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A Critical Review on Safe Disposal Techniques of Space Debris

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Authors' contributions

This work was carried out in collaboration between all authors. Author BP designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors KPK and PRM managed the analyses of the study. Author PRM managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

As the development and research work in space is greatly increasing now a days, more and more rockets, satellites, and spacecraft are made to sent in space for the various purposes, which work for proposed years and some of those also may fail to work but they are physically present in the orbit as a junk although they are not for any kind of further use and functioning these are called space debris or orbital debris it includes old satellites, spent stages of rockets, damaged parts of spacecraft's etc. This space debris is increasing very fast in the space and there are chances to get damaged of our working satellites by this debris. So it is compulsory and necessary to track and safe disposal of them to avoid in future accidents and other harmful activities in space. In this paper our focus will be on various safe disposal technologies that may use to dispose space debris.

Keywords: Space debris; satellites; disposal technologies; rockets; spacecrafts; orbits.

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1. INTRODUCTION

All the space agencies in the world are launching satellites, spacecrafts, etc for various purposes which are very much essential for the development in the fields of communications, defense, weather forecasting and space exploration. After the successful launch of first artificial earth satellite Sputnik 1, thousands of satellites has been sent to the space [1].

But, these satellites/ spacecrafts work for the proposed life span or some of them may fail to work due to malfunctioning or some other reasons but they are physically present in the orbit as a junk which are generally termed as space debris/ orbital debris. These debris may include spent stages of rockets, old satellites/ defunct satellites [2], damaged parts of spacecrafts, etc. Space debris can cause a serious problem for any space missions, orbiting satellites or international space stations. Debris in low earth orbit (LEO) and geosynchronous earth orbit (GEO) can be broadly categorized as a function of size [3,4]:

i) Objects larger than 10 cm in LEO and larger than 1 m in GEO: In this category, IADC (Inter-Agency Space Debris Coordination Committee) have included complete spacecrafts, launch vehicle stages, mission related debris, other fragmented debris.
ii) Objects between 2 mm and 10 cm in LEO and between 10 cm and 1 m in GEO: This category of debris include mission related and fragmented debris.
iii) Objects smaller than 2 mm in LEO: These are very tiny debris present in LEO and don't need much attention.

This debris play a vital role in planning the missions of spacecrafts, launch vehicles and it is necessary to remove it as population of debris in LEO and GEO is increasing at tremendously high rate [5,6,7]. Thus, active removal of debris is of the great relevance. To avoid these circumstances, all the space agencies are suggested to follow 25 years safety standard which means that a satellite should lower or raise its orbit to graveyard orbit within 25 years or after the completion of its lifespan [8].

For monitoring the database of the space debris, it is very much important to keep an eye in the sky to look for and document newly arising debris. Techniques used for measurement of debris are broadly categorized as:

1) Ground based measurements, and
2) Space based measurements.

Ground based measurements are then subcategorized as radar measurements and optical measurements. Also, space based measurements are classified as retrieved surfaces and impact detectors and space based debris measurements [9]. Record of characteristics of orbital population obtained from measurements is summarized in terms of catalogues and complete database is prepared and maintained for any future references and research [10]. These databases are very much crucial for the researchers and organizations attempting to provide remedies for space debris removal.

2. SPACE DEBRIS CAPTURING AND REMOVAL TECHNIQUES

There are various phases for the space debris capturing which are launch and early orbit phase (LEOP), far-range rendezvous, close range rendezvous phase, capturing phase and removal phase [11]. These phases are generally autonomously or remotely controlled by ground based mission operations. Capturing phase is very much of important for the complete mission operations. There are many capturing methods has been proposed and these methods are divided into two main categories which are stiff connection capturing methods and flexible connection capturing methods. Debris capturing and removal methods proposed by various researchers till now are categorized below.

In recent years, the active debris removal concept is under discussion, but implementation is quite difficult because of hurdles due to economic impact, political and legal issues [12,13]. Plenty of methods for space debris capturing and removal methods are suggested by various researchers, but till date not even single debris has been removed using any of these methods. On 28th February, 2014 JAXA launched a "Space Net" satellite for demonstration of debris removal which was only an operational test. Some of the popular debris capturing and removal methods are described here.

2.1 Ion Beam Shepherd Technique [14]

It is contactless debris removal technique [15] in which highly collimated neutralized plasma beam is ejected on debris lowering/ raising its altitude.

