CubeSat-Integrated Sensor System for Tracking Small Space Debris in Low Earth Orbit

Dual-Use Satellites: National Security Implications in Public-Private Partnerships

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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

The accumulation of space debris in Low Earth Orbit (LEO) is an important issue for space safety and sustainability that has yet to be effectively addressed. Caused by the rapid expansion of satellite constellations such as SpaceX's Starlink, these debris can be harmful to current spacecraft and future missions. Even the smallest pieces of debris can cause catastrophic damage to operational spacecraft due to their high velocities in LEO (Liou & Johnson, 2006). Smaller debris under 10 centimeters remain a critical blind spot and future satellite operations are at risk of collision with these particles. Our research will focus on developing a sensor for tracking small space debris integrated into a CubeSat.

The sociotechnical topic of the thesis will be about dual-use satellite technologies which are technologies that can serve both civilian and military purposes on the same satellite. These technologies enable activities like environmental monitoring, communications, and navigation while also supporting intelligence and defense operations (Finocchio et al., 2008). This overlap complicates regulations and security when commercial or foreign entities are involved (Vaynman & Volpe, 2023). There will be a specific focus on satellite technologies that operate for earth observation purposes such as climate change research, or surveillance by the government. The research topic that will be explored is how setting a precedent for public-private partnerships with these dual-use satellite technologies could impact the national security of the United States. As the government satellite industry becomes increasingly dependent on commercial partnerships, there is the potential for blurred lines between civilian and military applications leading to data security breaches, espionage incidents, and strategic vulnerabilities. This will be analyzed through a social construction of technology lens, examining societal, political, and economic pressures on satellite partnerships.

The main connection between the space-debris-tracking CubeSat Capstone and dual-use Earth observation satellite thesis is they both focus on satellite technology. Additionally, both of these satellite technologies can be used for commercial and military purposes. In a more technical sense, both of these technologies use sensors to track or observe certain elements. Finally, both projects have a policy connection, as data from space debris density can influence policies on de-orbiting or debris mitigation requirements for commercial and government entities, and dual-use technologies can influence public-private partnership regulations. Both topics are essential to the satellite ecosystem, as both increasing debris density and the expanding overlap between civilian and military satellite uses pose risks to space infrastructure and, therefore, to national security.

CubeSat-Integrated Sensor System for Tracking Small Space Debris in Low Earth Orbit

Space debris in LEO has become a major concern as space infrastructure continues to grow. Large constellations of satellites have greatly increased the amount of space activity, but they also contribute to the clutter orbiting Earth (Lewis et al., 2009). Even tiny pieces of debris can be incredibly dangerous in space due to their high speeds (Liou & Johnson, 2006). They can collide with active satellites and cause serious damage or disruption to important communication, navigation, and research missions.

Currently, tracking systems monitor debris orbiting earth in LEO, however they do not detect everything. The United States Space Surveillance Network (SSN), for instance, can only monitor objects larger than 10 centimeters in diameter (Bastida Virgili et al., 2016). This leaves a blind spot for smaller debris, which could still collide with and damage satellites. To address this issue, we’re working to develop a smaller satellite, called a CubeSat, that can track these smaller pieces of space debris. The goal is to design and test a sensor system that can identify debris that are 1-10 cm in diameter and relay that information to ground stations, helping build a clear picture of the debris density in LEO. Additionally, our project seeks to ensure that this sensor can operate efficiently, using as little power as possible, which is essential for small satellites. There are certain key requirements that our CubeSat must meet to be successful. First, it must be able to detect small debris with reliability, meaning that the sensor system we design needs to be both sensitive and accurate. Second, the CubeSat needs to acquire, store, and process data before sending it back to Earth. Finally, the system must be durable enough to survive both the launch and the challenging environment of space. These goals will shape the CubeSat's design, from its power and storage capacity to its data transmission capabilities.

Our team is exploring different types of detection technologies to find the best fit for the CubeSat. There are two main approaches to detecting debris: active systems, which transmit and receive signals to detect objects, and passive systems, which rely on external sources to reveal objects (Peral, 2017; Vargas, 2021;Pineau & Felicetti, 2023). We're comparing these approaches to find a system that is both efficient and compatible with the limited resources of a CubeSat. Beyond the sensor, the CubeSat will need to include additional subsystems that allow it to function as a whole. These will include a power system, a central processing unit (to command the satellite), an attitude control system (to maintain orientation), and a communication system for data transmission. The arrangement of these subsystems will be carefully planned to keep the CubeSat balanced and ensure smooth power flow and data processing. Overall, our project aims to address the growing issue of space debris by designing a CubeSat that can detect and track small debris in LEO. This data will help researchers understand the density and movement of space debris, providing valuable insights for the future of safe and sustainable space exploration.

