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STUDY OF CURRENT SCENARIO & REMOVAL METHODS OF SPACE DEBRIS

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ABSTRACT

Space debris, is a major concern over the space that occurred in the present day as an ever-growing orbital population. To eliminate a space debris object from its orbit, many techniques have been proposed. This space debris is accumulating at a high rate and chances of damaging of working satellites are quite possible. So, it is essential and necessary to track and remove the space junk to avoid accidents and other harmful activities in and around space. To eliminate space debris from the Earth's orbit with the help of different technologies, is posing challenge to researchers. Active Debris Removal (ADR) has become a very significant part nowadays for scientific and commercial space management. Many concepts and methods, which tend to bring the accumulating hazard to a halt have been classified and reviewed. In this paper, the focus will be on various safe disposal technologies that may use to prevent loss of spacecraft to debris collision. This space debris plays an imperative role in planning the missions of spacecraft, launch vehicles. This paper illustrates the recent technologies and current scenario of active space debris on earth orbits. In the prospect, space debris can be caused by collisions along with satellite and spacecraft as the number of orbital objects persevere to evaluate at a rate superior to the rate at which ordinary forces take away from orbit.

KEYWORDS: Space debris, ADR, LEO, Removal Technologies & Orbits

Original Article

1. INTRODUCTION

Space debris poses a major operational risk for aerospace missions. Active space debris has been predictable as a risk factor to any space operations. Agencies and concerned personnel are bothered with the growing amount of space debris. Also, it includes owners and agencies that launched the manned missions and expensive satellites into the space [1]. Considering the growing risks, some nations began to take proactively step to diminish the formation of debris or protect assets from debris.

The aim of this paper is to evaluate the various ongoing technologies proposed for space debris elimination. The debris is one of the major causes of a reasonable and protected space exploration. Space debris is usually lethal when it is close to the Earth at Low Earth Orbit (LEO) and Geostationary Earth Orbit (GEO) [2].

At present, approximately 950 operational satellites [3] in our earth orbit and three areas hold 95 percent of outfitted satellites as depicted in fig. 1.

- Low earth orbit (LEO): 300 to 2,000 km altitude, 7 to 8 km/s orbital speed, 1.5 - 3 hour period.
- Semi-synchronous: 20,000 km altitude, 4 km/s orbital speed, Navigation satellites, 12 hour period.
- Geosynchronous: 36,000 km altitude, 3 km/s orbital speed, Communication or broadcast satellites, 24 hour period.

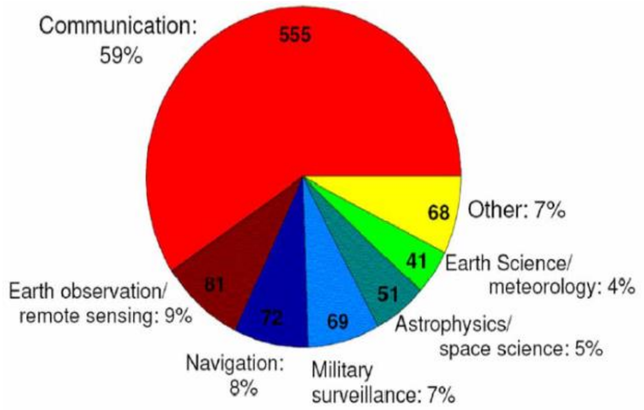


Figure 1: Currently satellite used for various areas [3].

Fig.1 demonstrates the compilation of space junk orbiting over space. Satellites are used today for communication and navigation. Therefore the demolition of satellites may lead to a crisis in the world economy as well.

The United States Space Surveillance Network (USSN) reports more than 21,000 objects that have larger than 3.93 inches of orbiting Earth [5]. Additionally, there are predictable 500,000 bits and also pieces of space junk are in range of 40 inches and 3.93 inches in size.

Space debris is the most prominent environmental problem related to space activities and it becomes a serious threat nowadays [10]. A large number of satellites in our earth orbit is gradually increasing and will ultimately be creating a serious hazard in space activities. Presently millions of space junk orbiting the Earth at speeds up to several kilometers per second. All space agencies in the world are launching satellites, spacecraft, etc for various purposes which are very much essential for the development in the fields of communications, defense, weather forecasting and space exploration.

