Mitigating Orbital Debris in Low Earth Orbit: A CubeSat Strategy

Analysis of the Environmental Parallels Between Orbital Debris and Ocean Pollution

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On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

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Introduction

As space technology advances, humans continue to build upon their presence in Earth's orbit. Consequently, the number of objects present in space has grown exponentially. Based on stochastic modeling, it is estimated that there are currently millions of tiny objects between one millimeter and ten centimeters in Low Earth Orbit (LEO), or approximately between 300 to 2,000 kilometers above Earth's surface (Douglas, 2023). These tiny objects are derived from several different origins, whether it be from satellite collisions, flecks of paint from spacecraft, rocket parts, or explosions of objects in orbit flying around in space at high speeds. Currently, the National Aeronautics and Space Administration (NASA) tracks any space debris that is larger than ten centimeters, approximately the size of a softball. Although these untraced objects may seem obsolete, they may cause severe damage to spacecraft like the International Space Station (ISS). It is estimated that at such low orbits, objects can travel at speeds of nearly eight kilometers per second, which is destructive even at under ten centimeters (Rand, 2019).

Due to the high density of small objects in LEO, it has been deemed difficult to fully trace all space debris at this altitude. To mitigate this issue, I will propose an orbital debris tracking CubeSat that uses sensor detection to locate objects under ten centimeters. A CubeSat is a classification of nano-satellites in the shape of a cube. The data taken from this CubeSat will contain information about the global positioning of debris as well as its size, altitude, and velocity. Given that the debris sensor can be applied to a series of spacecraft already in LEO, millions of small orbital debris can be tracked over a long period of time.

For the sociotechnical aspect of the thesis, I will analyze how orbital debris compares to the trends found with ocean debris. The rise of ocean debris and need for technology to mitigate this issue is a more localized problem that has been monitored for decades. By comparing the trends found in the increase in ocean debris over time to the new trends of increasing debris in LEO, it will become much more apparent why the space debris problem is a major concern for engineers and environmentalists.

Technical Memorandum

The mission goal is to design and test the integration of a space debris-tracking sensor into a modular CubeSat. The sensor must be able to detect debris smaller than ten centimeters. The detection of space debris is imperative for preventing exponential debris accumulation in Earth's orbit. The primary objective of the project is to accurately detect the debris by testing the functionality of a long-range sensor, whether it be light detection and ranging (LiDaR) or radar technology, integrated into a CubeSat. Additionally, the information recorded by the CubeSat must be transmittable to a receiver in the likes of the ISS or a ground station on Earth. The data tracked should contain information that describes the location of the debris in reference to the CubeSat position, a three-dimensional description of the velocity of the debris to predict its future trajectory, and the size of the debris in terms of surface area.

Apart from these main objectives, a few secondary objectives are intended to be accomplished. Primarily, the CubeSat must have the capability to balance its power consumption and sensor operation to maximize the CubeSat's lifespan. In other words, the ideal configuration for the maximum battery power must be equivalent to the voltage required to maintain the CubeSat's most strenuous functions. This is also intended to minimize the weight of the spacecraft by having the lightest possible battery. Furthermore, this project is designed to give hands-on experience to current and future students passionate about satellite technology and design. Currently, the end goal of this year is to have a computer-aided design (CAD) of the

CubeSat along with the electronic components for the debris sensor. This will allow future generations of students to continue this project and eventually launch a functional CubeSat into orbit.

A large concern for this design is the functionality of a sensor that has gyroscopic capabilities and can detect small-scale debris from at least one kilometer away. Though many options are still under consideration, the most likely sensor will be either a radar system or a LiDaR system. A radar device operates by sending out radio waves to the debris in which it is deflected back toward the device and received. Due to the high frequency sampling of a radar system, the data will convey the distance between the CubeSat and the debris as there will likely be nanoseconds between the radio wave emission and reception. An alternative sensor that may be more accurate in depicting the three-dimensional orbital landscape of space debris is the LiDaR sensor. This device uses laser pulses rather than radio waves to detect objects. Similar to radar scans, the reflected light emitted will be received and transmitted into useful data that can be relayed to a database.

Analogous to any spacecraft, the CubeSat must have attitude determination and control systems (ADCS). To maximize the stability of the satellite in LEO, the module will be equipped with actuators. This component will produce force, torque, or displacement when there is a slight delineation in the orbit of the CubeSat. Without this component, the spacecraft would likely fall out of orbit. To combat the additional likelihood of the spacecraft recklessly spinning, the CubeSat will have a magnetorquer stabilizer. This will also provide assistance with altitude control and detumbling. A final ADCS component that will play a large role in the tracing of space debris is the global positioning system (GPS). The intent of the GPS is to describe the three-dimensional coordinate of the CubeSat. This will include current latitude and longitude in addition to its altitude.

