Space Debris Tracking CubeSat

(Technical Report)

Analysis of the Environmental and Socio-Political Parallels Between Orbital and Marine Debris

(STS Research Paper)

An Undergraduate Thesis

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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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Sociotechnical Synthesis

Due to a rapid increase in human influence in space, there has been a clear uptick in the amount of space debris accumulated over this recent period. This congestion in orbit increases the likelihood that active spacecraft will collide with such debris leading to failures of satellite systems and other infrastructure. Currently, the National Aeronautics and Space Administration (NASA) keeps track of any debris that is over ten centimeters, leaving the approximately 120 million smaller pieces untraced. The technical portion of this thesis details a potential solution to this problem by demonstrating the function of a continuous-wave radar system built into a CubeSat that has the ability to track debris under this ten-centimeter threshold. The sociotechnical analysis portion of this thesis compares the growth and accumulation of orbital debris to that of marine debris, outlining their similar patterns and how these patterns influence human and technological behaviors.

A potential solution to the complexity of tracing debris that is under ten centimeters is detailed in the technical portion of this thesis. To summarize, a small satellite module in a cubic shape known as a CubeSat was designed with the main purpose of tracking such debris in Low Earth Orbit (LEO), or approximately 180 to 2000 kilometers above Earth's surface. To perform this task, a continuous-wave (CW) radar system was designed to emit a high frequency radar that will reflect off of debris and be received by an antenna. The ultimate goal of this project was to create a prototype radar system that could trace objects here on Earth where the atmospheric noise is much greater than that of space. By performing this task, the radar's potential could be propagated to the LEO environment where its detection range would be much greater. To better understand the LEO environment, a few simulations were constructed to maximize the effectiveness of the CubeSat. The first simulation designed was the Debris Determination Model.

This simulation was created to accurately describe the positions and orbits of unknown objects in LEO. The distribution of debris was propagated from known models of debris over ten centimeters assuming the smaller pieces follow a similar trend. To maximize the CubeSat's time over the Charlottesville ground station, the Orbit Determination Model was constructed by iteratively producing orbits and counting which of these randomly generated orbits would obey both the circular, Low-Earth Orbit, as well as maintain the highest amount of time over Charlottesville. The final simulation was the Orbital Debris Detection Model. This algorithm is the cumulation of the previous two models, simulating the actual performance of the CubeSat in the specified orbit with the semi-randomly distributed debris around it. The output of this simulation is a count of the amount of debris detected by the CubeSat within one optimal orbit.

The sociotechnical analysis portion of this thesis compares a local debris environment to that of space debris. By analyzing the growth and accumulation of oceanic debris, the space junk environment could be better understood, and preventative measures used for our oceans could be used up in space. Drawing from environmental science and policy responses to marine pollution, the analysis explores how global coordination, economic incentives, and awareness campaigns may be adapted to orbital sustainability. This process is also investigated through the lens of *Actor-Network Theory*. In summation, the two networks share common properties in their accumulation processes, distribution mechanisms, and the complex interactions between human and non-human actors involved. Understanding space debris through these sociotechnical parallels opens pathways for more holistic debris mitigation strategies that integrate engineering innovation with social and environmental responsibility.

Working on both the technical and sociotechnical components of this thesis in parallel provided a more comprehensive understanding of the challenges posed by orbital debris. While the technical project required critical thinking about system design, signal processing, and real-world constraints of a CubeSat, the sociotechnical analysis pushed me to consider the broader implications of that technology. Space debris as a whole is an emerging issue, and there are few researchers dedicated to identifying mitigation strategies. This project analyzes strategies used by policymakers, environmentalists, and other engineers to ameliorate the marine debris conflict that has existed for decades longer than the orbital debris environment, while also identifying a potential solution to the space debris problem through pure technological advancement. Ultimately, this interdisciplinary approach not only strengthened my problem-solving skills but also helped shape the way I view engineering. As a whole, engineering is critical to helping humankind advance in society. Through advancements, more problems arise, like that of space debris. It is up to the engineering community to continue its research and development efforts to mitigate further issues.