Smart Hybrid LENS for Space Sustainability

(Laser & Net Enhanced System for Orbital Debris Mitigation)

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Abstract

This paper proposes an innovative solution to the growing issue of space debris. Space debris poses a threat to space stations, satellites, and upcoming space missions. Having large objects moving at high velocities towards our atmosphere may also threaten the safety of people on Earth. To address this threat, we propose LENS (Laser-Enhanced Net System). Unlike previous innovations, LENS is a hybrid system combining three technologies: A ground-based laser unit, net capture mechanisms, and artificial intelligence (AI). The suggested system provides adaptable, versatile, and economical ways to identify, initiate, and remove debris by combining the three technologies. We expect LENS to reduce space debris safely.

Introduction

Since the launch of the first satellite in 1957, Earth's atmosphere has been increasingly polluted with inoperative satellites, spent rocket stages, and fragmented debris from collisions and explosions. The orbital debris cloud is continuously growing, which poses a threat to active and existing satellites, current space missions, and future space operations. The previously mentioned scenarios give reason to propose our solution. Traditional debris mitigation missions have only focused on a limited variety of debris, failing to consider the different types of debris size, speeds, and behaviors. A comprehensive and adaptive solution is urgently needed. This research paper proposes a solution, an integrated system "LENS" (Laser-Enhanced Net System) that combines three technologies in the field of orbital debris removal.

The first part of our solution is built upon NASA's ORION project (Optical Removal of In-Orbit Nuisances), which explored the uses of Earth-based and remote lasers to alter the orbit of small debris. The second part of LENS is examining net-based solutions, such as the RemoveDEBRIS mission. This mission was developed by Airbus, aiming to demonstrate the efficacy of detaining large debris with deplorable nets. The final part of the system utilizes artificial intelligence to identify debris under complex visual conditions. Specifically, deep learning-based tracking systems, such as SDT-Net, have previously demonstrated accuracy in identifying debris. While past applications of the three technologies have yielded significant findings, the current literature reveals a research gap: the combination of all three technologies into a unified and comprehensive system that leverages their individual strengths. The proposed solution, the LENS system, addresses this gap by providing an adaptive defense strategy. Figure 1 illustrates a conceptual illustration of the LENS project.

Figure(1): Conceptual illustration of the LENS project (for representation purposes only)

Background & Literature Review

This study suggests a solution to space debris pollution through the “LENS” (LaserEnhanced Net System) system, which is a hybrid and unified system that can adjust to various debris circumstances.Ground-based lasers are one of the most prominent technologies in the field of space debris removal. In 1996, Phipps et al collaborated on the ORION project, which proposed that garbage could be eliminated by sending a modest impulse from a powerful Earth-based laser at the trash. Their theory was that the laser's thrust would alter the orbit of the debris enough to cause it to crash into the atmosphere and burn up. One of the primary arguments they emphasized was that this system relies solely on ground infrastructure, which can be built up gradually rather than launching costly satellites or new systems into orbit. They also claimed that this strategy might handle greater orbital areas while avoiding the addition of new satellites that could one day become debris This concept is illustrated in Figure 1, which shows a simulation of a ground-based laser targeting orbital debris.

Figure(2): Simulation of ground-based laser firing for space debris removal

In addition to lasers, there have been proposals to utilize space robots with nets to gather trash. One well-known example is the Remove Debris experiment, which Airbus DS conducted as part of the Net Capture Mechanism. In 2017, Axthelm et al demonstrated how the system works by collecting debris with a five-meter-wide hemispherical net. This design stood out because it could catch rotating objects and adjust to targets of various shapes and speeds. They also tested it in a vacuum, vibration, and heat, and it proved to be quite dependable. The researchers suggested that it may be expanded in the future by adding more nets or capture units to strengthen the system and cover more orbital pathways Refer to Figures 3 and 4 for a visual representation of how the net system operates.

