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Space Debris Removal in Low Earth Orbit using A Satellite Mounted Mechanical Offshoot

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Abstract—*Removal of space debris is one of the most challenging task that the international community faces today. The debris in the LEO (low earth orbit) exists because of various reasons, few of them are used rocket stages, non-functioning old satellites and satellite collisions. Due to large amount of debris in the critical LEO, every functional satellite and space station faces the risk of impact which can be critically dangerous. This impact creates another set of debris and increases its density in the orbit, posing a threat to the existing and future space missions. This paper presents the idea of debris removal with the help of a mechanical offshoot/arm installed on a satellite. The satellite will be placed in orbit and will be maneuvered by the control room, back here on earth. This will remove the threat of that debris by exerting an ample amount of force on the debris to de-orbit it and make it fall towards earth which will then cause the debris to be destroyed by the phenomenon of orbital decay. The maneuverable satellite will be able to remove multiple debris of size range 10cm to 100cm using this mechanical offshoot at a high rate. This will help in decreasing the density of the space debris over a considerable period of time and securing the present and future space missions from catastrophic failure that may happen with any collision with such kind of debris.*

1. INTRODUCTION

Space debris, better known as space junk or orbital debris is the collection of manmade waste materials orbiting around the earth due to its presence in the Earth's orbit. It may include a part and segment of old and non-functional satellites or the used rocket stages.

1.1 Overview

Space debris is nothing new to the mankind and to the world of space exploration. Satellites have been launched into space right from late 50's till this date. Initially, it was all about Space race, and as a consequence of which, no one thought about the fact that what will happen to it once the satellite is past its predicted life. These modifications came in 80's when we started to get concerned about the increasing traffic density in the earth's orbit, especially LEO and HEO, i.e. the density of satellites present in a particular orbit and its impact on the future missions. The increasing number of satellites meant to have a defined path, so that they don't intersect each other's orbit at any point of time. Otherwise it may result in collision and a subsequent creation of a new space debris. But by that time, it had already become a threat. Today, many of those old satellites, along with the orbital collision between two satellites, and the Chinese anti-satellite missile test in 2007, among others have resulted in creation of uncountable small and big size space debris and now it poses a serious threat to our sub-orbital space missions, and also a threat to the existing satellites in the orbit.

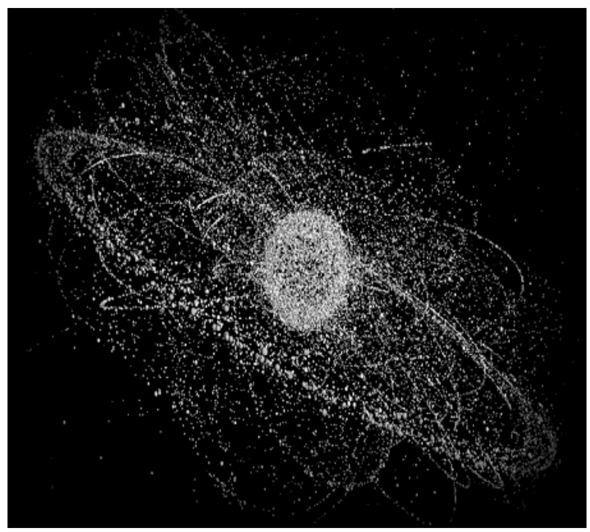

Fig. 1: This image shows the complete map of every single piece of space junk known to us by date. The density is very high causing a threat to present and future space missions.

1.2 Characteristics

Space debris can be characterized based on various factors ranging from size and velocity to the place where it is found in the orbit.

1.2.1. Size

Size of the debris is one of the most important characteristic of a space debris. It can be classified as follows:

i) Small: 1 cm or smaller.

ii) Medium: 1 cm to 10 cm.

iii) Large: 10cm and larger

1.2.2. Speed

It is estimated that a single particle of a space debris is travelling at a speed of 17,500 mph. In terms of kmph, it will almost be 28,000 kmph. With this speed, even a particle of size 1 cm will be enough to cause severe damage to an orbiting satellite.

