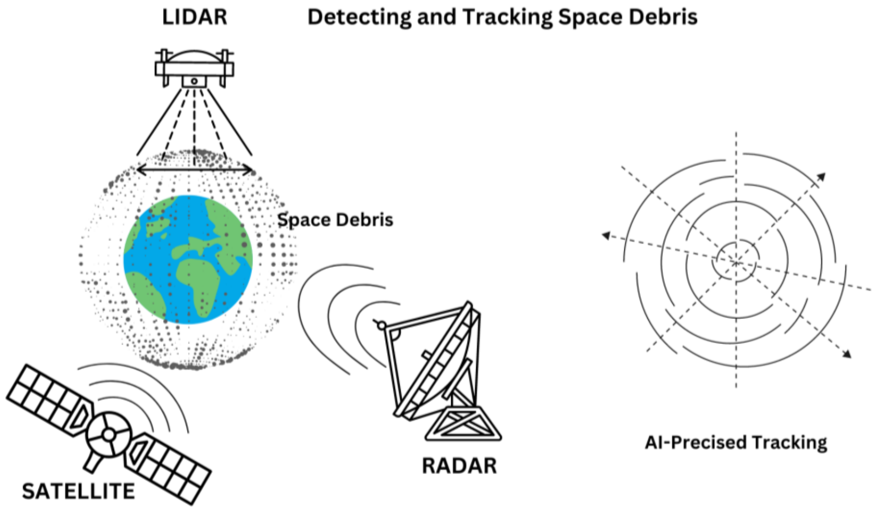

Figure 1 Space Debris Tracking and Detection [Typical Map and Illustration]

4.2. Robotic Debris Collection

Once the AI Trained robots identify space debris, they employ advanced manipulation capabilities, such as robotic arms equipped with grippers or specialized capture mechanisms. These mechanisms are designed to securely grasp and retrieve the debris, taking into account factors like object shape, size, and stability. The robotic arms are equipped with force and torque sensors to provide feedback and ensure a delicate and controlled grip on the debris during the collection process.

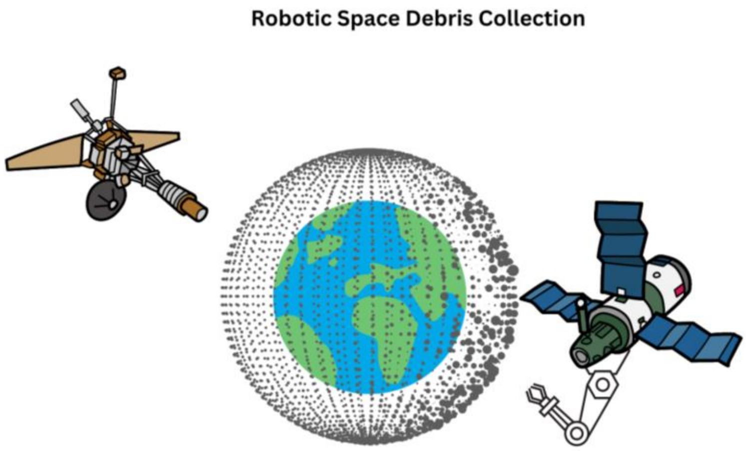

Figure 2 Robotic Space Debris Collection Using Robotic Arms

4.3. Transportation to Point Nemo

To transport the collected debris to Point Nemo, the AI Trained robots utilize advanced propulsion systems, such as ion thrusters or electric propulsion, which offer high efficiency and precise control over the spacecraft's trajectory. Trajectory planning algorithms are employed to calculate optimal paths that minimize fuel consumption and maximize the accuracy of reaching the designated disposal location. These algorithms take into consideration various factors, such as gravitational forces, atmospheric drag, and orbital perturbations, to ensure the successful transportation of the debris to Point Nemo.

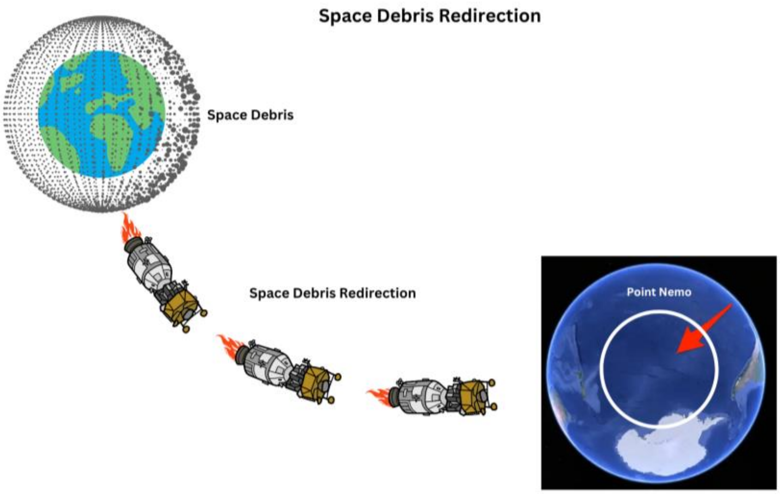

Figure 3 Space Debris Redirection and Mitigation at Point Nemo

4.4. Eradicating Space Debris from Point Nemo

Upon reaching Point Nemo, the debris is directed for re-entry into the Earth's atmosphere. Due to the high velocity and intense heat generated during atmospheric re-entry, the debris experiences significant aerodynamic forces, causing it to burn up and disintegrate into harmless ashes. This natural disintegration process minimizes the risk of debris surviving re-entry and ensures a safe and environmentally friendly disposal method.

5. Conclusion

By combining advanced sensor technology, AI algorithms, robotic manipulation capabilities, and precise trajectory planning, the proposed AI Trained robotic system offers a technologically sophisticated and efficient approach to space debris detection, collection, and disposal. This integrated solution holds tremendous promise in addressing the growing challenge of space debris accumulation, reducing the risks associated with orbital collisions, and safeguarding the integrity of future space missions.

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7. Biography

Adarshraja is a driven and talented student with a strong interest in aerospace and space sciences, particularly in the field of space debris removal. As a K11 Student Scholar and intern at Acceleron Aerospace, he has gained valuable experience and knowledge in the industry. With a keen eye for web development, Adarshraja has also contributed as a Web Developer Intern at Acceleron Aerospace. He is now actively seeking opportunities to join startups where he can apply his exceptional skills and contribute to innovative solutions in the aerospace field. Adarshraja's dedication and passion make him a promising individual in the pursuit of his aerospace and space aspirations.

8. Acknowledgement

I am deeply grateful to my family and guide for their unwavering support, encouragement, and guidance in my journey. Their presence has been instrumental in my achievements, and I am truly thankful for their belief in me.

9. Conflict of Interest

The author have no conflict of interest to report.

10. Funding

No external funding was received to support this study.