3U Nitrogen Dioxide CubeSat
(Technical Paper)

UAV Viability in the Commercial Sphere
(STS Paper)

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Introduction

While scientific discovery enriches peoples' understanding of humanity's place in the universe, technology is the result of that understanding which actively shapes the way people live and interact, and the effects can be quite profound. My technical research will focus on detecting levels of nitrogen dioxide (NO_2) in the atmosphere using a nanosatellite, known as a CubeSat. Nitrogen dioxide is a registered pollutant that is directly correlated to the combustion of fossil fuels. In order to measure the concentration of NO_2 in the atmosphere we are designing a 3U CubeSat, roughly thirty by ten by ten centimeters, that is scheduled to launch in 2020. While satellites used to be a strictly government enterprise due to the massive costs and mission timelines that were formerly required, recent advancements have made them much smaller and more cost efficient, enabling their widespread adoption into the private sector as nanosatellites. The payload that we are using to detect the gas is an instrument known as a spectrograph, which is able to detect certain chemicals based on their characteristic spectral properties (Jabr). The motivation for this research is to provide data that can be used to tailor regulatory policies to areas that are most affected by this pollutant and other biproducts of combustion.

Just as satellites have shifted into the commercial sphere with the advent of nanosatellites, recent advancements in the field of Unmanned Aerial Vehicles (UAVs) have shifted their applications as well (Edwards, 2019). While drones began in a purely military context, two major industries that could hugely benefit from drone technology are the agricultural and delivery industries (Bergin, 2015). However, despite displaying obvious potential in these fields, specifically regarding energy efficiency, pollution, and access to commodities, there are several obstacles that have impeded their economic and logistical viability (Tripicchio, Satler, Dabisias, Ruffaldi, & Avizzano, 2015). As these barriers are often legally and culturally driven, they are a direct result of social institutions reflecting society at large. As my technical topic is focused on promoting and directing regulatory policies to fight pollution in key areas, my STS topic is focused on determining how regulatory policies affect the feasibility of widespread drone implementation.

Technical Topic

While the benefits of living in a post-industrial world are self-evident, the data is overwhelmingly clear that this revolution did not come without consequences. In the modern world, there is a vast collection of information on the anthropogenic effects brought on by the widespread industrial practices that developed out of the 18th century. One of the major environmental consequences of this socioeconomic transformation pertains to rates of air pollution that are higher than ever before as a result of increasingly high emissions (Harvey, 2018). Polycyclic aromatic hydrocarbons (PAHs) are particulate biproducts of the incomplete combustion of petroleum fuels that are well known carcinogens and mutagens. These chemicals are difficult to measure across large areas. However, studies show that they are found in significantly higher concentrations in the presence of other pollutants such as sulfur dioxide, nitrogen dioxide, and ozone (Tham, Takeda, Sakugawa, 2008).

As each of these chemicals has a unique spectral signature, it was decided that we could determine the concentration of pollutants using spectrographic methods. Nitrogen dioxide is a known combustion-related pollutant that has been shown to suppress immune function even without the presence of other pollutants (McGrath & Smith, 1984). As a result, this was our target subject for detecting the levels of air pollution in specified regions. In order to measure the levels of NO_2 we have designed a mission whose primary objective involves developing a spectrograph suited to the constraints of a 3U CubeSat bus, that is capable of measuring NO_2

columns at a spatial resolution of at least 1 km^2 (200 m x 800 m). While there are other methods to measure NO_2, it was decided that a spectrograph would be the optimal instrument to maximize accuracy and minimize cost. We plan to use this data in order to improve our understanding of NO_2 emissions and their concentrations across urban and industrial landscapes.

Our primary customers are the University of Virginia IR&D funding, as well as the National Science Foundation (NSF) and the National Aeronautics and Space Administration (NASA). Our secondary customers are the U.S. Government, U.S. taxpayers, and the Commonwealth of Virginia. Our team is split into five main groups: Attitude determination & control, Communications, Power, thermal & environment, Structures & integration, and Software & avionics. Each of which works together to ensure that the nanosatellite is fully operational for the duration of its lifespan. Due to the complex nature of the mission there are several alternative mission architectures, concepts, and system drivers that are still being considered.

Alternative mission architectures are essentially the alternative options that are being considered at the highest level, such as the subject of observation, the payload, the orbit, the launch segment, etc. The alternative mission concepts get even more specific and basically outline the means through which any of the given architectures will be accomplished. The system drivers outline the critical requirements of our mission, summarizing the limitations set forth by the mission concepts. While some of the architectures, concepts, and drivers are set in stone, there are still several decisions to be made. The ultimate goal for collecting this data is to further advance the knowledge of combustion-related pollution throughout key locations, which can then be used to direct policy and outline health risks in these areas. With more information on pollution, legislators can make more informed decisions and create a larger impact on the issues associated with air pollution. The mission is tentatively scheduled to launch next year with construction beginning in the spring of 2020.