The most important system driver for the design of the modular CubeSat is the power source. Because the spacecraft will be in orbit for a long period of time, a rechargeable battery is required for proper functionality. Therefore, the CubeSat will be equipped with a Lithium-Ion or Nickel-Hydrogen battery that can be recharged via deployable or fixed-to-body solar panels. The batteries will be optimized based on the performance of their voltage output in relation to their weight.

To optimize the performance of the spacecraft, there are several mission constraints that must be met. For a three-unit CubeSat, the intended mass must not exceed 10 kilograms, or 22 pounds. The maximum height will be restrained to 35 centimeters, or approximately 14 inches. The bulk of the weight of the spacecraft will come from internal components like the electronic subsystems and battery. Due to the intended altitude of the CubeSat in orbit, there will be extreme temperature variations that must be accounted for. In LEO, temperature ranges can span from -157℃ to 121℃. Thus, the power systems must have proper thermal properties to ensure the CubeSat is operational.

Environmental Parallels to Ocean Pollution

Ocean debris accumulation has a variety of different sources, whether it be from runoff due to heavy rainfall, carried out to sea by rivers and streams, picked up off a beach by waves and tidal action, or deposited in streams or oceans from the atmosphere (Whitman, 2002). Some classifications of ocean debris like plastics and light rubbers are buoyant causing them to float above the surface, whereas paper, wood, and cloth items initially float but tend to sink once they become saturated with water. Glass, metal, and some types of rubber tend to sink given that they do not contain pockets of air. This jumble of debris in the ocean is analogous to the space junk found in LEO.

According to a report from the Environmental Protection Agency (EPA), several protocols have been taken to monitor the growth of the debris in local watersheds (Whitman 2002). For instance, the EPA along with other federal agencies helped to design the National Marine Debris Monitoring Program (NMDMP). This program is dedicated to identifying trends in the amounts of marine debris affecting the United States coastline and to determine the main sources of the debris. Similarly, as of August 2021, the European Space Agency (ESA) reports that approximately 29,210 pieces of space debris are tracked on a regular basis by Space Surveillance Networks (Luke, 2021). These Space Surveillance Networks demonstrate a parallel with the programs designed by the EPA to monitor harmful environmental debris, whether it be in space or in our oceans.

My thesis will detail the *Actor-Network Theory* proposed by Bruno Latour in the late twentieth century as it applies to the correlation between space debris and ocean debris (Latour, 1992). The intent of the paper is to outline how oceanic debris can be understood through the lens of Latour's actor-network theory by recognizing how non-human entities, such as waste and debris, actively shape and influence environmental and social systems such as the NMDMP. By demonstrating the trends found with the floatable debris, my thesis will aim to predict the future outcomes of the orbital debris environment as it relates to Latour's sociotechnical theories. To summarize how this may be applied to a vast system like the ocean, debris can be treated as an "actor" entering the marine environment where it interacts with a diverse array of wildlife, disrupting ecosystems. In turn, this directly motivates policies and international agreements targeting the reductions of these accumulations. Governments, organizations, and individuals are part of this network responding to the growing problem of marine debris.

To further define a comparison between the environmental effects of space debris and ocean pollution, and expand upon the idea of *Actor-Network Theory* as it applies to this network, ocean wildlife will be compared to working spacecraft as actors. For marine animals, the two primary problems that floatable debris poses to wildlife are entanglement and ingestion. Entanglement results when an animal becomes encircled or ensnared by debris (Whitman, 2002). This poses a huge threat to the marine ecosystem as the human-caused debris has led to infections and loss of limbs of several animals. Therefore, the identification of oceanic debris as an actor demonstrates the hazards presented to wildlife, the central actor of the network.

This connection between the oceanic debris and wildlife closely relates to the network of spacecraft and orbital debris. Hypervelocity impacts of space debris can cause severe damage to spacecraft currently in LEO (Space Environment Center, 2024). When considering the implication of debris as an actor in a network, these particulates cause harm to other actors in the network, most notably the working spacecraft. The oceanic wildlife are similar to the active satellite systems as they are central actors threatened by the presence of debris, whether it be from impact or entanglement. My thesis will further analyze these similarities while also providing data to suggest supplemental reasoning.

Conclusion

The Space Debris Tracking CubeSat is a crucial step in the right direction for the future of our space industrial complex. By implementing a sensor into a modular CubeSat that has the capability to detect space debris that is currently untraced by government entities, companies focused on orbital infrastructure will have a better understanding and verification of models that predict the densities of space debris currently in Low Earth Orbit. To further demonstrate the environmental effects associated with space debris, my thesis will outline the parallels that space junk has to ocean debris. This will be analyzed through Bruno Latour's *Actor-Network Theory* and how ocean pollution or space debris applies to a network of actors in their respective environments.

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