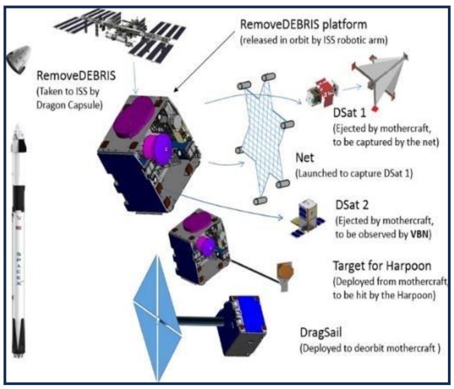


Figure (3): Infographic of the RmoveDebris mission

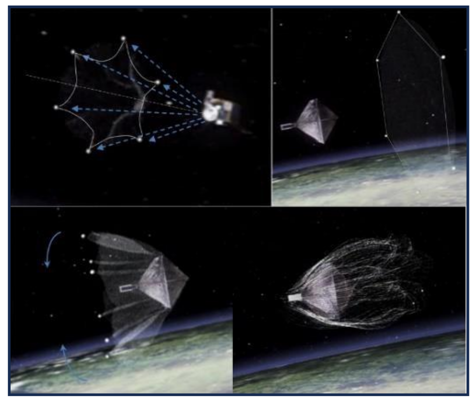


Figure (4):Sequence from video animation of net ejection and DSAT#1 capture

Artificial intelligence has started to take an important role in dealing with space debris too, especially in tracking and identifying objects. Axthelm and Klotz in 2025 introduced what is known as the SDT-Net model, which uses deep neural networks to help track debris even in difficult conditions, like bright sunlight or when the background is full of stars. Their study showed that this system can carefully measure the position and speed of even very small pieces of debris, and it worked well both in computer tests and with real data from monitoring stations. However, they also identified a challenge: AI takes a large amount of data to learn correctly and requires extremely powerful hardware to run continuously, making it difficult to rely on on its own.

Past studies treated lasers, nets, and AI separately, each with limits. Our “LENS” system is the first to combine all three, making debris removal faster, smarter, and more reliable. This integration turns partial solutions into a complete approach for keeping space safe and sustainable.

1. How you propose to resolve the problem

Thru our research in various sources and previous projects, most studies focused on developing a single method to address space debris. Each project developed excelled in treating one part of the problem or was only effective under certain conditions. However, when these technologies encounter different sizes, fast-moving objects, or irregular movements, they cannot be effective on their own, which significantly impacts our ability to maintain safe, efficient, and more sustainable operations.

Our project, LENS (Laser-Enhanced Network System), offers an innovative approach by integrating three powerful technologies into a fully coordinated system. By combining an intelligent space network controlled and synchronized by advanced artificial intelligence, with a high-precision ground laser capable of adjusting debris orbits when needed to ensure easy debris control, LENS provides a flexible, fast, and efficient innovation. This is because it is integrated, with each technology performing tasks specifically designed for it, and by combining them, we fill the gaps or deficiencies encountered when using a single technology

The suggested remedy

The LENS (Laser-Enhanced Net System) serves as two interconnected lines of defense against space debris:

Ground-Based Laser Unit:

Designed for small or hard-to-capture debris. It uses precise high-energy laser pulses to slightly change the debris' velocity or orbit, gradually steering it toward safe atmospheric burn-up.

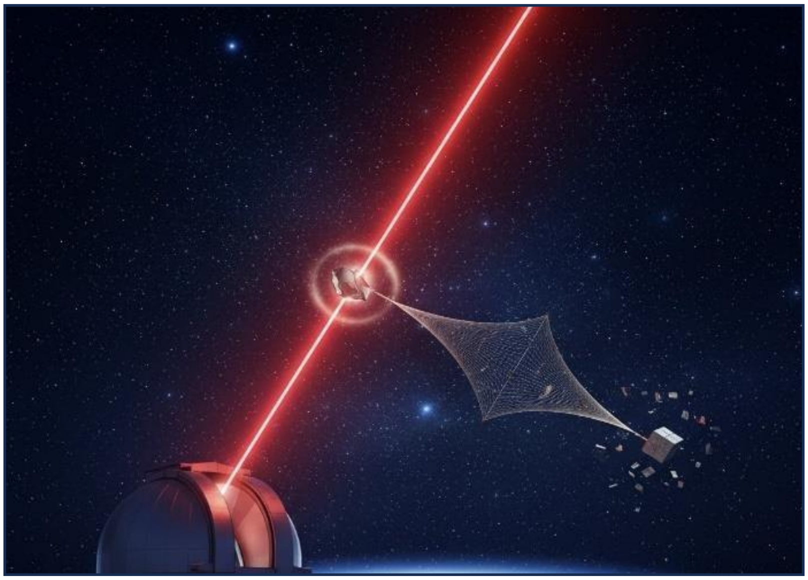
Smart Net Unit:

A small satellite deploys nets to capture large debris, then either deorbits it to burn safely or moves it to a graveyard orbit.

AI Coordination:

AI analyzes orbital data, predicts collision risks, and selects the optimal removal method (net, laser, or combined). The system continuously learns, improving accuracy and efficiency over time.

