Remote Sensing of Roadway Infrastructure via Spacecraft to Improve Monitoring Frequency
(Technical Paper)

Collision Possibilities and Interference with Ground Based Astronomy Caused by an Excess of Satellites in Orbit
(STS Paper)

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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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Current Methods of Road Testing and Issues with Satellites

Virginia has the third largest state-maintained highway system and is home to over 57,000 miles of road, all of which need to be kept in good condition to ensure a safe driving surface (NVTA, 2020, n.p.). Currently, the Virginia Department of Transportation (VDOT) does not have the capability to properly assess and maintain roadways and bridges in a way that minimizes costs and ensures safety (Gee, 2007, n.p.).

Due to a lack of efficient methods of assessing the health of roadway infrastructure, VDOT spends most of their time and money on reactionary methods of maintenance, which is fairly costly, instead of preserving the health of roads by using cheaper preventative measures (Gee, 2007, n.p.; Wilson, 2018, n.p.). The technical aspect of this project aims to assist VDOT by designing a satellite or aircraft equipped with remote sensing technology that will assess the health of roads and bridges and provide a cheaper method of evaluation. Remote sensing technology could also alleviate traffic caused by manual inspections and more frequent observation could prevent car crashes (Alhasan et al., 2018, p. 9).

The STS aspect of the project is examining the effect satellites can have on other satellites and ground based astronomy. While there are obvious concerns when creating a satellite, such as the cost and environmental effects of a rocket launch, this project will focus on the potential issues a satellite can cause once it is already in orbit. In 1978, Donald J. Kessler proposed a hypothesis called the Kessler Syndrome. The situation he describes is "As the number of artificial satellites in earth orbit increases, the probability of collisions between satellites also increases. Satellite collisions would produce orbiting fragments, each of which would increase the probability of further collisions, leading to the growth of a belt of debris around the earth" (Kessler et al, 1978, p.1). Another potential issue caused by satellites is

interference with ground based astronomy. Satellites can pass through images taken of outer space and ruin pictures or data. While this is a rare occurrence, as more and more satellites are put into orbit, this situation will happen much more frequently and astronomers are concerned. “The vast number of new satellites is one concern for scientists. As one astronomer put it, the night sky will be "crawling” with objects...” (Leslie, 2020, n.p.). The aim of the STS aspect of the project is to create awareness about the Kessler Syndrome and interference with ground based astronomy, while doing our best to not contribute to the problem.

Continuous Remote Sensing of Roadway Infrastructure via Spacecraft

Current methods of testing roadways such as visual inspection, acoustical techniques, and infrared/thermal imaging are inefficient and accomplished by use of a variety of ground based systems such as trucks that drive along the roads at slow speeds and visual inspection conducted by individuals. These have many drawbacks, including traffic buildups due to lane closures and being labor intensive (Vaghefi et al, 2012). Additionally, they each have limitations such as invalid assessment of interior infrastructure, inaccurate testing and limited usage (McGuire 2020, para. 1-3). To improve efficiency of the inspection process, the team’s solution must include remote-sensing enhanced nondestructive evaluation through the combination of the state-of-the-art that includes spacecraft and aircraft. A satellite could look at all the roads in the state multiple times per month and determine where problems arise, while drones could be deployed to these problem areas to get a closer look and determine what action needs to be taken. This would create a more efficient system for the state’s roadways that would cost less, require less labor, and cause fewer infrastructure related transportation delays.

Maintaining transportation infrastructure is vital for the wellbeing of the state and public. The collapse of bridges is extremely dangerous as shown by the death of 13 people when I-35W

collapsed in Minnesota in 2007 (Vezner, 2007, n.p.). Although the collapse has led to reform in how infrastructure is inspected, those methods are now dated and could be improved for more efficient and less costly methods of inspection. Research indicates that as road and bridge surface conditions deteriorate, there are more collisions and accidents tend to be more severe (Alhasan et al, 2018). By sensing all transportation infrastructure continuously, it would be possible to identify which roads and bridges are deteriorating at faster rates and put more time and effort into these problematic areas. By monitoring roadway infrastructure more frequently, VDOT would be able to provide the safest possible conditions to limit accidents as much as possible.

Research indicates there are a variety of remote sensing options available with either drones or satellites that allow for remote sensing from air and space. A paper published by Devin Harris, a Civil Engineering Professor at the University of Virginia and other contributors says "Remote sensing technologies can be used to assess and monitor the condition of bridge infrastructure and improve the efficiency of inspection, repair, and rehabilitation efforts" (Vaghefi et al, 2012, p.1). The paper discusses the wide variety of sensors that is the focus of the technical project, including Synthetic Aperture Radar (SAR), Interferometric Synthetic Aperture Radar (InSAR) on satellites, and a sensor called Light Detection and Ranging (LIDAR) on drones (Ma, 2019). These types of systems are already being used in other parts of the country and in the world. Drones are being sent into areas that might be dangerous for human inspectors, such as at heights or in areas with moving heavy machinery (Danielak, 2019); while satellite systems, like InSAR, are being used to monitor infrastructure such as the sinking of the Millenium Tower in San Francisco (Meyer, 2016).