Table 1. Orbital population till February 2, 2016 [16]

Source	Payloads				Debris			All		
	On orbit	Decayed	Total	Active	On orbit	Decayed	Total	On orbit	Decayed	Total
All	4, 146	3,129	7,275	1,484	13,397	20,646	34,043	17,543	23,775	41,318

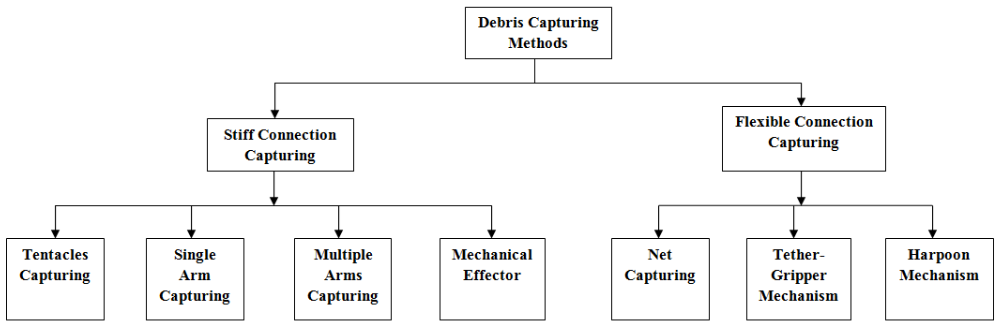

Fig. 1. Debris capturing methods [17]

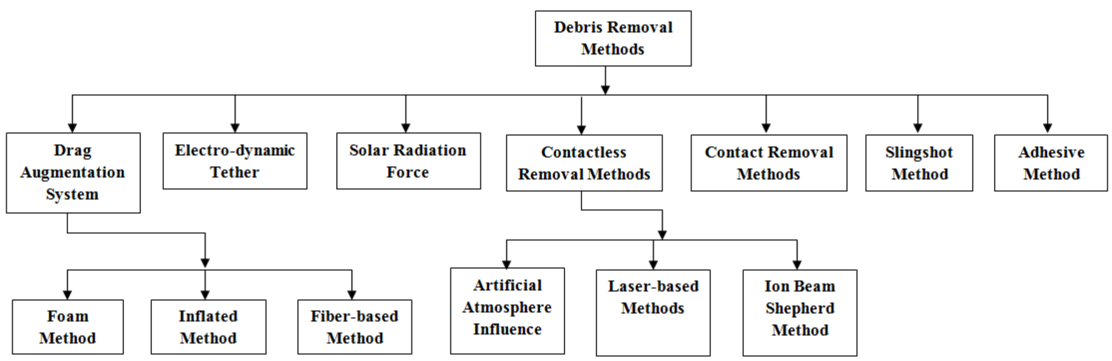

Fig. 2. Debris removal methods [17]

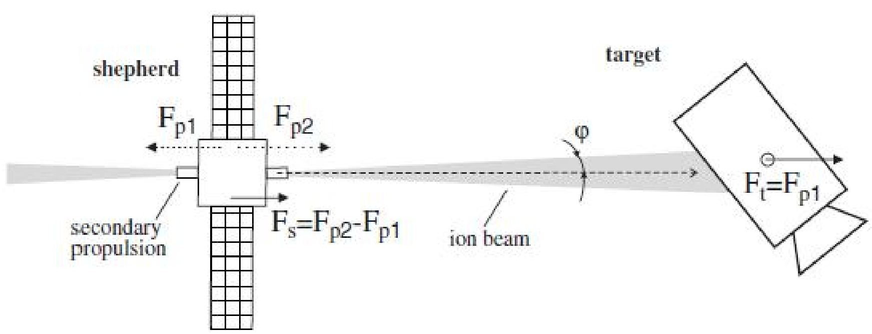

Fig. 3. Schematic of ion beam shepherd satellite deorbiting space debris [14]

Shepherd satellite is equipped with primary propulsion system which emits highly collimated quasi-neutral plasma beam towards space debris in order to apply a force through the momentum carried by plasma ions. Neutralized plasma beam is used to avoid the net charge on spacecraft. This technique provides an efficient method for contactless space debris removal [18].

Fig. 4(a). Schematic of net capturing method [19]

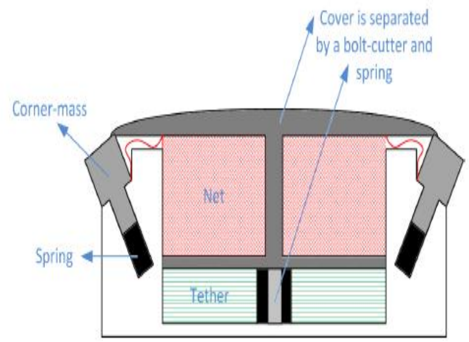

Fig. 4(b). Net ejection technique using canister [19]