2. CURRENT SCENARIO: HISTORICAL GROWTH OF SPACE DEBRIS

The first-ever launch to orbit, Sputnik 1 happed on 4th October 1957 [6]. Thousands of satellites have been sent to space [6] and opened the field to all the space applications and eased livelihood. Our daily lives depend more and more on such applications which turned out to be compulsory and strategically for climate, telecommunications, localization, security and defense, science. As a result, more than 65 years different space agencies are launching spacecraft into Low Earth orbit (LEO); this becomes a quite serious problem

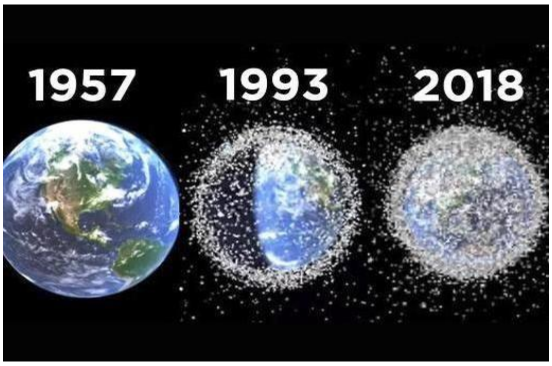


Figure 2: Space junk is growing up from 1957 to 2018 [7].

In the middle of 1957 and 2018, approximately 4600 launches have set somewhere in the range of 6000 satellites into space.

Along with these, 400 satellites were propelled past Earth into interplanetary order [7]; however the staying ones just around 800 are outfitted means typically 85% of space objects.

Figure 3: Manmade objects that are left in the space [10].

Orbital debris is man-made objects that are left in space, caused by a variety of reasons, as shown in fig. 3. Space debris is not consistently distributed on the entire space, certainly they move into the more common launch target regions, in particular in the LEO and GEO regions, as depicted in figure 3.

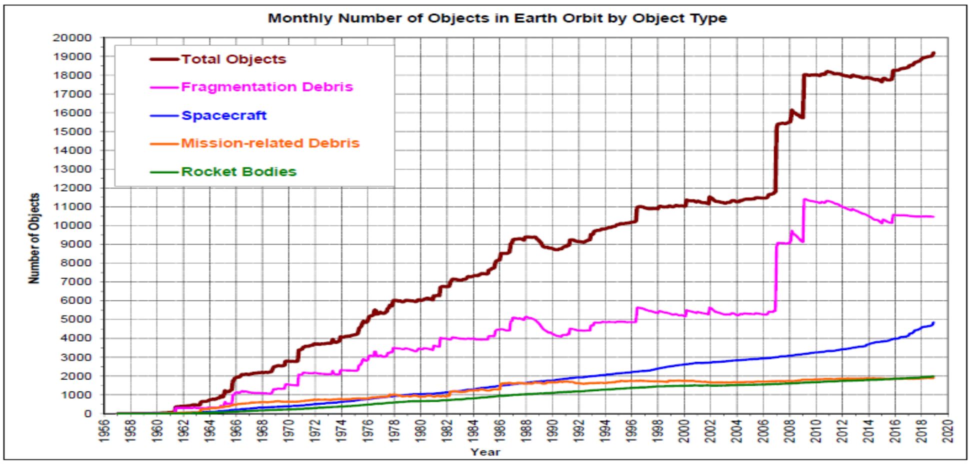


Figure 4: Evaluation of Number of Objects in Space over the Last 60 Years (NASA Orbital Debris, Quarterly News May 2019) [11].

The above graph demonstrates evaluation of the mass and quantity of objects within Earth orbit. Fig. 4 [11] demonstrates monthly numbers of cataloged objects in Earth Orbits. These graphs describe an overview of entire essence in Earth orbit listed by the US Space Surveillance Network (USSN) [10]. "Fragmentation debris" is the satellite and spacecraft fragments Junks and present over space in millions. The Earth orbit is an exceeding predicament by cluster parts of active space debris. Till May 2019, the quantity of debris present in the earth orbit is demonstrated by ESA using arithmetical model. To rundown of the entire objects in Earth orbit as suggested by the U.S. SSN (NASA Orbital Debris Program Office, 2019).