STS Topic

Despite their military origins, in recent years UAVs (Unmanned Aerial Vehicles) have shown much promise in the commercial sphere with a projected market growth of $12 billion by 2023 according to Gebicke and Krout, and an even higher figure cited by Ludwig. With applications in agriculture, infrastructure, delivery, and emergency services it is inevitable that UAVs will be increasingly used across a variety of industries. Nonetheless, despite their clear advantages over some existing technologies, drones still have their drawbacks. I plan to discuss the obstacles associated with the implementation of drones in the public sphere, as well as the viability of UAV technology across non-military industries, specifically agriculture and delivery (Bian, Fattah, Sun, & Zhang, 2019). In addition to some financial and technical constraints, the major issues that surround the use of drones in the commercial sphere pertain to regulatory policy and legislation (Lee, 2016).

As with any new technology, society has to be dynamic, adjusting accordingly so that it can be safely and legally implemented in the public domain. However, due to the elusive nature of drones as well as the extreme regulations that are placed on air traffic, their implementation is no simple undertaking. While this topic is a contentious new area of technological development, the adoption of drones could produce a lot of environmental benefits while increasing access to various commodities (Pederi & Cheporniuk, 2015). Some critical advantages UAVs have over formative techniques are that: they are typically electrically powered, they can operate in areas that are too dangerous to employ human labor, and they can scan expansive regions with greater speed and accuracy than humans.

These are just a few of the benefits attributed to the use of UAV technology; however, their commercial development has largely been stagnated by ethical concerns, rigid policies, and complex economic factors. Many of the legal and ethical concerns that are connected to drone technology relate to privacy, property rights, and safety. According to Welte, “constitutional issues pertaining to drones revolve around (1) the right to privacy and (2) illegal search and seizure.” Although these concerns were largely settled matters, they have made a resurgence with the advent of drones as they can fly over residential zones and were initially perceived as being subject to unenforceable legislation. Nevertheless, there have been some measures, such as a bill posed by Senator Cory Booker, that have been taken to temporarily relieve the legal tension of drone usage (McMillin, 2015).

The major stakeholders in the field of UAV technology for agriculture and delivery are the U.S. government, commercial drone manufacturers, farmers, delivery providers, and consumers. The physical artifacts relating to this topic are, of course, drones and the preexisting machines that have led to the mechanization of farming and delivery such as tractors, crop-dusting and delivery planes, and trucks (Vempati, Crapanzano, Woodyard, & Trunkhill, 2017). Some non-physical artifacts are the laws surrounding drone use and the economic variables that weigh into their viability.

One of the earliest questions in STS refers to the degree of influence that technology places on society and vice versa. While some scholars contend that technology and society mutually shape one another, others deliberate that the mutualistic nature of this relationship is disproportionate. The main STS framework that I will use to support my analysis is the social construction of technology (SCOT), which explains how technological development is directed by societal forces and constructs. This framework contrasts the theory of technological determinism, which is in many ways critical of social constructionism. Technological determinism states that it is technology that dictates the actions of a society, but not vice versa. While technological determinists are often critical of social constructionism, since my argument refers to the societal forces that are impeding the advancement of drone technology, it is clear that SCOT will be more useful for the analysis.

The second framework that I will use to support my argument is actor network theory (ANT), which weighs the influence of both human and non-human actors linked to a given problem, providing a more holistic analysis of technological happenings. Some critics of actor network theory have issues with the fact that human and non-human actors have equitable degrees of influence. While it is true that some actors have a more significant impact than others, this critique does not weaken the analysis because actors with little influence do not add anything substantive to the investigation. Furthermore, I would argue that in the case of drone implementation, the non-human actors such as laws, social constructs, and economic forces have as much if not more influence on the development. While each of these theories have their respective critiques, I find that they are the most suited for analyzing this technological development.

This research is worthy of attention because drone implementation has so much utility outside the bounds of military operations. For both agriculture and delivery, energy is one of the key inputs. As a result of using a tremendous amount of fuel for energy, there are several environmental concerns that arise. Both the agricultural and delivery industries can be made far more efficient, producing a much smaller carbon footprint, with the implementation of drones. Lastly, with their implementation in the agricultural industries we could cut down on the amount of water that is wasted, pesticide use, and eutrophication from fertilizers while also providing humanitarian relief in agriculture-based communities (Shahid & Rashid, 2016). My research is currently in the data collection phase, but I plan to begin analysis in the spring of 2020.

Research Question and Methods

What are the potential benefits of UAV technology in the agricultural and delivery industries and what are the obstacles preventing their widespread implementation? What I want readers to understand from my research is that drones are, or are not, a commercially viable undertaking based on the costs and benefits of their usage. For my method, I plan to employ policy and network analysis while incorporating elements of wicked problem framing. I will also cite existing studies and their methods while annotating and emphasizing their findings. These are the most useful methods for the topic at hand because the use of drones in these fields is still in its infancy. As such, it only makes sense to determine the existing data on the environmental and economic costs of agricultural and delivery services and weigh the potential benefits posed by recent drone studies. In discussing legislative issues, I will outline the existing laws and compare the works of those in favor and those opposed. For example, I will compare and contrast the motivations of Senator Cory Booker's Bill promoting drone use as stated by McMillan to the legal obstacles cited by Welte. As there is a lot of data on drone capabilities and limitations, it should be easy to adapt this information to applications in the designated industries.

