Thesis Portfolio

A SPACE-BASED SOLUTION TO IMPROVE ROADWAY SAFETY AND EFFICIENCY IN VIRGINIA: REAL-TIME WINTER WEATHER DATA FOR NAVIGATION
(Technical Report)

TECHNOLOGICAL MOMENTUM IN THE ASTEROID MINING INDUSTRY
(STS Research Paper)

An Undergraduate Thesis

Presented to the Faculty of the School of Engineering and Applied Science
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In Fulfillment of the Requirements for the Degree
Bachelor of Science, School of Engineering

Jimmy Smith
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Department of Mechanical and Aerospace Engineering

Real-Time Weather Tracking for the Purposes of Roadway Safety

(Technical Paper)

Technological Momentum and the Exploitation of Space Resources

(STS Paper)

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Jimmy Smith

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Technical Project Team Members

Andie Daniels   Luke Dennis   Graham Fitzgerald   Brandon Ghany

Alex Griffin   Dominic Pinnisi   Annish Vegesna   Xavier Castillo-Vieria

Ian Wnorowski   Victor Yang

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

Signature ____ Date __________
Jimmy Smith

Approved ____ Date __________
Dr. Chris Goyne, Department of Aerospace Engineering

Approved ____ Date __________
Bryn Seabrook, Department of Engineering and Society

Introduction

With advancements in imaging and remote sensing technologies as well as satellite design and manufacturing techniques, space-based solutions are becoming more feasible for more modern-day problems such as monitoring roadways. Since the Soviets first succeeded in escaping the terrestrial grasps of Earth's gravity by putting humanity's first satellite, *Sputnik*, in orbit in 1950, human capabilities in space have increased exponentially (Bellis, n.d.). Weather tracking and monitoring satellites are fairly commonplace now; however, none of these satellites are monitoring weather for the sole purpose of roadway safety.

Weather in Virginia is notorious for providing the full range of conditions; sleet, snow, ice, rain and hail are not all uncommon in the state and can lead to dangerous roadway conditions. While there are many independent apps that provide updates on roadway conditions as it pertains to traffic, accidents and even the location of police; none of these integrate real-time weather updates, which are just as important, if not more-so, than traffic conditions. The methodology of real-time weather data collection in Virginia, and the architecture for its dispersion, is the technical topic considered in this paper, with a bias given towards space-based solutions per the nature of the Spacecraft Design course.

As technology advances, space has become not only just a resource for research, it has become a seemingly infinite source of resources. As asteroid mining and exploitation of planetary resources becoming more and more feasible, questions of legality and morality have been raised. The United Nations (UN) has established a treaty pertaining to the regulation of space-based resources; however, this treaty remains unsigned by most space fairing states, leaving private industry untethered (Foust, 2015). With the current boom in private spaceflight, companies like SpaceX and Blue Origin are now capable of launching astronauts to space almost entirely independent of the government (Fernholz, 2018). As the momentum behind the private space industry continues to increase, the merits and money promised by the asteroid mining industry are poised to leave the realm of science fiction and become reality. The purpose of the STS Research portion of this thesis is to examine the feasibility of asteroid mining, as well as the potential impacts it could have on industry and society.

Technical Topic

Virginia has one of the largest state-maintained highway systems in the United States, behind the states of North Carolina and Texas (Virginia Department of Transportation, 2019). Given the expansive nature of Virginia's infrastructure, it plays a pivotal role in the economic development of the commonwealth as well as the quality of life for every Virginian. One issue the Commonwealth faces is severe traffic congestion, most notably in the Northern Virginia and Hampton Roads regions. The traffic congestion cost Virginia $6.4 billion due to traffic incidents, primarily due to lapses in driver judgment and weather conditions, in 2018 (TRIP, 2020). Currently, Virginia acquires their weather data in the same manner as most of the United States—through a synthesis of data collection from the National Oceanic and Atmospheric Administration's (NOAA) Geostationary Operational Environmental Satellite (GOES), local ground stations, and physical observation (National Oceanic and Atmospheric Administration, n.d.). The satellites that NOAA use boast the ability to support 1-2-day forecasts and severe storm monitoring. They can offer 3x more imagery with up to 4x better resolution compared to previous generations of weather satellites, can scan the Western Hemisphere every 15 minutes, the Continental U.S. every 5 minutes, and areas of severe weather every 30-60 seconds, all at the same time (National Weather Service, n.d.). The accuracy of weather data has never been better, with the ability to create extremely reliable short-term forecasts and augment the accuracy of longer-term weather outlooks (National Oceanic and Atmospheric Administration, 2019). Similarly, navigational information is delivered through the use of GPS satellites as well as prior user data to provide time-dependent estimates on route durations. As it currently exists, both data streams exist independently of each other.