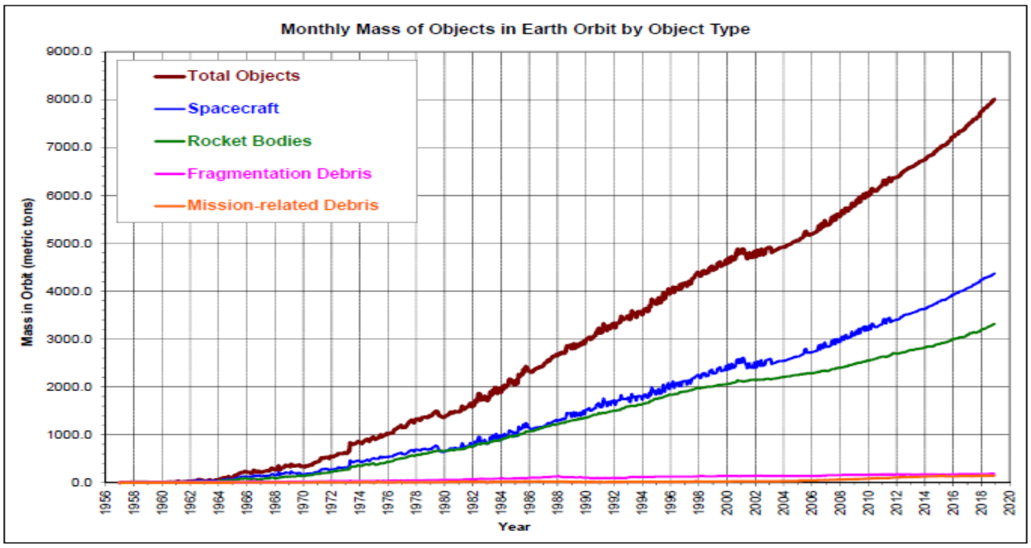


Figure 5: Illustrates the month to month mass of objects in Earth Orbits [10].

The graph shows the mass of entire particles in Earth orbit authoritatively classified via U.S. Space Surveillance Network. Mass of spacecraft in orbit is increasing nowadays and it can create a serious problem in space missions. A number of rocket bodies also are increasing day by day over space.

Space track of earth satellite population by 4th July, 2018 represents in percentages ranges related with foremost RSO-type classifications as explained in fig. 6. The total numbers or percentage is liable to pose constrains to track or record debris in extremely elliptical and deep-space orbits.

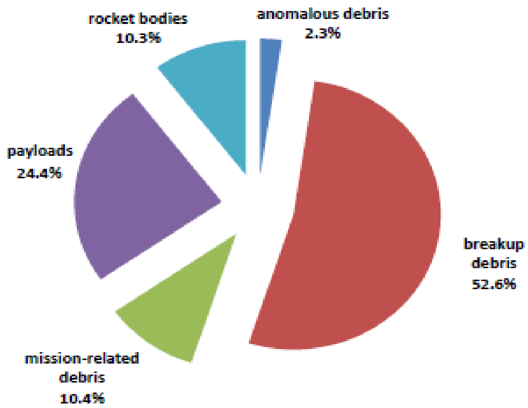


Figure 6: Space-Track of Earth Satellite Population (4 July 2018).

Union of satellite updates database three times a year. Further 1,950 active satellites are now orbiting in Earth, as listed in table 1 and plenty more could rapidly be joining them [5].

Table 1: Total Number of Operating Satellites till March 2019

Country wise	Orbit wise	Area wise
United States: 901	LEO: 1,338	Government: 164
Russia: 153	MEO: 125	Civil: 38
China: 299	Elliptical: 45	Commercial: 523
Other: 709	GEO: 554	Military: 176

United States has launched maximum number of operating satellite till 2019. Basically more number of satellite launch for commercial purpose in elliptical orbit. Orbit wise LEO regions have maximum number of operating satellites are 1,338. As of March 2019, total numbers of satellites are 2,062.

3. SPACE DEBRIS REMOVAL REFERENCE SCENARIO

Recently, the research confirmed that space debris is gradually becoming a very crucial issue for the prospective use of outer space [12]. Several studies suggested that the number of objects in orbit might grow and appropriate collisions are caused by fragments produced by other collisions. This feedback collision consequence highlighted for the first time in 1978 by Kessler and Cour Palais [13] and has turned into popular as Kessler syndrome still devoid of ever having had a severe definition [14].