This hybrid system combines multiple methods to handle debris of different sizes, reduce collision risks, and improve satellite safety. By integrating these technologies, LENS supports long-term space sustainability and a safer orbital environment for future missions.



Figure(5): Conceptual illustration of the LENS (Laser-Enhanced Net System) in orbit

2. Methodology

This project focuses on removing space debris using a set of integrated technologies that work together in a structured manner. The process is divided into stages, each of which paves the way for the next, helping to reduce costs and increase the chances of success without major problems or risks.

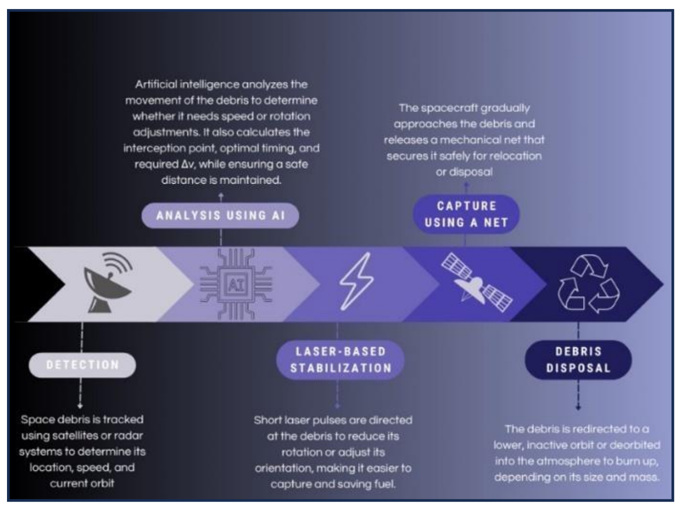


Figure (6): Summary of the LENS system operational steps for space debris removal

First, the debris is located and its movement is analyzed to determine if there is a possibility of collision in the coming days. If the situation is deemed dangerous or there is an opportunity to intervene, we move on to the second stage. Here, lasers are used to send short pulses that control the movement of the debris, especially if it is rotating at high speed or moving at a complex angle. These pulses help to calm it down and prepare it for capture.

Then comes the role of artificial intelligence, which is used to calculate the ideal point of interception and determine the most appropriate time based on the speed and location of the debris. The required change in speed (Δv) is also calculated, and the lower this value, the better for the vehicle in terms of fuel consumption and cost. In addition, a safety distance is set to avoid any unplanned collisions.

If the calculations are correct, the spacecraft begins to gradually approach, releasing a special net that wraps around the debris and secures it. After that, the debris is directed to a less dangerous orbit or disposed of permanently, depending on its condition and weight. the overall methodology is illustrated in Figure (6), which provides a step-by-step summary of how the LENS system operates to detect, manage, and remove space debris.

3. Expected Impact & Beneficiaries

Our solution could change a lot in the field of space, because space debris has become a real problem. Over time, there have been many satellites, some of which have malfunctioned or become debris orbiting in space. This poses a danger to new satellites and missions sent by space agencies.

From an economic standpoint, having a system that removes space debris is very helpful. Instead of losing satellites due to collisions, it is possible to preserve them. It will also reduce fuel consumption because satellites do not need to change their trajectory as much to avoid debris,which means saving money and resources.In terms of regulation, a project like this will force countries to agree on clear rules. Instead of each party acting on its own, there will be coordination. This reduces problems and improves cooperation between them.

There are many beneficiaries, such as space agencies, companies that work with satellites, and even researchers and scientists. Because when the orbit is cleaner, there is greater safety and more opportunities for the future. We must use space responsibly, and this project helps with that.

4. Constraints & Assumptions

When using technologies such as lasers, nets, and artificial intelligence to remove debris from space, there are some issues that we need to be aware of. First, lasers may not be powerful or precise enough for small or fast-moving pieces, making them difficult to control. Second, satellites must be very precise when approaching debris and firing the net so as not to miss the target or cause it to ricochet. As for artificial intelligence, it is useful but cannot be fully relied upon without human oversight, especially in predicting debris trajectories and assessing risk. Furthermore, the use of lasers or nets requires good fuel and energy management, as resources are limited. Finally, there must be legal coordination with international bodies before using any technology that could affect other objects in space, in order to avoid legal problems.

On the other hand, we assume that the data on debris locations is accurate, which helps artificial intelligence work better when supported by humans. We expect that the entire process will be feasible within the available time and resources, and that we can start with small-scale trials before expanding their use. Overall, the project needs a balance between technology and reality in order to be successful and safe.

5. References

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