Clearing the Skies

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Would anyone expect that by 2025, the Earth will be orbited by more than 1 million pieces and objects that are larger than 1 centimeter (ESA, 2024)? Space debris has become a new global challenge that humanity has faced in the 21st century. As Stubbe noticed, “human activities in outer space have led to various forms of pollution and undesirable effects” (Stubbe,2017, p.13). The abundance of space junk, which consists of millions of pieces of broken and non-functioning satellites, is extremely dangerous - even the pieces are 1-10 cm - due to the possibility of collisions with working satellites and the International Space Station. There is also a threat of pollution of the atmosphere and surface of the Earth with dangerous substances. The era of space satellites started in the 1950s, and since then, more than 10,000 objects have been launched into Earth orbit (Editors, 2024). The first collision between an operational satellite and a piece of space debris happened in 1996, and its number continues to increase because a lot of countries are operating in orbit and launching hundreds of satellites every year. This situation leads to a high risk of new collisions. While some space programs in North America and Europe can track large objects, change the way of functional satellites to avoid collisions, or place future satellites in very low Earth orbit to reenter them into the atmosphere after they become non-functional, it is not enough to clean the orbit of current garbage. Developing and applying more effective solutions to redirect satellite pieces to the Earth's atmosphere to burn up, such as a laser-based tool, a robotic arm mechanism, and a magnetic capture system, can help to mitigate and remove space debris.

One of the development plans for removing debris in the Earth’s orbit is using technology based on lasers. Space-based laser systems aim to address the challenge by targeting small debris fragments to melt them, change their trajectory to enter the atmosphere, and burn up. According to Walker (2023) in "Space Debris Remediation Using Space-based Lasers", the study suggests that using lasers to heat debris, causing small bursts of force to change its orbit, could have reduced debris orbiting at 1200 km by several decades. This approach leverages directed energy to modify the velocity of debris and gives the possibility to reenter the atmosphere, effectively reducing the population of hazardous objects in low Earth orbit. Although there are currently no operational projects, some programs perform successful experiments to use laser systems in space, for example Japanese Aerospace Exploration Agency made research and "Thrust Measurement Experiment for Space Debris Nudging", which demonstrated that laser irradiation could be effective (Minagawa, 2024). Employing such laser systems on a satellite or even a space station gives the possibility to remove fragments 1-10 cm from orbit. While space-based laser technology is still developing, experiments show it has great viability for future applications for active small debris removal.

The next potential solution to address space debris is utilizing a robotic arm mechanism to capture and deorbit non-functional satellites. Space debris removal requires precise technologies capable of handling large objects, such as defunct satellites or rocket parts, which represent significant risks for working satellites as well as for people and infrastructure on the Earth's surface. "The ClearSpace-1 mission consists of a giant four-armed robotic spacecraft that can grab space debris" (Paleja, 2023). This Switzerland space company's mission demonstrates in experiments the capability of robotic arm mechanisms to safely remove large debris items, reducing the risk of collisions and ensuring long-term sustainability in Earth's orbit. ClearSpace was picked by the UK's Active Debris Removal mission for the contract to "target multiple pieces, with the removal spacecraft designed to be left in Earth orbit, possibly for future refueling to tackle more junk” (O’Callaghan, 2022). This means that this mission will find, capture with 4 robotics arms, and transport to orbit several objects one by one, and this spacecraft can be refueled for further work in low orbit. There are essential reasons that the robotic arm mechanism can effectively reduce the amount of large objects in the Earth's low orbit in the future.

The most promising solution for removing space debris is the magnetic docking mechanism, which uses magnetic forces to capture and redirect satellite pieces to Earth's atmosphere. Magnetic docking mechanisms use specially designed magnetic plates or components to hold debris. It allows for capturing objects without causing additional fragmentation because this method is non-contact. This system has already been tested in space. According to a press release by Japanese company Astroscale, a leading company in space sustainability, “End-of-Life Services by Astroscale-demonstration (ELSA-d)” mission completed a series of controlled close-approach operations between its dual spacecraft in orbit using magnetic docking (Astroscale, 2022). During this demonstration in space, the spacecraft safely approached the inactive object, captured it by using magnet plates, and changed navigation to transport the object to low-Earth orbit. However, the magnet system requires magnet plates on satellites to be captured. In cases where the debris object does not have a magnetic plate, Professor Alexander Ledkov and Professor Vladimir Aslanov describe in their study a mechanism that allows the object to be slowed down and a magnetic plate to be attached to it (Ledkov & Aslanov, 2022). Although this complicates the process, the application of magnetic force still enables the effective capture of fragile or irregularly shaped debris. By integrating magnetic docking mechanisms into future missions, space agencies can efficiently capture debris and redirect it for atmospheric reentry, enhancing orbital safety.

In order to address the increasing threat of space debris, it is essential to implement groundbreaking solutions such as space-based laser systems, robotic arms, and magnetic capture mechanisms to redirect and remove dangerous fragments from Earth's orbit. Although some of these projects are in the development or experimental stages, take a long implementation time, and cost millions of dollars, these advanced technologies offer innovative and effective approaches to managing both small and large debris, ensuring greater safety for active satellites and space missions. As the number of debris objects in orbit continues to increase rapidly, combating space debris requires the collaboration of all nations because this is the common responsibility of humanity. Therefore, international cooperation and investment in active debris removal, establishing and agreeing on a unified international policy for using advanced technology must become a global priority. If countries involved in space exploration do not take strong actions, future generations may experience serious issues with space exploration, so it is time to take full responsibility for clearing our skies.

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