- It is feasible to categorize the growth progress into three major phases [4-15]:
- 1960-1996: The growth is roughly linear at a rate of 260 debris per years.
- 1996-2006: The growth is approximately linear, most likely due to execution of debris mitigation.
- 2006-2010: which two impact events fashioned more than 1250 debris per year.
- 2006-2019: the growth is fashioned more than 2,062 debris per year.

Collision risk in orbit generate different consequences: it is no longer a problem of safety, but a commercial risk associated with the damage of active satellites, useful or often fundamental in our day to day life. A collision between small debris, un-cataloged, and an active satellite can cause the functional loss [16] of the spacecraft. Indeed, the kinetic energy released during a collision is being extremely high.

Table 2: Present Estimation of Debris in Orbit [17]

Debris	1 to 10 cm	Less than 10 cm
LEO Debris	400000	14000
Debris at all altitudes	750000	24000
Total	1150000	38000

An object can be tracked only if its size is larger than a given threshold. In order to define this threshold, it is possible to classify space debris in three categories [15]: small, medium and large. Spacecraft can avoid possible collisions with large debris by maneuvering well in advance because large debris is traceable. Collisions with small debris can be protected by shields; however, those with medium debris can cause lethal damages to spacecraft.

Table 3: Overview of the Operations of Space Debris

Physical Size	Comments	Comments
Less than 10 cm.	Tracked and no efficient shielding	Absolute obliteration
1 to10 cm.	Bigger objects may be tracked	Severe damage or absolute destruction
Less than 1 cm.	Can't tracked and Valuable shielding exists	Chances of damage

Space debris also classify in three groups by size as listed in table 3. Debris less than 5 mm are cataloged as small and are considered non-traceable, debris between 5 mm and 10 cm are medium, again non-traceable and debris bigger than 10 cm is cataloged as large. The large debris is usually traceable.

4. ACTIVE SPACE DEBRIS REMOVAL METHODS

There are several space debris removal concepts such as ESA's drag augmentation method, JAXA's electro-dynamic tether method, and solar sail propulsion method, and Texas A.M University's slingshot method, which motivated this research [30].

Active removal are often additional efficient in terms of the amount of collisions prevented versus objects removed, once the subsequent principles are applied for the choice of removal targets [32], which may be used to generate a criticality index and therefore listed, accordingly:

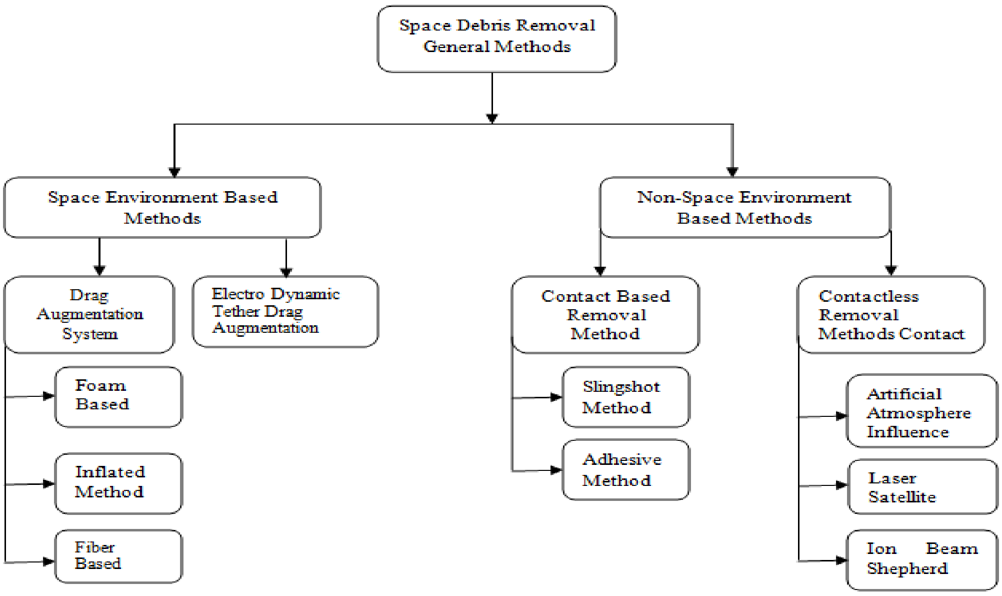


Figure 7: Space Debris Removal General Methods.