Designing a system that will be able to see all the roads of Virginia and accurately determine which roads and bridges have damage will come with various challenges. The most

effective solution the project team has decided upon is to design a system with an overarching satellite that collects information on all roadways daily with a few drones or UAVs that can be sent to analyze the problematic areas in more detail. Satellites are limited in what resolution they are able to detect and the best technology is expensive, so the state of the art may not be within reach and we may need to use suboptimal sensors to offset cost. Drones are also limited by Virginia laws requiring them to be manually piloted as well as blocking them from flying overhead a moving vehicle, which greatly decreases the range they can cover in a day and could also lead to road closures. Camera systems installed in vehicles through companies like MobilEye and Tesla could provide intel into transportation infrastructure usage and quality, but it may be difficult to gain access to the data. A combination of multiple sources of data allows for a good combination of coverage and detail.

Problems Caused by an Excess of Satellites in Orbit

Since 1957 humans have been sending man made objects into space. Now, there are over 2,500 active satellites in orbit around the earth and when dead satellites and other free floating pieces are included, there are over 29,000 space objects larger than 10 cm in orbit (Datta, 2020, n.p.). These satellites and other space objects have the ability to cause problems for other satellites and ground based astronomers. The Kessler Syndrome proposes that the density of artificial satellites in Low Earth Orbit (LEO) could become so high that collisions could occur which explode into thousands of pieces. These pieces can then collide into other satellites, creating a snowball effect (Kessler et al, 1978). Another potential issue caused by the ever increasing number of satellites, is interference with ground based astronomy. As satellites fly overhead, they sometimes cross through the telescopes and cameras being used to observe outer space, occasionally causing errors in data or images. Satellites are often the most visible in the

early mornings and evening which are also the best times to detect asteroids (Leslie, 2020). If satellites start to affect the ability of humans to detect asteroids, it could cause serious problems if the asteroid is earthbound. The STS aspect of this project aims to promote awareness problems caused by Kessler Syndrome and interference with ground based astronomy, as well as do all that is possible to ensure the system created through my technical project does not further exacerbate the issue.

The original proposal put forth by NASA scientist Donald Kessler creates the most extreme scenario possible. Kessler revisited his paper 32 years later in 2010 with more accurate models and a better idea of the growth of space objects. In this paper he concluded that while the situation is not as dire as previously thought, by retrieving some orbital debris and enforcing guidelines the situation should be manageable (Kessler et al, 2010). However, there are still some troubling trends. Figure 1 displays the total number of known space objects in orbit and their growth from the beginning of space exploration until 2010. The spike in 2007 was caused by an accidental collision between the Iridium 33 and Cosmos 2251 spacecrafts leading to over 1500 new pieces of space junk in LEO (Kessler et al, 2010, p.4). This spike in objects gives evidence to support Kessler Syndrome showing how collisions can occur and in turn, create objects which increase the probability of more collisions.

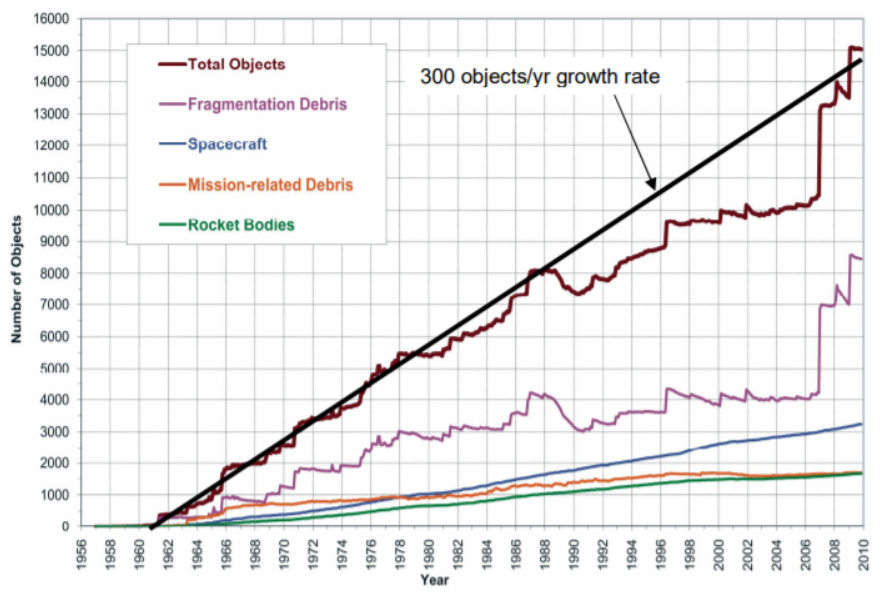

Figure 1: Number of Catalogued Items in Low Earth Orbit (Kessler et al, 2010, p.4)
Figure shows how the number of objects has increased since humans first began space programs. Huge jump in 2007 shows the impact an orbital collision can have.