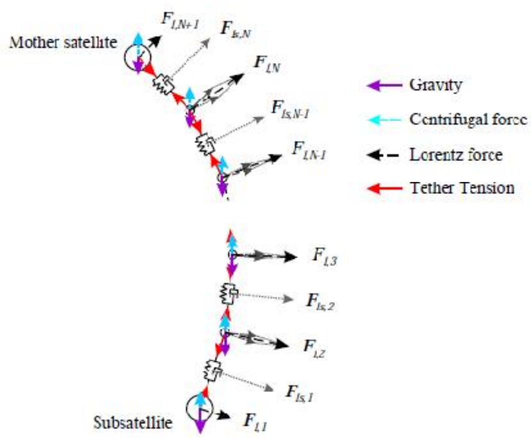

Fig. 5(a) Flexible Electro-dynamic tether [21]

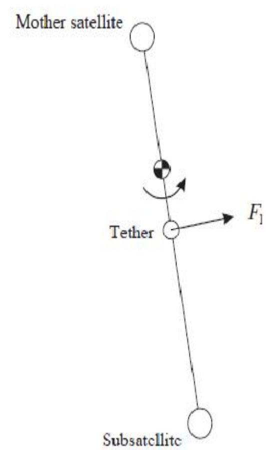

Fig. 5(b). Simple Electro-dynamic tether [21]

2.2 Net Capturing Method [19]

It is flexible connection debris capturing technique which uses a canister to eject the net which is thrown on the target to transport it to the graveyard orbit [20]. The net is pulled open by the inertia of the masses in the corner having relatively higher mass compared to that of the net. This method have several advantages over other methods such as allowing larger distances for capturing, close rendezvous and docking is not necessary, one of the cheapest method, and no necessity bulky components.

2.3 Electro-dynamic Tether Method [21]

It is also a flexible debris capturing technique which contains plasma contractors at both ends of the tether. It allows the flow of current in both directions. One electrode collects electrons and other emits electrons to generate the current. Tether is usually multi-stranded to protect it from damages from debris impacts. Tether material can be made up of aluminum for light weight construction. There are two types of models conveyed by the author simple electro-dynamic tether model and flexible tether model.

2.4 Laser Based Methods [22]

It is contactless space debris removal method in which small and large size debris can be removed by shooting a pulsed laser onto the object which decreases its velocity and changes its altitude to move it graveyard orbit. Due to the use of high intensity lasers there is a possibility of ablation of debris surface which can further increase the number of debris. There are generally two types of methods suggested by researchers first one is ground based laser technique and other one is space based laser technique. However, it is more convenient to use space based laser technique.

2.5 Robotic Arm Capturing Methods [23]

It is one of the stiff connections capturing method in which a robotic arm technology is mounted on a small satellite/ chaser spacecraft to capture the target. It can be used for both cooperative and non-cooperative objects. Non-cooperative tumbling targets are not so easy to capture by robotic arm technique, it offers a bigger challenge in planning a mission to capture these types of targets. Single arm and multiple arm techniques can be used to capture multiple debris at a time. Robotic arm technique is used in several on orbit servicing missions such as ETS-7 of JAXA.

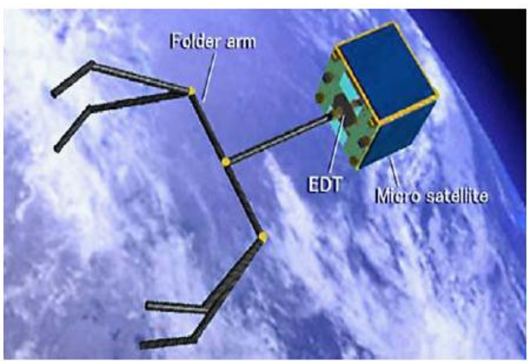

Fig. 6. Space debris remover satellite using robotic arm technique [23]

2.6 Drag Augmentation Removal System [24]

It is a debris removal method in which drag of the object is increased by enhancing the area to mass ratio of the object. There is no necessity of close range rendezvous as this method allows larger distances between chaser and target. Various sizes of debris can be removed by using this method. There are three methods proposed by researchers, first one is foam based method, second is fiber based method and third one is inflated method.

In foam based method, chaser satellite ejects foam onto the target which sticks on the target and covers it to make a foam ball. In Fiber based method, a fiber is extruded from a heat source and wound on the target. Principle of working of this method is similar to foam based method, the only difference is that it uses fiber instead of foam. Inflated method is similar to foam method, in which foam ball is replaced by inflated ball. Inflated ball can be attached on board or on a space debris object.

3. CONCLUSION AND FUTURE SCOPE

Several methods of space debris capturing and removal methods are discussed in this paper. Various methods have been suggested by several researchers but not even single debris has been removed from the space because of the mission complexity and high cost of mission. It will be convenient to design a specialized spacecraft having 25 to 30 years of mission for safe disposal of the space debris. This spacecraft will track the debris in the space and dispose it and further repeats the same process for other debris till its life span.

Removal of these debris is very much essential to lower population of debris than the current environment [25].

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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