The chosen objects should have a high mass (they have the biggest environmental impact just in case of collision)

- Should have high collision chances (e.g. they must be in densely inhabited regions and have an outsized cross-sectional area)
- Should be in high altitudes (where the orbital period of time of the ensuing fragments are long).
- Therefore, space debris removal methods are diverse from capturing methods and classified into two forms namely space environment based methods and non-space environment based methods as depicted below in fig. 7.

The most significant and capable removal methods are Electro-Dynamic Tether (EDT), Drag Augmentation System (DAS), contactless and contact-based removal techniques [32]. Space Environmental based methods consist of Drag Augmentation methods and Electro Dynamic Tether drag Augmentations.

4.1 Drag Augmentation System

The ESA Clean-Sat program Cranfield University [29] is growing family of drag augmentation system modules to alter small satellites in Low Earth Orbit (LEO) to accommodate space junk mitigation is the need of the hour. The purpose of this technique is to throw out some substances through very small density. Therefore, arrival is needed using this methodology and space debris supporting this conception is introduced.

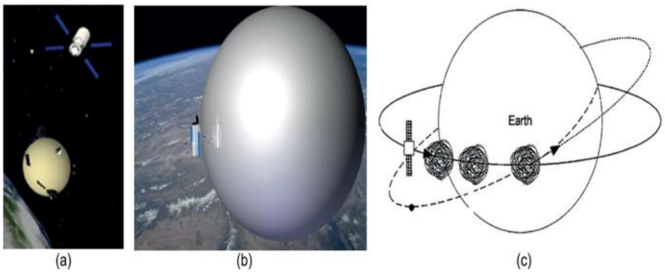


Figure 8: (a) Foam Based Method [29], (b) Inflated Based Method [30] (c) Fiber Based Method [31].

It is a debris removal method, in which drag of the object is increased by enhancing the area toward a mass ratio of the objects. 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, the first one is foam based method, second is a fiber-based method and the third one is inflated method.

In foam-based method [29], 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 resource on the target. Principle of working of this technique is related to foam-based method; the only difference is that it uses fiber instead of foam. An inflated base method is similar to the foam based method, in which foam ball is replaced [30] by an inflated ball. The inflated ball can be attached on board or on an active space debris object.

Fiber based elimination strategies employed fibers to remove a space debris object over space. The regulation of fibers removal method based on the exclusion methodology proposed to remove debris [31].

Each one of these three strategies can be supported presenting their pros and cons but, as a matter of fact, the second one represents the most viable option. Indeed, a strategy aimed to target each one of the millions of debris represents a huge task in terms of time and technical requirements.

4.2 Electro Dynamic Tether

This method consists of a clean semiconducting tether [33] and two field electrode array cathodes using the power of electricity. Developed by EDT, JAXA primarily uses the geomagnetic field to re-enter the Earth's atmosphere [33].

EDT the system contains plasma contractors at each end of the tether, to alter current to flow in both directions [34]; additionally, the EDT removal technique was once employed within orbit transfer and orbit maneuvering [35].

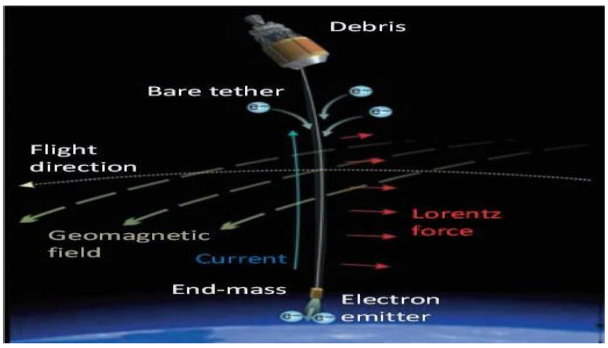
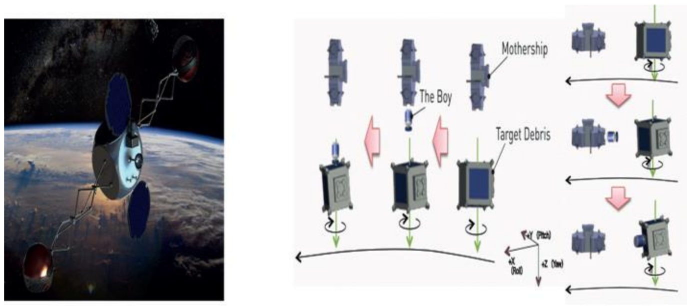


Figure 9: Working principle of Electrodynamics Tether [36].

