Space Debris Detection and Characterization using CubeSat Constellations

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Project Description: Research in Industrial Projects for Students (RIPS) Program - 2016

(Institute for Pure & Applied Mathematics – IPAM)

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Project Background:

The problem of orbital debris in low Earth orbit (LEO) is becoming of increasing importance to satellite owners and operators internationally across the civil, commercial, and military sectors. Concern over debris has fostered improved satellite shielding, energy passivation and other end-of-life disposal guidelines, and conceptual development of active debris removal and remediation technologies. The sun-synchronous orbit (SSO) regime in LEO is of particular interest because it holds high-value satellites for remote sensing and imaging. The SSO regime is experiencing the highest debris collision hazard in LEO, with an annual probability of collision of 0.8% for a 10 m^2 satellite with debris objects 1 cm or larger in size [1]. Studies performed by NASA's Orbital Debris Program Office and by the European Space Agency's Space Debris Office show that the debris population is experiencing rapid growth in particular altitude and inclination bands characteristic of typical SSO missions [2].

Although large objects such as defunct satellites and expended rocket bodies contribute to the growth of the debris population, smaller objects ~1-10 cm in size pose a special hazard to active satellites because they are numerous, have significant energy, and cannot be tracked from the ground [3]. This lethal, non-trackable (LNT) population is large and energetic enough to cause mission-ending damage to an operational satellite if impact were to occur, but small enough to make observations and tracking with ground sensors difficult. As a result, the LNT population has only been characterized statistically in debris environment prediction models developed by NASA and the European Space Agency, which disagree by orders of magnitude as the debris size decreases. To close this "observation gap" and validate these statistical models, an in-situ, space-based sensor mounted to a LEO satellite flying within the high-density SSO regime could collect measurements of LNT objects inaccessible for ground-based electro-optical sensors or radar [4].

Project Description:

The objective for this RIPS project is to investigate how well a hypothetical population of LNT objects in LEO could be characterized by a constellation of SSO satellites carrying both optical and ranging sensors. Given sensor field-of-view angles, maximum distance, and optical detection thresholds, RIPS students will study the impact to debris position and velocity uncertainties while considering the effects of errors in sensing satellite position, orientation, and sensor alignment. In addition, the students will study and implement one or more track correlation methods to assign optical and range measurements to specific objects in the debris catalogue, based on probabilistic correlation metrics that serve to distinguish whether an observation:

1. Belongs to a “new” object not in the catalogue
2. Belongs to an object already in the catalogue (for which data is available)
3. Is a “false positive,” that is, an erroneous detection due to noise in the sensor

Status:

Space debris and the hazards it poses to satellites and other orbiting spacecraft has become a serious concern for the U.S. government. Although the probability of satellites being struck and disabled by debris is somewhat low, it can happen, as a few high-profile events have illustrated in recent years. How to prevent debris from causing catastrophic damage and/or propagating further is now at the forefront of space management.

At the same time, space debris draws a lot of interest from the public. The topic and fantasy stories related to it has been featured in some recent blockbuster movies. Space debris is also an area of great interest to children. This fact makes for a nice tie into STEM (science, technology, engineering, and math). The topic can introduce kids to space in a way that is appealing, and can stimulate their interest in these fields.

For many of the early years of the space race, the focus was on what was being put into space, and whether each launched satellite, space capsule, or orbiting spacecraft could successfully achieve its mission goals. What would be done upon the eventual demise of these pieces of hardware was not of so much concern. Still, members of the engineering and scientific staff at The Aerospace Corporation (Aerospace) have been studying space debris and reentry hazards for many years, stretching back to the early days of the company.

Aerospace is one of the major contributors of orbital debris expertise to the National Security Space and Civil/Commercial Space communities. This extends to real-time debris risk assessment, debris minimization planning, support for end-of-life on-orbit and reentry disposal, launch collision avoidance, debris threat management and assessment, and survivability analysis.

References:

1. P. Chrystal, D. McKnight, P. Meredith, “Space Debris: On Collision Course for Insurers?” Swiss Reinsurance Company Ltd., 2011.

2. J.-C. Liou, “An active debris removal parametric study for LEO environment remediation,” *Advances in Space Research*, Vol. 47, No. 11, 2011, pp. 1865-1876.

3. L. E. Z. Jasper, P. V. Anderson, D. McKnight, “Economic and Risk Challenges of Operating in the Current Space Debris Environment,” *3rd Workshop on Space Debris Modeling and Remediation*, CNES-HQ, Paris, France, June 16-18, 2014.

4. M. Gruntman, “Passive optical detection of submillimeter and millimeter size space debris in low Earth orbit,” *Acta Astronautica*, Vol. 105, 2014, pp. 156-170.