The growth of objects in space is only going to accelerate as large artificial constellations, such as Elon Musk's Starlink, are planned and being launched. These large, bright objects are low enough that astronomers say they could interfere with astronomical observations. The number of satellites that can interfere with ground based astronomy will rise 400 to almost 42,000 with the launch of man made satellite constellations (Leslie, 2020). Although these satellites are being built in ways to counteract some of the astronomical issues, astronomers say this will not fully eliminate the problem. Figure 2 shows how satellites can impact observations of outer space, the white lines going across the image are due to the initial satellites of the Starlink constellation.

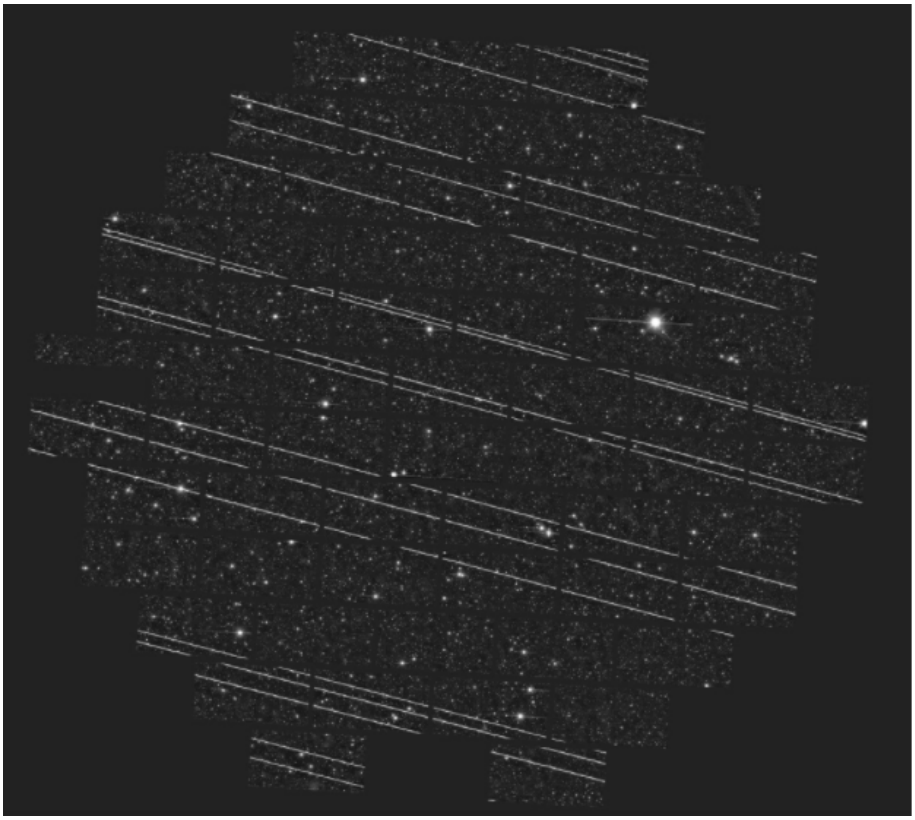

Figure 2: Telescopic Image Marred by Satellite Crossings (Leslie, 2020, n.p)
The white streams going horizontally across the image are the result of satellites. This interference can cause significant errors in lengthy extra-terrestrial investigations.

The purpose of the STS aspect of this paper is to raise awareness of the possible side effects of satellite launches and what our future sky could possibly look like. The knowledge gained from this research will be applied to the technical solution created. Any satellite that is designed by the technical project team will be equipped with the correct avoidance technology and dimming techniques. This will ensure that the project team does not create a negative impact on the world and the night sky.

Conclusion

The most likely solution to the problem of "Remote Sensing of Roadway Infrastructure via Spacecraft" will be a satellite in low earth orbit equipped with sensors such as SAR or InSAR. The project team will be charged with designing this satellite to minimize cost and

maximize accuracy and availability. This satellite when used in conjunction with existing ground systems or a new system of drones and UAVs could greatly increase VDOT's ability to monitor the safety of roadway infrastructure. As a result, VDOT will save money by being able to focus on preventative measures of roadway maintenance instead of more expensive reactionary techniques.