This technique is a formative debris capturing technique, which consists of plasma contractors at both split ends of the tether system. It permits the flow of current in both side of tether. First electrode collects electrons and second radiate electrons to produce the current [33]. Tether is usually multi-stranded to protect it from damages from debris impacts. Aluminum material is used in tether for their light weight construction.

4.3 Contact Based Removal Methods

These methods introduced the removal techniques from space surroundings to remove space debris from Earth orbit. Further, non-space surroundings based techniques are often separated into two major two categories: contact-based and contactless removal methods. Contact based technique could be constructed that takes benefit of an immediate interface among the software-based chaser satellites and spacecraft to target throughout the elimination methods of space debris [38]. The sling-shot technique and also adhesive technique are two classic removal methods of space debris over space.



(a) (b)

Figure 10: (a) Slingshot method [39] (b) Adhesive method [43].

4.4 Slingshot Method

Sling-Sat based may Remove Space Junk developed by the University of Texas as the name of “Sling-Sat Space Sweeper". It is intended to remove several targets of debris in a single launch of satellite and reduction of energy for ADR [39]. Also, confine a space debris objects and try to emit it towards over space. Then it slides to different debris objects and exhibits the momentum accomplishes from the expulsion [44]. The ‘Sling-Sat is Space Sweeper’ based on two collectors associated by same number of detachable masts, which are tri-scissors used in this method.

4.5 Adhesive Removal Methods

The adhesive methodology is projected by the “Astro Scale” in Singapore for finding the solution of orbital sustainability [45]. In this technique, a de-orbiting kit outfitted with a propulsion module is often discharged from a shipper. The de-orbiting kits six in number plunging space junk then remove it from its main orbit. On the fore component of the kit [42], a plate including silicon adhesive multipart is installed through a universal joint which comprises 20 degrees allowance for targeting the desired surface. By adopting this methodology, approximately 1% - 2% tumbling rate can be achieved.

4.6 Contactless Removal Methods

On comparing contact and contactless based removal techniques, the contactless removal technique is influential. Mostly contactless removal techniques are demonstrated in Fig. 11 is an artificial atmosphere created by ion beam shepherd and a laser system method.

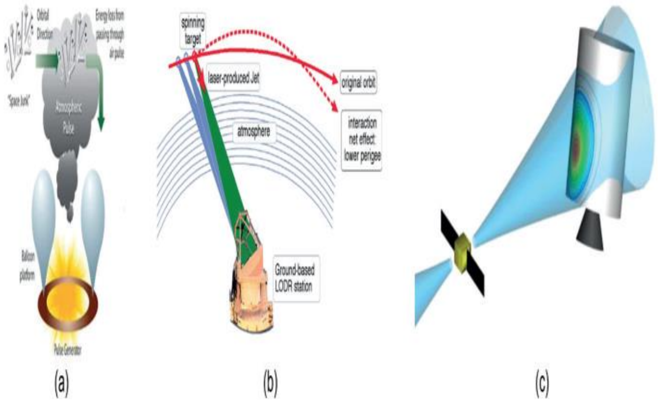


Figure 11: (a) Artificial Atmosphere [47] (b) Laser based system [28] (c) Ion Beam Shepherd [30].

On the basis of the above three removal techniques, laser-based system and Ion beam shepherd may reduce the velocity of debris by ejecting several objects in trajectories consequently dispersing the altitudes. After all, it constantly holds extensive instance to eliminate the debris over space.

4.7 Laser Satellite

It is contactless based debris technique, in which small and large size space debris can be eliminated by shooting a pulsed laser onto the object which in turn reduces its velocity and changes its altitude to move it graveyard orbit [33]. Owing 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 researcher's ground-based laser and space-based laser methods. However, it is more suitable to avail space-based laser technique [50].

4.8 Ion Beam Shepherd

It is a contactless based removal method [51] in which an extremely collimated neutralized plasma beam is expelled on debris lowering or elevating its altitude, as depicted in fig. 12. Shepherd satellite is equipped with a propulsion system which emits a highly collimated quasi-neutral plasma beam with huge momentum towards space debris.

