"COLLISION AVOIDANCE TECHNIQUE FOR NANO SATELLITES"

1. Background

Recent space debris catalogue, as on October 2016, shows that there are 17,817 objects are present in the Earth bound space in which only 4,257 (24 %) are the operating spacecrafts. The remaining objects existing are the orbital debris formed due to the end of life, fragmentation, collision, launch/spacecraft anomalies and things left by astronauts during extra-vehicular activity. In case of GSO region, there are 1,438 objects out of which, 454 (31.5 %) are controlled in their longitude slot, as reported in [2] during end of the year 2014.

It is evident that the number of satellites in Earth orbit is steadily growing and with the high amount of space debris, either crossing through or resident in orbit, collision probabilities between two such objects can become critical.

and orbit in which satellites revolve in is 350-700 km which is very small.

Traditionally, debris avoidance is performed by operators on the ground. Satellite operators request information about possible collisions from the US Strategic Command (run by the Department of Defense) who tracks all objects orbiting earth larger than 10cm. Other sources for debris objects include the Haystack Auxiliary Radar operated by the Massachusetts Institute of Technology for cataloging debris using Ku-band radar and the Goldstone and Kwajalein for radar based ground debris tracking. NASA also has several optical telescopes that are used for debris tracking. Also, the US Air Force has a network of ground based radar stations, called the Space Fence which detects debris using the S-band radio waves.

The Flight Dynamic and Systems of MCF, Indian Space Research Organization (ISRO), is involved in orbit determination, using ranging data acquired using C-band tone ranging, planning of station keeping maneuvers for orbit control and co-location of spacecrafts. As a part of FDS operations, using the publicly available two line elements (TLE) published in www.space-track.org by United States Strategic Command (USSTRATCOM), close approach encounters between the ISRO spacecrafts and other objects are checked regularly.

For space debris related debris information, two programs used by ISRO, called the Collision Analysis (COLA) program developed by Applied Mathematics Division, Vikram Sarabhai Space Centre, ISRO, India and Co-location Monitoring (COLMON) program developed by Flight Dynamics Division, ISRO Satellite Centre, ISRO, India are currently used . COLA program provides the time of close approach, minimum distance and TLE age and COLMON (Co-location Monitoring) program includes the inactive object (debris) as one of the participating spacecraft in co-location.

Satellite operator's use the data collected from all these sources to determine if their satellite is at risk of being hit by space debris and calculate avoidance maneuver if necessary. Tracking data collection for the operational spacecraft is sought from the ground station network for orbit determination. Collision avoidance maneuver is planned for the operational spacecraft based on the minimal delta velocity at an optimal time, required to achieve a safe distance. Impact on the existing co-location due to collision avoidance maneuver on orbit maintenance and control is also analyzed. Once the maneuver planning is finalized, details are sent to the Spacecraft Operations Team for further actions

Although much of this process is automated by commercial software, it still requires advanced planning and lots of man hours. As the number of active satellites in orbit grows and satellite constellations get larger, satellite operators will require more people to handle the debris problem.

Small satellite missions usually operate with limited capabilities when it comes to locating potential collision occurrences and avoiding collision. The mission of most nano satellites and pico satellites is relatively short, of the order of several months to years, although some have operated for over a decade. The time that will elapse before any satellite decays from orbit is highly dependent on orbital characteristics and spacecraft design, and may be as little as a few months or as long as a few decades. Just like larger satellites, nano satellites or pico satellites that operate for only a matter of months can present a risk of collision with operational satellites and other orbital debris for decades.

Though these programs help mitigate the issue of space debris, non-operational satellites in orbit have become an increasing collision risk for operational satellites and this problem is expected to become even worse as the number of satellites launched every year increases. Furthermore, as more and more smaller satellites are launched, it will be extremely difficult to just rely on ground based operators to navigate small or nano satellites through the ever increasing clutter of space debris. Therefore it becomes imperative to supplement ground based space debris detection and navigation systems with satellite onboard autonomous for more effective collision avoidance.

Given the amount of space debris that is increasing every year, it has become a very challenging task for smaller satellites to avoid colliding into space debris. Satellites need to be able to autonomously detect and avoid colliding into space debris, without requiring human intervention. Given the number of smaller satellites that are getting launched every year and an equal no of these satellites getting decommissioned, its becomes imperative to come up with a strategy to mitigate the risk of such small satellites either encountering space debris

This proposal tries to address this concern and provides an approach for implementing an autonomous collision avoidance system on board the nano satellites. This provides advantages such as reducing the number of operators needed to maintain a satellite or a large no of satellites thus reducing operating costs. With the increased amount of processing power on modern satellites, this system is possible with current technology.