The mutually exclusive nature of both weather data and GPS data births the problem of neglecting the impact of weather conditions on the safety of a certain route. Nearly all traffic engineering guidance and methods used to approximate highway capacity assume clear weather—an invalid assumption to make considering a majority of states encounter inclement weather conditions for a significant portion of the year (Agarwal, 2005). Furthermore, it has been identified that adverse weather conditions are a primary cause or underlying circumstance in vehicle crashes each year. There has been a plethora of incidents – such as in Fancy Gap, Virginia – where excessive driver speed in the dense fog caused 17 distinct crashes on March 31, 2013 (Barjenburch et al., 2016).

Although a human decision is at the core of every traffic incident, there is a lack of understanding of current weather impacts on road safety for the average commuter. It was found that the average driver employs anywhere from two to four sources of weather information, and a subsequent 34% of people modified their actions thereafter. By incorporating real-time weather data into navigational platforms and quantifying their impacts on roadway safety, time, money, and human lives can be saved. Virginia's road systems are also continuously evolving due to the growth of electric vehicles and autonomous driving capabilities. Currently, 2% of passenger vehicles in Virginia are electric, yet this metric is expected to balloon to 46% by 2040 (TRIP, 2020). This growth of electric vehicle usage, which introduces autonomous driving features, would further benefit from a combined stream of data in optimizing their routes and increasing passenger safety.

My team proposes to develop a remote-sensing solution, in the form of a CubeSat, to monitor the on-road accumulation of precipitation and calculate average speed changes to provide users with in-app weather warnings as well as real-time route delays and alternatives. A CubeSat is a miniature satellite comprised of 10 cm x 10 cm x 10 cm units housing avionics and instruments for a certain mission. The CubeSat will be placed in Low Earth Orbit (LEO) to allow for high resolution imaging and data collection over a particular area. To validate the design, we will verify rain accumulation detected by our satellite with that of real-time observations by local observers and ground-based sensors in the vicinity. Additionally, we will seek to integrate data collected from our satellite directly with that of popular navigation apps, such as Waze, Google Maps, and Apple Maps to better serve a larger population.

We have partnered with the MITRE Corporation under the mentorship of Dr. CJ Rieser and Dr. Michael A. Balazs, as well as our technical advisor Professor Chris Goyne, to investigate and tackle the problem.

Due to the research and design emphasis of this project, there are minimal initial resource requirements necessary to complete this semester’s tasks successfully. One requirement would be ample access to the stakeholders previously mentioned, as they provide first-hand accounts about where the problem lies and what solutions have been implemented in the past. Additionally, the mentorship of Dr. Cj Rieser and Dr. Michael A. Balazs provides valuable input on gaps in our team’s knowledge and on possible shortcomings of proposed space-based solutions. The last resource requirement would be access to literature on the current state-of-the-art.

My specific role within this project team is that of Attitude Determination and Control System (ADACS) and Orbits. As a member of the ADACS and Orbits team; along with Dominic Pinnisi, Ian Davis, Reed Curtin, Khamal Saunders and Cooper Dzema; I am responsible for performing determining the optimal orbital parameters for our satellite(s) such that they can collect the necessary data. The project will be broken down into 12 tasks – largely based on the Space Mission Engineering Process (SME) – the first three of which – involving stakeholder interviews and preliminary research – have been completed in order to define the problem. The next three – solution research and proposal – will be completed by the end of this fall semester, and the final six – detailing the solution technical design – will be completed in the spring semester. The project team has already presented its initial progress to MITRE and will present again at the end of the semester and in the spring.