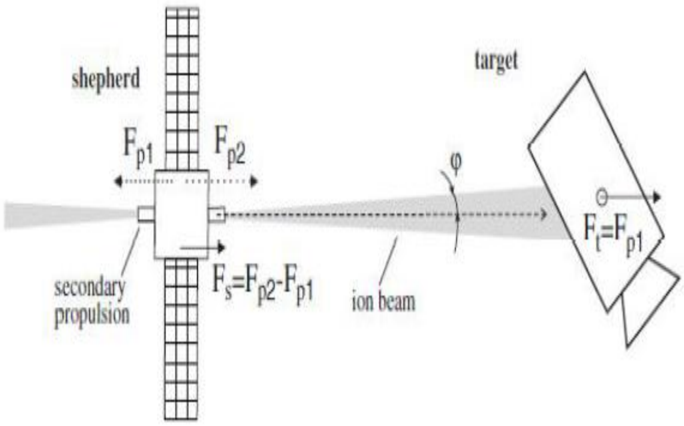


Figure 12: Representation of Ion beam shepherd for de-orbiting space debris [53].

Neutralized plasma beam technique is used to circumvent the net charge on satellite and spacecraft. This gives a competent technique for contactless space debris removal [53].

Table 4: Outline of significant of various removal

Removal Methods	Advantages	Drawbacks	Illustrations
Drag Augmentation System (DAS)	Concur for large expanse; companionable with diverse sizes of space Junk.	Risk of breakup; Less efficient.	Foam
			Inflated
			Fiber-based
Electrodynamics Tether	No requirements for propulsion System; High TRL.	Capture desirable; Unavailable in GEO.	EDT
Contact Based Removal	Numerous targets detached; Short operational period.	Rendezvous desirable; Multifaceted control system.	Slingshots
			Adhesive Method
Contact less Removal	Allows a long distance; well suited with dissimilar sizes of debris.	Less proficient; Partially accessible in GEO.	Artificial Atmosphere
			Laser based system
			Ion Beam Shepherd (IBS)

Various removal techniques of space debris advantages and disadvantages are discussed in table 4 with illustrations. However, researchers have focused on removing traceable debris which can be detected from the ground. Some previous concepts required precise rendezvous and complicated control. Although traceable debris is regarded as sources of new debris and so they are valuable to be eliminated.

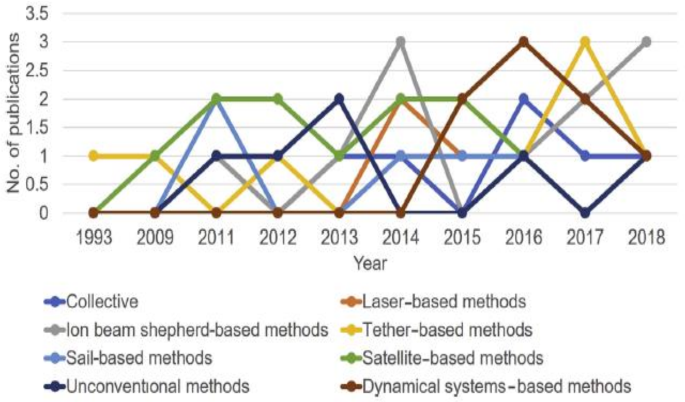


Figure 13: Recent trends on active debris removal methods [56].

The above figure depicted the latest trend on ADR removal methods from 1993 to 2018. The different methods are used to remove the space debris from the orbit in recent years by various researchers and scientists.

5. OBSERVATION AND CONCLUSION REMARKS

This paper presents the brief introduction about the current scenario and most used removal methods of active space debris. Numerous studies have shown that the level of compliance with the mitigation rules should be higher than 90 percent to frontier the growth of space debris in Earth orbit the last past two decades. Almost all removal methods are found to be compatible with unlike shapes, sizes, types, and orbits of space debris.

Various space removal methods have been suggested by many researchers. However, not a single space junk has been eliminated till date form space only because of the complication and high cost of the mission. It'll be convenient to design a specialized artificial satellite having 25 to 30 years of mission for protected disposal of the space junk. An artificial satellite can track the active debris within the space and dispose it.

Small debris is difficult to trace, therefore almost "invisible", hence there is no way to prevent such collisions. Collisions among large objects are very seldom, taking place every 5 to 8 years depending on models, but they generate a large number of new debris, and can, therefore, increase the global risk in orbit significantly. This regeneration effect following collisions raises the risk of the number of debris.

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