<u>Dual-Use Satellites: National Security Implications in Public-Private Partnerships</u>

The research question that will be explored in my thesis will be the topic of dual-use satellite technology, in order to understand how setting a precedent for government and commercial partnerships may impact the security of the United States. The importance of this research cannot be overstated because, as the government satellite industry becomes increasingly dependent on commercial partnerships for launch capabilities and technical knowledge, there is the potential for blurred lines between civilian and military applications, leading to the possibility of data security breaches, espionage incidents, and strategic vulnerabilities. Commercial partnerships are beneficial both economically and technologically, and with that comes the increase in targeting commercial satellites for sensitive information. In an age where surveillance is one of our national security's best tools but also a potential weakness, ensuring that there is no easy way to gather sensitive data on soft spots in the United States is crucial. The Federal Bureau of Investigation (FBI), the National Counterintelligence and Security Center (NCSC) and the Air Force Office of Special Investigations (AFOSI) have stated the importance of being weary of foreign entities not only accessing satellite trade secrets, but also sensitive data of satellite payloads and communications in a 2023 warning bulletin (Martina, 2023). Overall, exploring the implications of dual-use satellite technologies is crucial to better understanding how these partnerships shape security landscapes.

This research topic will be analyzed through a social construction of technology lens. The social construction of technology emphasizes how societal factors can influence the development and, more importantly, the use of technology (Francisco, 2024). It differs from technological determinism, in which society helps shape the technology rather than the technology solely shaping its environment. This lens will allow the exploration of how societal and political pressures, such as economic incentives, global competition, and government policy, could shape the partnerships between government and commercial entities in their uses of satellite surveillance. This frame will allow the examination of interests and concerns of different social groups, including government agencies, private companies, and allied or non-allied countries. Through examining these influences, the inquiry into whether the change in the use of satellite technologies to become dual-use would affect the national security of the United States can be addressed. Another helpful methodology tool would be using a social impact matrix that takes into account social, economic, political, and ethical considerations from a variety of stakeholders to build upon and support the social construction of technology-based argument.

There are five types of evidence that I have collected to support my research question: background evidence, policy documents, argumentative literature analysis, stakeholder public statements, and legislation/regulations analysis. The background evidence will lay out all the actors that influence technology and all of the societal factors that come into play. Policy documents will help show the stance of the government as an actor and as an influencer and also bring in some perspective about national security such as NASA's policies on changing approaches to public-private partnerships (Mazzucato, 2017). Argumentative literature analysis will be able to highlight diverse perspectives, helping to identify existing debates about the security implications and ethical considerations of dual-use satellite technology. Stakeholder statements will be able to show influences through different actors, such as government officials or private companies involved. Finally, legislation/regulatory analysis will offer hard evidence for how this technology is being used and acquired. Overall, these five types of evidence will be used to interpret stakeholder influence, societal values embedded in policies, alignment of interest between commercial and private stakeholders, and even changes in perceptions about dual-use satellite technology over time.

Conclusion

The technical capstone project focuses on addressing the growth of small space debris in LEO by developing a sensor system that will be integrated into a designed CubeSat. This sensor will be able to detect space debris between 1-10 cm that currently is not tracked by the United States Space Surveillance Network. The goal is to enable better detection and tracking of debris that pose significant threats to operational and future space systems. In conjunction with this, the STS research will explore the implications of dual-use satellite technologies on national security. It will specifically focus on earth observation and surveillance as that has both civilian and military implications.

The impacts of both the technical work and STS research are related to the critical societal issue of space safety, both in the physical and intellectual sense. Space debris could harm vital national security resources in space that deal with communications, surveillance, and navigation. Tracking the debris would allow public and private companies to better safeguard their space assets and therefore contribute to the scientific community, economy, and country. Research potential national security implications of public private partnerships will allow for better knowledge of how to maintain security and safety of physical assets and information about the United States.

In the end, the Cubesat sensor system is expected to successfully track small debris in LEO and fill a crucial current blind spot in debris monitoring leading to enhanced space safety and long-term sustainability. Additionally, the STS research will provide insights into how public-private partnerships in satellite technologies could evolve and affect U.S. national security. The social construction of technology framework allows the paper to examine how societal, political, and economic pressures shape the development and regulation of dual-use satellite technologies that lead to the ability to effectively suggest policies that will protect national security.

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