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Review of Active Space Debris Removal Methods

C. Priyant Mark, A.R. Surekha Kamath

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Abstract

This article gives an overview of the active space debris removal methods that are currently in development. Orbital debris removal has become a very critical part of the commercial and scientific space management. It is an aggregating risk which needs to be immediately addressed to prevent loss of spacecraft to debris collision. The various concepts and methods which tend to bring the accumulating risk to a halt have been classified and reviewed. They are classified into collective, laser-based, ion-beam shepherd-based, tether-based, sail-based, satellite-based, unconventional, and dynamical systems-based methods. The dynamical systems-based method is a contemporary concept, which is developing at a rapid pace. Recent trends were analyzed to ascertain the evolution of the active space debris removal programs. State-of-the-art methods are essentially required to address the various sizes of space debris that need to be removed. This brings a huge opportunity in the area, which includes discovering commercially viable options, cleaning orbital regions, and optimizing crowded satellite orbits.

Introduction

The space environment beyond low Earth orbit (LEO) is teeming with space debris. These debris are mostly the remnants from human-made objects such as dead satellites, used rocket stages, and particles from the collision of other debris. Space debris was not considered an issue around 50 years ago because little was known about the practical applications of space above the stratosphere. Today, the world is different from what we knew back then. Satellite networks, for example, are an essential part of our life, and more and more satellites are required to enhance their coverage. These enhancements have not addressed the issue of accumulating space junk, which has been collecting in the belt of existing satellite orbits. It has, in fact, raised the risk for existing satellites because of the increasing possibility of collision, which will add even more debris into the belt. This build-up has been classified as the “Kessler Syndrome”, which might turn worse if left unresolved. Each debris particle has the potential to travel at 30,000 km/h relative velocity and can cause an immense deal of damage.

Kessler et al. (1978) [1] predicted the collision risk involved in Earth orbits and the threat's immense magnitude. This article popularized the term “Kessler Syndrome”, commonly attributed to the build-up of orbiting space debris and its multiplication. The accumulation and the cascading effect were further described by Kessler et al. (2010) [2] to clarify the intended definition of the above said term. They discussed the frequency of collisions and the ensuing consequences, which could have a major impact worldwide. They also describe the common mitigation measures undertaken to avoid any catastrophe in the future. Pelton (2013) [3] explains the cascading effect of collisions and how debris generates debris. He describes the international standards that are in place for mitigating debris and for space traffic management, which could become the safety and operational standards for space and stratospheric missions and activities. Pelton (2015) [4] gives the current debris scenario, which is estimated to be around six metric tons and number about 22,000 tracked objects. There are two prominent debris addition events which have been recorded in recent history. These are the antisatellite missile test (2007) which downed the Chinese Fen Yun 1C satellite and the collision of Kosmos 2251 and Iridium 33 (2009). Despite the progress in developing the guidelines for debris mitigation, there is a serious lack of policy to outline the removal aspect. To have a clear picture of where the active debris removal (ADR) concepts stands, there arises a need for a compilation of all the recent work done. Hence, a review of all the major concepts has been compiled in this article.

The different methods which have been envisioned to clean the frequently used orbital regions are classified in Fig. 1 and are elaborated further below. Each method varies in the aspect of implementation, philosophy, and design. A limited set of literature in each category has been sampled and reviewed. The sampling was done based on the importance of the work done, which helped moved the concept forward. The sampled data does not represent the total papers on the concept published in a year. But all the methods have been carefully studied and classified based on their core competency. A highlight table is provided after the different methods to show the important parameters of the classification. The figures following the methods highlight the main aspect (milestones), which moved the concept forward with every paper.

Section snippets

Collective methods

Bonnal and Ruault (2013) [5] have compared the findings of different organizations working on ADR projects for entire national d'études spatiales (CNES). They discuss a strategy on sorting and prioritizing debris for removal which includes high-level functions for creating a removal model. Even though they try to answer the question of prioritizing the debris removal aspect, they could not settle on the answer for what has to be actually performed. This still leaves us with a major paradox to...

Observations

Observing the ideas incorporated in every method, the review has thrown light on the important aspects moving the ADR concept forward. Based on the study, significant progress has been accomplished in proving the various concepts associated with the methods, such as collective method, laser-based method, IBS-based method, tether-based method, sail-based method, satellite-based method, unconventional method, and dynamical systems-based method, in the domain of space debris removal. Each concept...

Conclusion

It has been determined that all the ADR systems are at a conceptual/experimentation phase and require more study to be established into commercially viable platforms. Different ventures have already capitalized on the emerging trends to start standalone ADR programs. Based on the focus of research and observations, the tether-based method and dynamical systems-based method are at the forefront. Further on, the concept of a mixture of methods is also catching on. Some of the extraordinary...

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