A Review on Space Debris and Its Detection

Prof. R.H.Vijaylaxmi[1]
[1]Professor
[1]Department of Electronics & Communication Engineering
[1]KLE Dr. M. S. Sheshagiri College of Engg & Technology, Udyambag, Belgaum, India

Abstract— Space debris is non-functional man-made objects in earth's orbit. Their number has increased tremendously and this can be attributed to the number of space launches in the last few decades. Their increasing growth has become a threat to the operational satellites and space crafts. This paper makes a survey of the threats posed by space debris and creates an urge to mitigate them. The paper also makes a review of the detection schemes employed to detect the space debris in order to build models to determine their orbits and to keep track of their population.

Key words: Space debris, satellites, space missions, optical detectors

I. INTRODUCTION

Science has seen tremendous growth and this is evident from the domains like human computer interaction, brain computer interface [1], internet, automobiles, aviation, marine expeditions and ultimately space missions. The man-made non-operational objects of rockets, old satellites or any other material from space missions which revolve in earth's orbit are termed as space debris. The ultimate basis of the generation of space debris of all kinds is the launch of any material in space from the Earth. Fig. 1 shows the usage of satellites for different purposes like earth observation/remote sensing, communication, military surveillance, navigation and earth science/meteorology, astrophysics, etc. The amount of junk in the orbit of earth has increased considerably in the last few years. Approximately, there are more than 19,000 objects in the orbit of earth that are bigger than 10 cm. These are a threat for all current and future space expeditions since they are continuously increasing in number. Though there is scarcity of data of the objects above 2000 km, they have been studied exclusively from the past few decades.

Space debris comprises of non-functional man-made objects which are either large objects like spent upper stages of rockets, worn out satellites or small millimetre sized debris like slag, dust from rockets, weathered paint flakes, etc. Their number is mainly increasing in the region used to operate satellites. Fortunately atmosphere acts as a natural sink for the debris lying in lower altitude levels. Steps to mitigate space debris have been exclusively studied like the ground-based high power lasers (which perturbs the orbits of small objects, thereby forcing them to re-enter the atmosphere); and tethers to de-orbit the larger objects [2]. However, they are either too expensive or are not feasible in the coming decades. Hence the only measure is to limit their production by proper in hand predictions and effective management of weathered objects.