1.2.3. Orbit

Satellites are placed in different orbits according to its purpose. Ranging from LEO to sun synchronous orbits, there are wide variety options available to us. But each option comes with the risk of increasing the density of debris in that orbit.

i) LEO: Most of the early satellites that were launched were placed in the lower earth orbit, with a maximum altitude of 2000 kms. It is estimated that there are nearly 5 lakh debris in the LEO of which nearly 3,70,000 debris present is of the size between 1 cm to 10 cm while nearly 17,000 debris is of the size greater than 10 cm.

ii) HEO: High Earth Orbit accounts for comparatively less number of debris with estimated number rumoured to be around 40,000.

iii) GEO: Orbital perturbation plays an important factor in the geostationary earth orbit. Although the number of debris is very less in GEO, but whatever is there, its velocity is very much, since these debris are of a satellite which have become derelict. It increases by as much as 160 kmph. Its orbital inclination also increases by almost 8^o.

iv) Other Orbits: It is estimated that a huge amount of debris is also present in other orbits. It becomes a threat to interplanetary missions.

1.2.4. Source

The source of a debris can be anything between a man-made object, like satellites to any natural object like meteorite. Major source of the debris are:

i) Old Satellites: Satellites launched way back in 1958, for example, Vanguard I, is still in orbit and it is known to be the oldest surviving piece of man-made space debris in orbit. In a similar way, there are many non-functional satellites which possess a threat of becoming space debris, increasing the risk of collision with other functional satellites.

ii) Used Rockets: Rockets which are used for upper stages, such as the inertial upper stage actually begin to function in the orbit and once the task is achieved, they detach and remain in the orbit. This become a major debris problem. The Ariane incident is one such example.

iii) Weapons: Destroying the non-functional satellite with the help of anti-satellite missiles have created large amount of debris in the orbit. While such test conducted by US and USSR were at relatively low altitude, most of the debris suffered orbital decay. But the Chinese ASAT created thousands of debris of size greater than 1cm and it is orbiting around the earth at an altitude of almost 800 kms, which is the densest area in terms of operational satellites. These debris possess a great threat to the present and future of space missions.

iv) Lost Objects: Objects such as camera, astronaut gloves, space shuttle equipment, etc possess a great threat to the satellites and being small in shape, they are hard to detect and have greater piercing power.

1.2.5. Orbital Decay

Many theories and ideas have been presented on how to deal with the space junk. But till the time these theories turn into reality, we shall stick to the only available method of removing debris from space and it's a natural phenomenon of orbital decay. Decay is the process of gradual decrease in the minimum distance between two objects in orbit at their periapsis, or the closest distance between the two, over orbital periods. In terms of debris, orbital decay causes the gradual decrease in the altitude of the debris orbit, and eventually burning it out, or making it fall onto the earth's surface depending on the size of the debris. This is the only known natural method of removing the space junk. Orbital decay can be caused due to various factors. Some most prominent causes of orbital decay are:

i) Atmospheric Drag: At an orbital altitude, there is frequent collision between the gas molecules of the atmosphere and the debris. This phenomenon is known as atmospheric drag. It is major cause of orbital decay. As the altitude decreases (from orbit to earth's surface), the atmosphere becomes thick. The increase in the density of atmosphere causes increase in the number of gas molecules which interact with the debris, thus increasing the drag experienced by it. This intend increases the heat, thus either burning out the junk or reducing it to smaller size which then falls on the surface of the earth. As it can be made out from the process, the lower the altitude of the junk is, the faster the decay occurs.

ii) Tidal Effects: If the orbiting body is large enough to raise a tidal force on the body it is orbiting, then it causes to decay the orbit. This is known as orbital decay by tidal effect. This interaction with the tidal force decreases the momentum of the orbiting body and transfer it to its rotation, thus decreasing its orbit till the time atmospheric drag starts to act upon it.

iii) Radiation: For smaller objects in the orbit, radiation plays an important role in decay. The most prominent radiations are thermal, light and gravitational radiation.

2. METHODOLOGY

2.1 Launch and Placement

The basic idea is to install the mechanical offshoot onto a cubic satellite on one of the six faces of the satellite. This can be designed in two ways. One way of designing it, is to make it completely independent satellite which will orbit the Earth, and once it is in the vicinity of the debris, it can operate over it.

Second way is to design the mechanical offshoot as an accessories part, which will then be sent into orbit and with manual support, it can be installed into existing Space Stations, like ISS(International Space Station) or future space stations. This will protect the Space Station and other satellites from the immediate impact of the debris.