2. Challenges in Nano Satellite Navigation

For bigger satellites, navigating around space debris is carried out by firing its thrusters which use either liquid or gas as a propellant. However, storing liquid and gas propellants usually take up 50% of the total weight of the satellite. So for example a 3U cubestat, 1.5U is usually occupied by the propellant. This is not a problem for micro satellites weighing about 100kg or more, where the propellant weighs about 50% of the total weight or 50kg. However for nano satellites, weighing only 1 to 10 kg, there will be a serious space and weight constraint to accommodate both the payload and the propellant.

Due to size and weight constraints, most nano satellites and pico satellites have not included propellant or maneuvering capability, and, once injected in orbit, have limited or no autonomous maneuvering or station keeping capabilities. Consequently, as with larger satellites that lack maneuvering capabilities, the orbital elements of nano satellites and pico satellites will decay naturally over time and cannot be intentionally changed.

3. Approach to autonomous debris collision avoidance in nano satellites

For successfully avoiding a collision, the satellite has to first be able to detect very early on, whether there is space debris that it may collide into. Secondly, once the space debris has been identified, the probability whether the satellite will collide with it or pass by has to be ascertained. Finally, after identifying the space debris, the bigger task for the satellite is to successfully navigate around the debris either by making attitude control adjustments or by raising or lowering its orbit.

For nano satellites to detect space debris early on and then navigate itself safely away from the debris, the following subsystems will be needed:-

- **Space Debris Autonomous Obstacle Detection Subsystem :** Sensors such as ultrasonic sensors, camera or Lidar technology to detect the debris that is in its orbital path
- **Thrusters for Propulsion Subsystem :** Some kind of thrusters that are very light weight to raise or lower the orbit of the nano satellite so as to avoid colliding with the space debris in its path

4. Space Debris Autonomous Obstacle Detection Subsystem

Typically the most commonly used sensors for autonomous obstacle detection have been ultrasonic sensors, cameras and Lidars (Light Detection and Ranging). However, in space, using ultrasonic sensors is not as option since ultrasonic sensors require a medium to travel in and hence cannot travel in vacuum. Cameras are better for obstacle detection, since Field of Vision (FOV) is very high. Just one image can give the shape, size and distance of the debris. However image processing requires more computational power. Also, since the lighting conditions can vary a lot, the quality of the image may be quite poor. Recently, Lidars are been used extensively in the automobile industry and space, for collision avoidance. The main advantage of using Lidars is that they have a very good range of a few kilometers, unlike ultrasonic sensors. Another advantage that Lidars have over conventional cameras is that it can detect obstacles even in very poor lighting conditions.

a. About Lidar Technologies

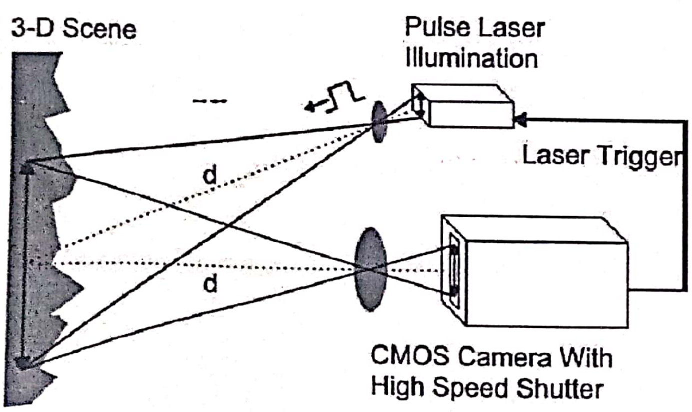
Relative navigation is a key functionality for emerging new mission needs in automated rendezvous and docking, active debris detection and removal, collision avoidance and lately in satellite formation flying. Usually stereo vision, monocular vision and LIDAR (light detection and ranging) sensor are the sensor types used in collision detection in space applications. Stereo vision approaches provide measurements of high accuracy at a high rate, but their working distance is limited to the baseline and the computational requirements increase with the increase of resolution. Monocular vision lacks of depth information, it often needs other additional information. LIDAR sensors, which output is the point cloud data, are robust against lighting changes. Each point cloud data contains a range vector in the sensor frame. In recent years, flash LIDAR is gaining popularity for pose estimation.