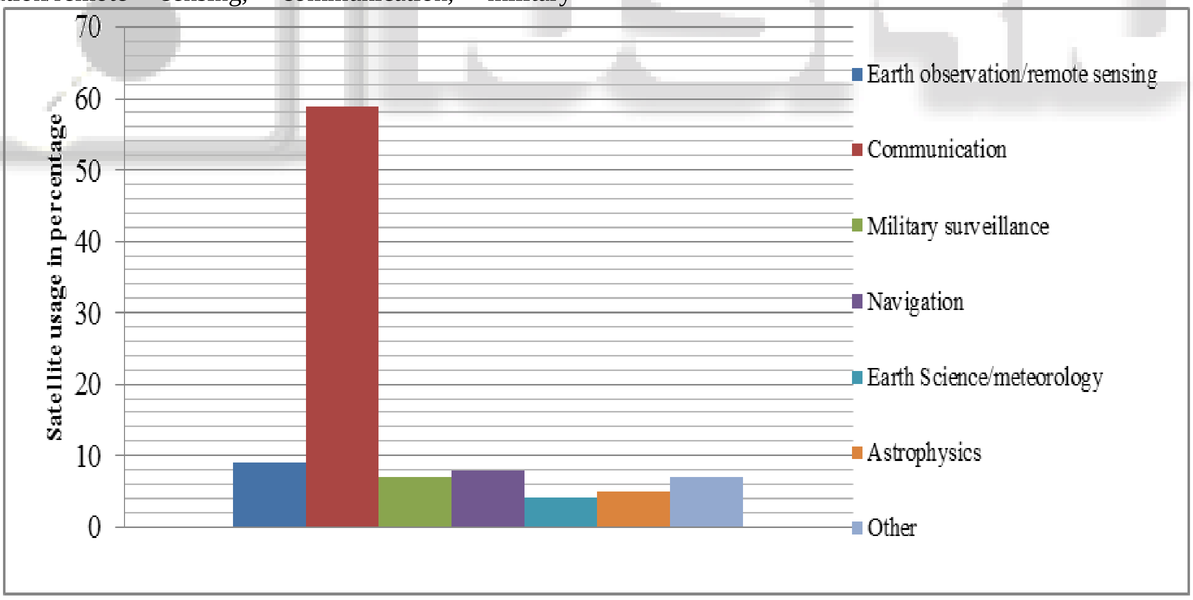

Fig. 1: Usage of satellites for different purposes

II. THREATS POSED

Every day at least one of the larger objects of space debris falls back to the earth along with the many unknown minor debris. During their re-entry, they usually get burnt due to the friction of the atmosphere. However there are instances wherein they have survived their re-entry. According to the UN technical report on space debris 1999, the risk to be hit by a falling debris is surprisingly smaller and this accounts to around one part per trillion per human per lifetime. Fig. 1 shows fragments from the Delta second stage. Though they don't pose any risk to the biosphere, they are inevitably a risk for any space missions as they may hit a larger object as operational satellites or spacecraft. The velocities of space debris in LEO are around 7-8 km/second which can cause severe damage to the active satellites. Only one operational spacecraft named the French Cerise reconnaissance satellite has been hit by space debris up to now. The fragment belonged to the third stage of Ariane launcher (exploded 10 years earlier) [3].

Fig. 2: Two large fragments of a Delta second stage (Courtesy: [4])

Their quantity is increasing every year due to new space missions, collisions and explosions between objects that are both operational and non-operational. Proper space surveillance of space debris in orbit of earth is vital to minimise the risk of collisions between other space debris and satellites. Lots of research has been carried out with respect to optical observations of space debris [5]. Optical telescopes are the most feasible tools to detect them [6].
Different types of debris do exist, for instance:

(1) Historical sources.
(2) Fragmentation debris-collisions and explosions.
(3) Non-fragmentation debris-worn out satellites, solid motor firings from rockets, mission related objects, surface degradations, etc.

III. SPACE DEBRIS MODELLING

The population of the space debris are modelled mathematically since they are a pre requisite to perform risk analysis for any space launch. During the construction phase of any space mission, the impacts of space debris on the design are assessed and suitable measures are taken to either lessen or to mitigate the effect. This involves the selection of a safer orbit or shielding critical components. Models serve as an effective tool to assess the mitigation measures of space debris and their future evolutions. The parameters to these models are the assumptions of the number of future launches, number of satellites, explosions, orbits used, etc. One of the reasons for the formation of space debris is the collision among objects. The models have predicted that within a few decades, if no mitigation measures are undertaken, then, the collisional fragments will become the main source of space debris. Fig. 2 shows the prediction results bestowed by a number of models (for three scenarios). The case A corresponds to the business carried on a normal rate with no substantial growth.

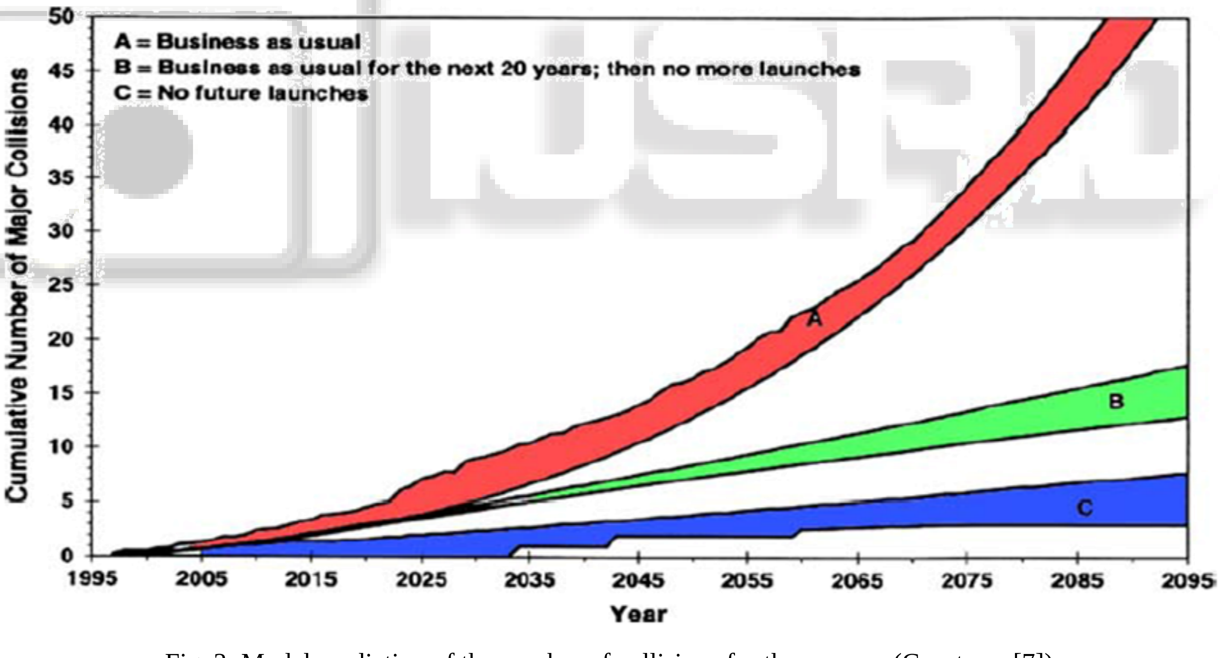

Fig. 3: Model prediction of the number of collisions for three cases. (Courtesy: [7])