Conclusion

For the technical report we will produce the plans for the 3U CubeSat mission beginning construction in the spring. For this mission, we have hypothesized that the data collected will indicate significantly higher concentrations of NO_2 and other air pollutants over certain areas of the U.S. For the STS research I will support or refute the legislative, economic, and environmental viability of drones for use in the commercial domain based on the capabilities and limitations of existing drone technology as noted by Hassanalian and Abdelkefi. In terms of the outcome of this research it is hypothesized that drones will be considered a commercially viable undertaking in the two spheres of interest.

References

Bergin, B. (2015). How Drones Are Shaping Diverse Industries. *Food Manufacturing; Rockaway*, n/a.

Bian, H., Fattah, R. J., Sun, Y., & Zhang, X. (2019). Noise prediction of drones in urban environments. In *Aeroacoustics Conferences*. *25th AIAA/CEAS Aeroacoustics Conference* (Vols. 1–0). https://doi.org/10.2514/6.2019-2685

Edwards, B. (2019). Drones and Security: The Future of Public Space Safety. *Security; Troy*, *56*(8), 39–41.

Gebicke, S., & Krout, T. (2014). Unmanned Aircraft Must Rise Above Barriers for Commercial Applications. *NASA Tech Briefs; New York*, 36–40.

Hassanalian, M., & Abdelkefi, A. (2017). Classifications, applications, and design challenges of drones: A review. *Progress in Aerospace Sciences; Oxford*, *91*, 99.

Jabr, F. (n.d.). How Does a Spectrograph Work? [Infographic]. Retrieved October 23, 2019, from Scientific American website: https://www.scientificamerican.com/article/ancient-stars-how-does-spectrograph-work/

Lee, B. (2016). Protection, Profit, or Privacy: Exploring Strategic Solutions for Integrating Unmanned Aerial Systems (UAS) and the Delicate Balance Between Commercial Opportunity and Public Safety . *Homeland Security Affairs; Monterey*. Retrieved from https://search.proquest.com/ataindex/docview/2206253996/abstract/17F80E63AEE24766PQ/1

Ludwig, S. E. (2018). Drones: A Security Tool, Threat and Challenge. *Security; Troy*, *55*(3), 36,38,40.

McGrath, J. J., & Smith, D. L. (1984). Respiratory responses to nitrogen dioxide inhalation:

Nitrogen dioxide. *J. ENVIRON. SCI. HEALTH, PART A.*, *19A*(4), 417–431.

McMillin, M. (2015). Proposed Bill Would Allow U.S. Commercial Drone Operations. *Aviation Daily; Washington*, *401*(37), 5.

News, C. H., E&E. (n.d.). CO2 Emissions Reached an All-Time High in 2018. Retrieved October 23, 2019, from Scientific American website: https://www.scientificamerican.com/article/co2-emissions-reached-an-all-time-high-in-2018/

Pederi, Y. A., & Cheporniuk, H. S. (2015). Unmanned Aerial Vehicles and new technological methods of monitoring and crop protection in precision agriculture. *The Institute of Electrical and Electronics Engineers, Inc. (IEEE) Conference Proceedings.*, 298–301. http://dx.doi.org/10.1109/APUAVD.2015.7346625

Shahid, Z., & Rashid, A. (2016). Applications of UAV in Daily Life. In *AIAA SciTech Forum*. *54th AIAA Aerospace Sciences Meeting* (Vols. 1–0). https://doi.org/10.2514/6.2016-1895

Tham, Y. W., F, Takeda, K., & Sakugawa, H. (2008). Exploring the Correlation of Particulate PAHs, Sulfur Dioxide, Nitrogen Dioxide and Ozone, A Preliminary Study. *Water, Air and Soil Pollution; Dordrecht*, *194*(1–4), 5–12. http://dx.doi.org/10.1007/s11270-007-9611-x

Tripicchio, P., Satler, M., Dabisias, G., Ruffaldi, E., & Avizzano, C. A. (2015). Towards Smart Farming and Sustainable Agriculture with Drones. *The Institute of Electrical and Electronics Engineers, Inc. (IEEE) Conference Proceedings.*, 140–143. http://dx.doi.org/10.1109/IE.2015.29

Vempati, L., Crapanzano, R., Woodyard, C., & Trunkhill, C. (2017). Linear Program and Simulation Model for Aerial Package Delivery: A Case Study of Amazon Prime Air in

Phoenix, AZ. In *AIAA AVIATION Forum*. *17th AIAA Aviation Technology, Integration, and Operations Conference* (Vols. 1–0). https://doi.org/10.2514/6.2017-3936

Welte, P. (2018, June 10). Navigating the legal issues surrounding UAVs. Retrieved October 23, 2019, from https://www.agweek.com/opinion/columns/4458007-navigating-legal-issues-surrounding-uavs