Different from scanning LIDAR which employs a scanning device to collect one point cloud data at a time, flash LIDAR can collect the entire point cloud data image at once. This characteristic helps reduce distortion in the point cloud data and provide pose estimation result at a fast frame rate.

b. Using Flash Lidar for collision avoidance in nano satellites

In recent years, flash LIDARs, have been increasingly selected as the go-to sensors for proximity operations, obstacle avoidance and docking. Flash LIDARS are generally lighter and require less power that scanning Lidars. Flash LIDAR systems are analogous to a camera with a flashbulb (flood illumination), but with the flash being provided by laser illumination and the use of a detector with a clock to determine the time it takes for the flash to depart, reflect off of the target, and return.

These sensors provide both the angle and range measurements, which can be easily converted to the three-dimensional point cloud data in the sensor frame. By measuring the time of flight of the reflected laser pulse, the sensor can determine a range measurement along with intensity for each pixel in the image. Flash LIDARs do not have moving parts, and they are capable of tracking multiple targets as well as generating a 3D map of a given target. This characteristic helps reduce distortion in the point cloud data and provide pose estimation result at a fast frame rate.



Flash lidars, also have the ability to track targets as far out as 10 kilometers with range accuracies of 10-15 cm. The advantage to the flash technology is that with a single shot, the complete 3D point-cloud of a target is able to be captured. LIDARs are an important sensor technology for enabling obstacle detection, autonomous rendezvous, docking and formation flying, in future spaceflight missions.

c. 3D Flash Lidars

Two of the Flash Lidars that are suitable for collision avoidance for Nano Satellites, some of which have already been tested on space missions include the following:-

Flash Lidar	Specifications	Test history
ASC DragonEye 3D Flash Lidar Space Camera	The ASC DragonEye was Prior to flying on their Dragon vehicle, SpaceX performed two flight experiments (DTOs) on STS-127 and STS-133. The DragonEye is a Flash LIDAR, employing a InGaAs Avalanche Photo-Diode detector array, comprised of 128x128 pixels (16,384 total pixels). FOV 45 deg x 45 degs Range 1.5Km	selected by SpaceX as their primary means for performing proximity operations and capture. Tested on NASA's STS-127 (Endeavor Orbiter) for Automated Rendezvous and Docking
Ball's Vision Navigation Sensor or BATC VNS Flash LIDAR The VNS is currently planned to be the primary relative navigation sensor for the Orion Multi-Purpose Crew Vehicle (MPCV).	Focal plane array 256x256 (65,536 pixels) FOV 20 degrees DTO Flash LIDAR images were collected at a rate of 30 Hz --- Range – 5km	was flown on STS-134 as part of the Sensor Test for Orion RelNav Risk Mitigation (STORRM) DTO

5. Thrusters for Propulsion Subsystem

Thrusters used for propulsion of satellites, enables a satellite to maneuver while in orbit, maintain an assigned orbit path and orientation, in addition to a host of other capabilities. Since conventional thrusters used liquid and gas as a propellant requiring significant space, scaling down propulsion devices from large satellites to small satellites has been challenging and largely impractical due to power requirements and sheer size. However, this is changing in today's space environment.

A growing number of organizations are developing propulsion technologies specifically for small satellites. Previously small satellites have been largely unable to propel themselves, with only attitude stabilization available. Engineering efforts are succeeding in reducing the size of electric thrusters that could easily be added to small satellite buses and which could fit into single CubeSat units.

Electric propulsion: Electric propulsion relies on the use of electromagnetic fields to accelerate very small quantities of propellant to very high velocities, resulting in systems that trade thrust and acceleration for low propellant consumption. These systems are becoming increasingly popular on satellites as the technologies advance and their performance outstrips older propulsion techniques. The high performance of electric propulsion systems allows them to produce very large changes of velocity, meaning a small satellite could maintain its orbit for a very long time, or make large changes to its initial orbit. A high performance electric thruster could accelerate a satellite by thousands of meters per second.

