Technological Advancements for Combating Space Debris

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Introduction

There is no doubt that space debris can pose significant risks to human safety and the future success of space missions. In fact, according to Vijay Iyer from the Federation of American Scientists, “The space economy is enormous, but one of its biggest challenges is tiny: space debris, where a collision with an object the size of even a nickel can cause catastrophic damage.” (Iyer, 2024). This is concerning, as more than 170 million pieces of debris are currently in space, according to Iyer. Space debris significantly threatens human safety and the success of space missions, potentially causing catastrophic damage to equipment and endangering lives. For this reason, to address the space debris crisis, scientists and engineers are actively developing advanced technologies to mitigate and remediate the growing concern.

Currently, there are two main types of space debris technologies: mitigation technologies, which aim to reduce the creation of new debris, and remediation technologies, which focus on actively removing existing debris from orbit. Examples of mitigation technologies include reusable rockets, which reduce the need for disposable components (Reddy, 2018), and deorbiting programs programmed in spacecraft to ensure they safely reenter the Earth’s atmosphere at the end of their missions (Sheetz, 2024).

Jason Rainbow, a journalist covering satellite telecom, finance, and the commercial space sector for SpaceNews, explains that remediation technologies, such as advanced laser systems capable of vaporizing or deflecting orbital debris, are being developed to address existing space junk (Rainbow, 2024). In addition, a French aerospace company highlights innovations like robotic arms and nets designed to capture larger debris, as well as drag sails that accelerate the natural deorbiting process (Airbus, 2024).

As recent advancements continue to grow, issues remain, such as the cost and complexity of removing larger debris from orbit. Innovative solutions like drag sails and nets are still in development, with successful tests needed to prove their effectiveness in real-world space conditions (Das & Mhapankar, 2022). Experts highlight the necessity of a combined approach to the space debris problem, where both the prevention of new debris and the active removal of existing debris are used to safeguard the orbital environment for sustainable space activities. (Christensen, 2024). Together, these technologies play a critical role in addressing the growing crisis of space debris, safeguarding future space operations, and preserving the orbital environment although their effectiveness may vary depending on factors such as the scale of implementation and the technological challenges involved.

Mitigation

One of the key approaches for achieving sustainability in space is through mitigation technologies, which focus on preventing the generation of new space debris. To achieve this, scientists and engineers have developed solutions such as reusable spacecraft and deorbiting systems for sustainable space exploration. These technologies are considered essential to reducing debris accumulation and ensuring the long-term sustainability of space operations. While these technologies offer significant advantages, including reducing debris accumulation and lowering costs for future missions, they also present certain challenges. For instance, Vidya Sagar Reddy from the Observer Research Foundation on Nuclear and Space Policy Initiative states that reusable spacecraft require rigorous inspections and maintenance to ensure safety and reliability, which can increase the complexity of their operation and operational costs (Reddy, 2018).

Despite these challenges, the benefits of reusable technology are substantial. For example, companies like SpaceX have demonstrated the feasibility of reusable rockets, significantly reducing launch costs and minimizing waste. According to Reddy, the use of reusable rockets cuts down on the number of discarded components, a major contributor to space debris (Reddy, 2018). Additionally, the development of self-deorbiting systems within spacecraft is a complementary strategy that further mitigates debris risks. According to The European Space Agency (ESA), “ESA missions must ensure the safe disposal of space objects through atmospheric reentry or re-orbiting to a safe altitude with a probability of success higher than 90%.” (ESA, n.d.).

Another example is SpaceX's Starlink program, which has made large feats in reducing debris accumulation in low Earth orbit. As of 2024, the company has already deorbited around 400 satellites, with plans to discontinue first-generation satellites to minimize space junk. While some of the satellites were not successfully deorbited due to extreme weather conditions, this initiative still reflects a growing commitment within the space industry to manage space debris responsibly (Das & Mhapankar, 2022). If these technologies are successfully adopted on a larger scale, they could revolutionize space exploration by ensuring a sustainable, cost-effective approach while addressing the pressing issue of space debris. This dual focus on innovation and sustainability is essential to preserving orbital environments for future generations.

Remediation

While mitigation technologies aim to prevent the creation of new space debris, remediation technologies focus on addressing the existing debris that already poses significant risks to space operations. These technologies are critical for actively removing or managing space debris to reduce potential collisions and safeguard the future of space missions. The goal of remediation technologies is to actively remove the debris currently orbiting in space, thereby reducing the risks it poses to operational satellites and future missions. Scientists and engineers have developed innovative solutions, such as laser-based systems designed to target and vaporize smaller debris or alter its trajectory to accelerate its deorbiting process. Moreover, the European Space Agency (ESA) plans to launch ClearSpace-1, a robotic claw based mission by 2025 to assist in the facilitation of addressing space debris (ESA, n.d). Additionally, technologies like drag sails, which increase atmospheric drag to facilitate the natural descent of debris, and robotic systems equipped with nets or arms to capture and remove larger debris, are under development.

These technologies play a crucial role in maintaining the long-term sustainability of space operations. For instance, the use of lasers not only helps clear smaller fragments but also minimizes the risk of further collisions that could generate additional debris. Similarly, the implementation of self-deorbiting mechanisms in dysfunctional satellites ensures they safely burn up upon reentry into the Earth's atmosphere, reducing the overall clutter in orbit. Initiatives such as ClearSpace and Astroscale exemplify these technologies, while the discussion of legal and financial challenges aligns with achieving long-term sustainability in space (Picard, 2024).

One promising development is a new initiative in Japan led by JSAT, in collaboration with RIKEN and universities. They are working on using lasers in space to vaporize debris, which will generate thrust to push the debris into a lower orbit, where it will eventually burn up in the atmosphere. While still in the development phase, this project aims to begin operations by 2029. However, challenges remain regarding the effectiveness of laser-based debris removal, as concerns about its precision and potential unintended consequences must be addressed. (JSAT, 2024).

When considering these potential solutions for tackling the overbearing crisis, they must also consider the potential risks associated with them. In sum, a focus on removal methods for space debris is essential to advance in future space exploration and space missions.

Conclusion

Overall, from the current technological advancements in combating space debris many scientists and engineers devised two main focuses on tackling the growing space debris concern using both mitigation and remediation strategies. Mitigation technologies aim to prevent further debris generation through improved spacecraft design and operational practice with reusable spacecraft and self-deorbiting systems, while remediation technologies focus on actively removing or neutralizing existing debris by targeting existing debris with laser systems, robotic arms, and drag sails. While both approaches present significant challenges, including high costs and technical complexities, they are essential for ensuring the sustainability of space operations.

Continued investment and development of these technologies are crucial to tackling the growing space debris problem, reducing collision risks, and preserving Earth's orbital environment for future missions. Space agencies have been able to come up with effective solutions that require more time and energy to continue and for that, the federal government may need to further fund their efforts. Both approaches, although challenging, are essential to maintaining the long-term viability of space exploration and satellite operations.

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