2.2 Working

A mechanical offshoot is a type of a mechanical arm fitted with a blunt device on the front of it which will transfer momentum to the oncoming space debris. This will result in a decrease in the velocity of the debris and hence cause it to deorbit towards the earth's surface. This will result in the debris getting destroyed due to the atmospheric drag. Since plastic collisions do not conserve kinetic energy, the debris and satellite impulses are determined according to

$$\Delta V_d = \sqrt{\frac{2m_s\Delta E}{m_d(m_s+m_d)}}$$

$$\Delta V_s = \sqrt{\frac{2m_d\Delta E}{m_s(m_s+m_d)}}$$

where subscripts *d* and *s* correspond to the debris and satellite, respectively. ΔE refers to the fixed energy of the expulsion.The final velocity of the debris i.e the velocity after the impact with the offshoot is given by [1]

$$V_{final} = \frac{M_{sat}V_{sat1}+M_dV_{d1}}{M_{sat}+M_d}$$

where V_{d1} and V_{final} refers to the initial velocity and final velocity of the debris respectively. The system will work such that the final velocity of the debris will become less than the orbital velocity of the debris and hence cause of it to deorbit and then decay in the atmosphere. The momentum to be transferred depends on the orbital velocity of the debris. The velocity of the debris will be measured by the debris removal system with the help of a vision based tracking system mounted on the satellite. The system will then calculate the angle and the magnitude of the force to be applied on the debris with respect to the relative position of the debris with the satellite.

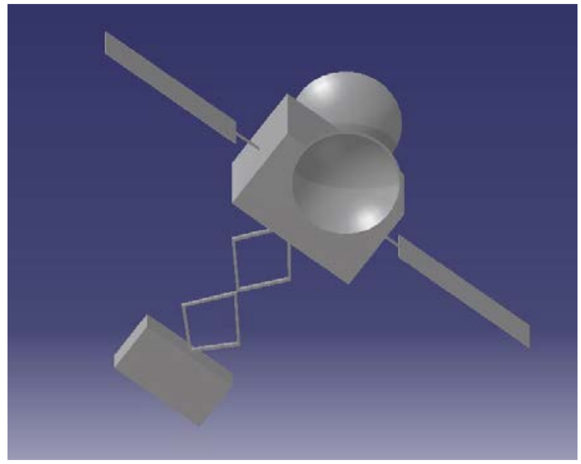

Fig. 2: The satellite mounted with a mechanical offshoot in its extended position. The front of the offshoot will transfer momentum in the such a direction so as to deorbit the oncoming debris.

3. CONCLUSION

NASA and several other space agencies of the world have been working hard to characterize the implications for space debris for the risk of satellites and other spacecraft. It is widely known and accepted that the risk is growing and may be fatal, and before it goes completely out of control, it needs to be dealt with. It is important to limit these risks as it may grow with the growth of space exploration. There still isn't any threshold value, beyond which the threat becomes high, but it is not something for which we can wait and let it happen. The satellite mounted mechanical offshoot can solve the problem of space debris more effectively when compared with other methods of debris removal such as laser debris removal.. We analysed all major aspects of debris removal using a satellite mounted mechanical offshoot and conclude that this method of orbital debris removal will work for all sizes of space debris classified above. Satellite mounted mechanical offshoot can provide target access at the very high velocities. It can also tackle tumbling debris or very fast moving debris and can effectively destroy or deorbit it. This method of debris removal also increases the speed and accuracy of debris removal because of the vision based targeting and tracking system and hence is an efficient way to remove space debris at a low cost. Development and construction of the satellite mounted mechanical offshoot to overcome the problem of space debris offers the opportunity for international cooperation.

4. FUTURE SCOPE

With the advancement of technology, humans have been able to set their feet outside the earth and into space. What once seemed to be a distant imagination has now turned into reality. Ground based laser gun and other methods of debris removal has been proposed and worked upon, and its shortcomings can be overcome with the help of satellite mounted mechanical offshoot. Once fully developed, this will definitely help in decreasing the debris density along with assisting in collision control. It will help us to keep a check on space debris, to monitor them and then to tackle them with high efficiency. In future, if we can increase the the length of the offshoot and the maximum amount of force it can apply by a significant amount, then we can tackle larger debris cleanly and in less amount of time. Further research of this project can also lead to the development of multiple offshoots mounted on a single satellite and increase the speed of debris by great bounds.Future research can also be conducted to improve the accuracy of the targeting system.

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