There are many kinds of Electric thrusters, namely Electro-thermal thrusters, Ion Thrusters, Hall thrusters and Pulsed Plasma Thruster (PPT). A pulsed plasma thruster is expected to be used as a thruster for a micro or nano satellite due to its features which are superior to other kinds of electric propulsion. It has simple structure, low power consumption, small impulse bit level and high reliability. These benefits make the PPT an attractive and reliable on-board propulsion alternative for the navigation of nano satellites.

a. Pulsed Plasma Thruster

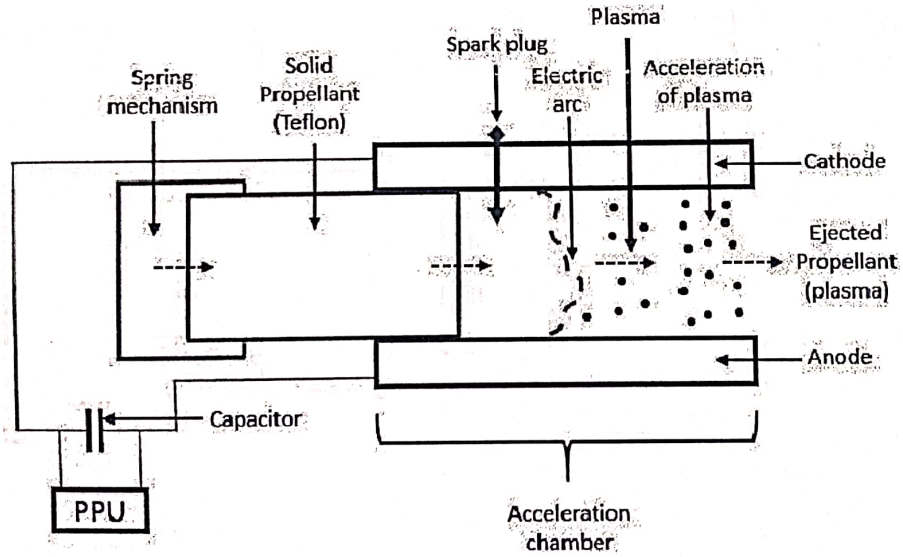
The mass advantage of the PPT system derives from its high specific impulse capability. The PPT achieves its high specific impulse by using electrical energy from the spacecraft powerbus. While other electric propulsion devices, such as the resistojet, arcjet, ion, and Hall thrusters are also capable of improved specific impulse, they require much more power than most small satellite power system sources can provide, and are much more complex. Operational PPTs have ranged in power from 6 to 30W, however, for ACS applications; the PPT operates at an average power of less than 5W.

PPT's are completely self-contained propulsion devices. Most PPTs employ solid Teflon as propellant. Teflon is a preferable propellant because of its ease of storage and supply. Teflon, when transformed into plasma, exhibits uniform ablation while being discharged. Teflon also does not char, or leave residue that would short the electrodes.

The use of solid Teflon™ propellant eliminates the expense, reliability concerns, and mass of propellant feed system components such as tanks, valves, and heaters, as well as the safety requirements associated with pressurized propellants. The advantages of a PPT are its ability to provide small impulse bits for precision maneuvering, robustness by programming impulse bits to cater to mission needs, design simplicity owing to the ability of using wide variety of propellants (solid/liquid), and its ability to maintain constant specific impulse and efficiency over a wide range of input power levels.

b. Operating Principle of a Pulse Plasma Thruster (PPT)

Pulsed Plasma Thrusters (PPTs) create a pulsed, high-current discharge across the exposed surface of a solid insulator (for instance, Teflon) that serves as a propellant. The arc discharge ablates (sublimates/vaporizes) the propellant material from its surface, thereby ionizing and accelerating the propellant to high speeds. A current pulse lasting few micro-seconds is generally driven by a capacitor that is charged and discharged approximately once every second



The schematic of a PPT is shown in Figure above containing a spring loaded mechanism, propellant, capacitor, anode, cathode, acceleration chamber and a spark plug.

During the process of propulsion, the spring feeds the propellant (usually solid) between the two electrodes (anode and cathode) and the spark plug is simultaneously fired (through a small discharge) to raise the electrical conductivity of the acceleration chamber. Now, the electric current from Power Processing Unit (PPU) flows to the electrodes through the capacitor and then into the arc, thereby completing a current loop and simultaneously generating a magnetic field.

The electric arc formed ablates the propellant and ionized plasma is formed. The plasma is then accelerated due to Lorentz Force generated by electric arc and the induced magnetic field

6. Conclusion

Although the debris environment of today is a manageable risk, this problem will become greater as the debris gets denser and the number of operational and defunct satellites increases. An autonomous system like the one proposed using 3D Flash Lidar for debris detection and using four or more PPT thrusters to steer the satellite away from the debris and later bring it back to its original path, could reduce the number of operators needed to operate a satellite or a constellation of satellites reducing operating costs. The system proposed has a modular design so that future advances in collision probability and avoidance maneuver algorithms can be accommodated without major system redesign.