Relevant Topics:

1. Advanced Calculus
2. Linear Algebra
3. Probability and Statistics
4. Partial/Ordinary Differential Equations
5. Mathematical Physics
6. Numerical analysis
7. Mathematical Programming

Keywords:
Space Debris, Orbital Debris, Space Hazards, Space Debris Mitigation, satellite disposal, active debris removal, CubeSat, Satellite Clusters, and Satellite Formation Flying

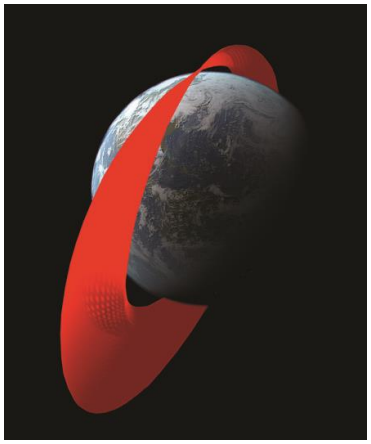

Figure 1. As the mechanics of orbital motion come into play, the cloud of fragments, the debris, spreads around the orbit close to the plane of the parent orbit. Eventually, all of the debris will return to the point of the collision, because that point is common to the orbits of all the debris. This is called the pinch point.

Debris size	Quantity	Impact
1 mm to 3 mm	Millions	• Cannot be tracked • Localized damage
3 mm to 1 cm	Millions	• Cannot be tracked • Localized damage • Upper limit of shielding
1 cm to 5 cm	500,000 (estimated)	• Most cannot be tracked • Major damage
5 cm to 10 cm	Thousands	• Lower limit of tracking • Catastrophic damage
10 cm or larger	Hundreds to low thousands	• Tracked and cataloged by space surveillance network • Catastrophic damage

Figure 2. The size and quantity of debris distributed from a given event are factors affecting the impact and potential damage caused by the occurrence.

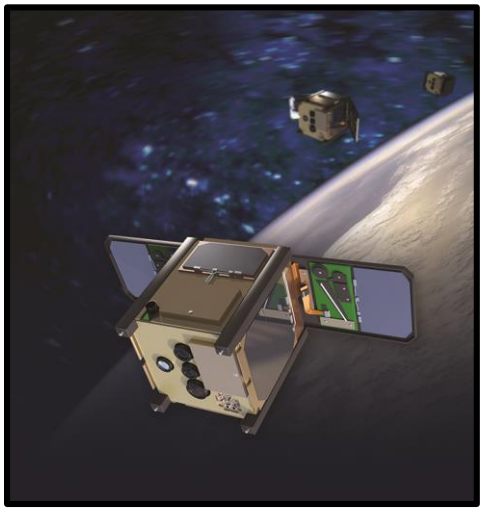

Figure 3. Artist depiction of CubeSat.

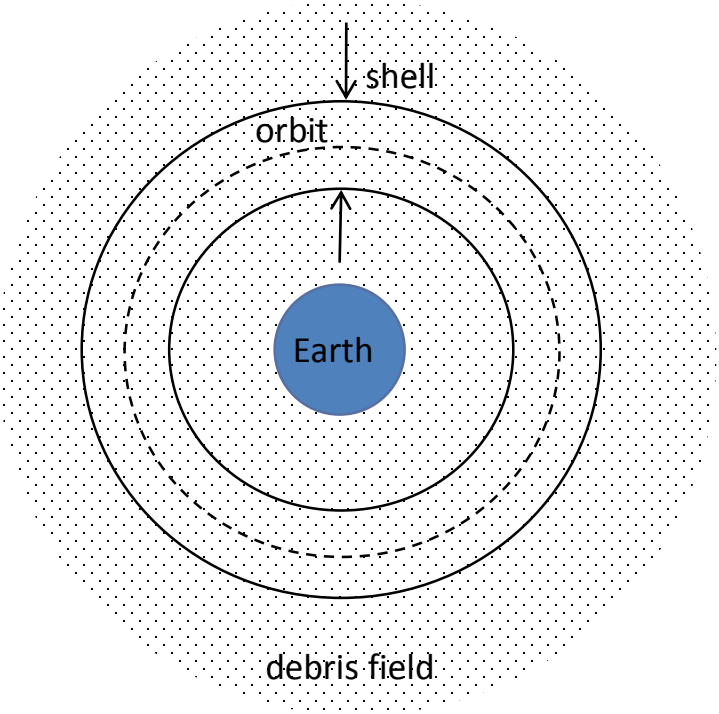

Figure 4. For each configuration, a certain number of tracked pieces of debris will be available for observation