Throughout the process of researching and designing this technical solution, I will learn more about the complications of satellite launches and the importance of designing a satellite the correct way. By confirming that the entire project team understands the repercussions of satellites in orbit, the knowledge gained by this research can be spread further as they head into the aerospace industry.

Resources

Alhasan, A., Nlenanya, I., Smadi, O. G., and Mackenzie, C. A., (2018). Impact of pavement surface condition on roadway departure crash risk in Iowa. *Infrastructures, 3*(14), 14-31, doi:10.3390/infrastructures3020014

Brinson, K. (2018). How satellites avoid attacks and space junk while circling the Earth. Retrieved from https://www.forbes.com/sites/oracle/2018/07/02/how-satellites-avoid-attacks-and-space-junk-while-circling-the-earth/#93958c6596ab

Danielak, M. (2019). Drones improve safety of infrastructure inspections. Retrieved from https://www.roadsbridges.com/drones-improve-safety-infrastructure-inspections

Datta, A. (2020). How many satellites orbit Earth and why space traffic management is crucial. Retrieved from https://www.geospatialworld.net/blogs/how-many-satellites-orbit-earth-and-why-space-traffic-management-is-crucial/#:~:text=Debris%20in%20orbit,around%20in%20their%20orbits%20incommunicado

Gee, K. W. (2007). Highway Bridge Inspections. Retrieved from https://www.transportation.gov/testimony/highway-bridge-inspections

Kessler, D. J., and Cour‐Palais, B. G. (1978), Collision frequency of artificial satellites: The creation of a debris belt, *J. Geophys. Res.*, 83(A6), 2637– 2646, doi:10.1029/JA083iA06p02637.

Kessler, D. J., Johnson, N. L., Liou, J. C., and Matney, M. (2010). The Kessler Syndrome: Implications to future space operations. *Advances in the Astronautical Sciences, 137*(8). Retrieved from http://aquarid.physics.uwo.ca/kessler/Kessler%20Syndrome-AAS%20Paper.pdf

Leslie, M. (2020). Internet Satellite Boom Presents Astronomical Problems. *Engineering, 6*(8), 849-850. doi: 10.1016/j.eng.2020.06.008

Ma, P. (2019). Eyes in the sky: How satellites can monitor infrastructure health. Retrieved from https://theconversation.com/eyes-in-the-sky-how-satellites-can-monitor-infrastructure-health-117216

McFall-Johnsen, M. (2019). SpaceX's Starlink internet satellites could make astronomy on Earth 'impossible' and create a space-junk nightmare, some scientists warn. Retrieved from https://www.businessinsider.com/spacex-starlink-satellites-risks-astronomy-space-junk-2019-11#:~:text=Too%20many%20satellites%20could%20lead%20to%20a%20space%2Djunk%20catastrophe&text=The%20more%20stuff%20we%20put,making%20additional%20collisions%20more%20likely

McGuire, S. (2020). A look into the modern bridge inspection technologies: Giatec Scientific. Retrieved from https://www.giatecscientific.com/education/bridge-inspection-technologies/

Meyer, F. J. (2016). Using interferometric synthetic aperture radar for network-wide transportation infrastructure monitoring. Lecture. Retrieved from http://onlinepubs.trb.org/onlinepubs/webinars/161107.pdf

NVTA. (2020). Roads/Bridges. Retrieved from https://nvta.org/resources/transportation-profiles/roads-bridges/#:~:text=State%2Dmaintained%20System%3A%2057%2C867%20miles&text=Primary%20%E2%80%94%208%2C111%20miles%20of%20two,are%20numbered%20600%20and%20above.

Sheetz, M. (2020). SpaceX is manufacturing 120 Starlink internet satellites per month. Retrieved from https://www.cnbc.com/2020/08/10/spacex-starlink-satellte-production-now-120-per-month.html

Vaghefi, K., Oats, R. C., & Harris, D. K. (2012). Evaluation of Commercially Available Remote Sensors for Highway Bridge Condition Assessment. Journal of Bridge Engineering, 17(6). Retrieved from https://ascelibrary.org/doi/10.1061/%28ASCE%29BE.1943-5592.0000303

Vezner, T. (2007, August 20). I-35W bridge collapse / 13th, final victim recovered. *Twin Cities Pioneer Press*. Retrieved from https://www.twincities.com/2007/08/20/i-35w-bridge-collapse-13th-final-victim-recovered/

Wilson, J. (2018). The 3 types of road maintenance. Retrieved from https://everythingroads.com/2018/the-3-types-of-road-maintenance/