STS Research Topic

Humanity stands on the precipice of a new space race; however, this race is not driven by war or attempts at displaying military superiority, but instead by private industry. When writing on the motivations of space exploration, Cragg claims that it is unreasonable to expect a private citizen to be able to fund such expeditions (Cragg, 2017). Now, with the rise of companies such as SpaceX and Blue Origin, privatized spaceflight has become a reality. Once these companies break the Karmen line – which is the officially recognized "edge of space" – they find a universe ripe with resources, and no real laws or regulations restraining them.

Regulations for the harvesting and exploitation of space-based resources – including asteroids, the moon and planets – is almost non-existent. The US essentially doubled-down on its hands-off stance it first took in 1979 by not agreeing to the UN's treaty when then President

Barrack Obama passed the *SPACE Act of 2015*, which is meant to facilitate the growth of the commercial space industry (McCarthy, 2015).

On May 26th, 2020, Elon Musk's private company SpaceX used their Falcon 9 rocket and Dragon spaceship to do what hadn't been done in America since the end of the shuttle program a decade earlier – they sent humans into space. Jeff Bezos' company, Blue Origin, and their New Glenn rocket are poised to also fly humans in space by the end of 2021. These "rocket billionaires" are at the leading edge of private spaceflight and are poised to have the capabilities to launch space vehicles independent of government agencies – save for the FAA and the use of space ports like Kennedy Space Center and Vandenberg AFB. As these companies continue to grow and develop more efficient and effective technologies, and grow independent of government agencies like NASA, the technological momentum of the private space industry continues to snowball.

The prospect of asteroid mining and its impact on societies and infrastructure will be evaluated through the lens of Technological Momentum. In addition to Technological Momentum, the Paradigm Shift framework will also be used to examine the state of current national and international space utilization regulations as well as the perceived limitations of industry. By understanding the demand and merits of asteroid mining we can better predict and account for its impact on industry, human infrastructure and societies.

Technological Momentum is an STS framework first proposed by Thomas Hughes as an alternative to the dichotomy posed by Technological Determinism and Social Construction (Hughes, 1994). It basically states that technology and society can influence one another in such a way that they create a positive feedback loop, causing the technology to gather "momentum". This framework is preferred when discussing large scale systems as determining the source of influence can be difficult and it is much easier to see the two influences playing off of one-another than it is to isolate them. Paradigm Shifts is another STS framework through which shifts in well-established societal paradigms occurs (Kuhn, 1970). In the context of this paper, the paradigms that will be contextualized and investigated is that of the lack of space regulations as well as the current perceptions of what is currently feasible as it pertains to space industries.

As the private space industry is currently still in its infancy, its trajectory will be examined using the lens of Technological Momentum as detailed above. Sources will be collected detailing the feasibility of asteroid mining technology, current investors in the venture, the origins and evolution of private spaceflight as well as national and international laws/ regulations on the exploitation of space resources. These sources will be found by searching for keywords and phrases such as “asteroid mining”, “space resource exploitation”, “private space industry”, “asteroid mining technologies”, “UN Space regulations”, etc. Through these search methods, a robust and diverse list of sources will be gathered to help in the analysis required to answer the research question as comprehensively as possible.

Conclusion

This thesis will provide a space-based, remote sensing solution for the real-time monitoring and transmission of weather data as well as a sociotechnical paper examining the technological momentum in the private spaceflight industry as it pertains to asteroid mining. By creating a space-based solution to the weather tracking problem, it will allow for the integration of satellite weather data and information on roadway conditions with existing roadway apps to inform roadway users which route is the safest, effectively decreasing weather related accidents.

Through examining the potential asteroid mining industry, a more comprehensive understanding of its benefits and impacts on human society and industry is sought.

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