IV. DETECTION

Space debris covers a larger space around the earth. Fig. 4 shows their movement around the Earth's orbit with respect to time. Hence monitoring their positions and prediction of their future movements is a challenging task. A lot of research has been carried out in the detection of space debris [8-11]. In [12], 3D rendering and GPU acceleration have been used for this purpose. In [13] a signal processing approach towards the surveillance of space debris is proposed.

Moving objects appear differently on a CCD image. This can be attributed to the following reasons:

A. Brightness:

Object that is bright is obvious whereas faint objects appear too faint that they become invisible beyond the noise until and unless several images are co-added. Sometimes, rapid moving faint objects become undetectable above the noise in a single pixel. They become visible by integrating along their trail. Human eye is efficient in identifying such trails. But the act of automating this by deploying it in software poses a great challenge, especially when the trail curves marginally at the time of exposure.

B. Variation in Brightness:

Some objects have constant brightness whereas other objects like rotating pieces of space debris show large variations by a factor of 10 or even more.

C. Angular Velocity:

Objects that move slowly remain in one pixel; hence it is difficult to differentiate them from stars; whereas objects that move many pixels leave a trail.

Moving objects in space can also be classified based on their motion with respect to the solar system and the earth:

1) Objects Orbiting Around the Sun:

Comets and asteroids orbiting around the sun basically show only small variations from the sidereal rate, since their positions with respect to the stars are fixed. The possible way to detect such images via telescope is by tracking them at the sidereal rate and looking for their motion relative to the stars.

2) Objects in Geostationary Orbit:

Space debris and geostationary satellites have their orbits which are almost fixed in azimuth and altitude at a given site of observation on Earth. These bodies show a periodic motion with amplitude that is dependent on their maximum declination and any orbital corrections that are required.

3) Objects in Low Earth Orbit:

The objects in these orbits move so quickly that only the brightest among these get detected.

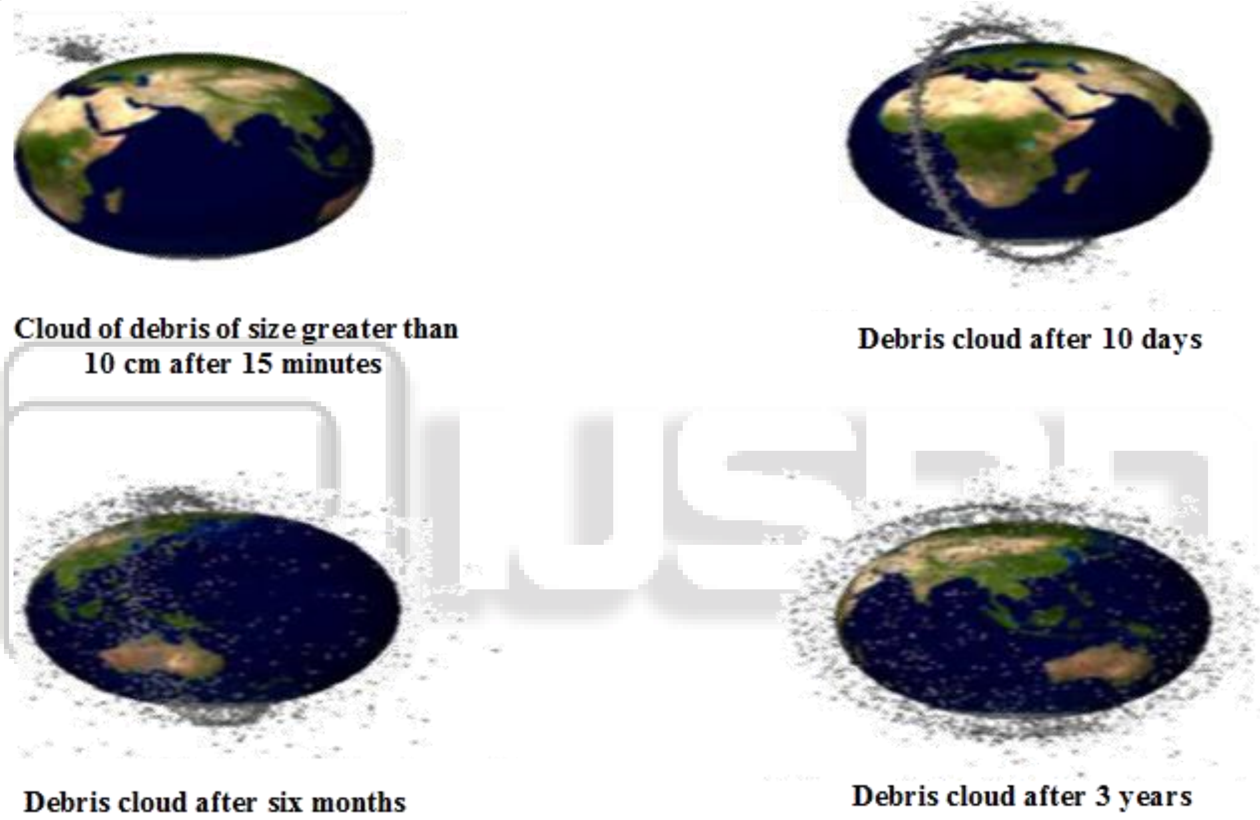

Fig. 4: The movement of space debris around the Earth's orbit over a period of time.

V. DETECTION TECHNIQUES

Different types of detection methodologies imply for the different orbits of the Earth. According to [14], the orbits of Earth can be classified into: Low Earth Orbits (LEOs) < below 2000 km, Medium Earth Orbits (MEO) altitudes around 20000 km, Geostationary Earth Orbits (GEOs) around 36000 km from the ground.

In optical survey methodology, with respect to the stellar background, the space debris appears as objects with higher velocity that may range from a few arc seconds/seconds to higher than about 1000 arc seconds/seconds. They can be detected with optical telescopes when they are illuminated by sun light while the background sky is relatively dark. Their brightness depends on the properties like distance, illumination, size and light reflection at the observation epoch. Hence the telescopes used must consist of fast optics with very large field of view. This results in the focal plane getting large. The most challenging aspect here is the high angular velocities of the objects that result in the limitation of the exposure times to a few seconds. It requires the frame rates of the order of several frames per minute. Hence data acquisition gets as higher as gigabytes of image footage which have to be processed in real time situations. Ground based observations are largely accomplished using either optical or radar methodologies. Radar is appropriate for routine investigations of low Earth orbits (LEO), whereas, optical observations are better than radar for the objects at higher altitudes (mainly in the geostationary transfer regions and the geostationary ring).

For optical surveys to be accurate and efficient, the following features have to be incorporated in the telescopes:

(1) Sensitive detector
(2) Large aperture
(3) Large field of view (FOV)

The size of the aperture determines the cost of the telescope. The classical survey device with a very large

FOV in astronomy is called Schmidt camera, which is conventionally used with big photographic plates. Such devices are quite insensitive when compared to modern solid state detectors like CCDs. Programs to restore the focal planes of Schmidt cameras with CCD mosaics are available. However, the larger the number of CCDs in the mosaics, the greater is the amount of data. Currently, telescopes with sensitive CCD detectors and larger apertures are designed for narrow FOVs of a few arc minutes. In [15], a new Zimmerwald 1m telescope has been developed for the space debris observation. It consists of a 2k X 2k four sections CCD. To achieve automation of the detection of faint moving objects, efficient algorithms have been developed and deployed into an online processing scheme as in [15].

The introduction of effective and robust observation system must include specialized components like advanced image processing algorithms, linking up techniques for observations from moving objects and predicting their physical size and orbits, advanced detectors, sophisticated data acquisition and analysis tools, etc.

There are a number of constraints to be undertaken while performing surveys for space debris in high-altitude objects:

A. *Milky Way:*

The detection technique requires the elimination of star fields without which the area to be scanned gets reduced to an undesirable degree. Hence the Milky Way must be avoided.

B. *Moonlight:*

Moonlight must be avoided since it reduces the detection limit by increasing the sky background.

C. *Shadow From The Earth And The Moon:*

GTO/GEO objects are to be observed close to the Earth's shadow to maximize their apparent brightness and to minimize their phase angle. But they shouldn't be observed inside the Earth's shadow. Space debris in the geostationary ring either enters the Moon's penumbra or the Earth's shadow cone.

D. *Survey Field's Elevation:*

In order to minimize the atmospheric extinction, the observations should be performed at higher elevations.

VI. CONCLUSION

As a summary, the paper draws sharp inferences of the consequences of space debris from the available literature. The growing population of space debris has caused alarming effects on future space missions. Though the available techniques to mitigate them are not quite robust, the only possible solution is to take suitable measures to curb their population and build effective space mission designs so as to escape or sustain the collision from them.

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