DESIGN OF AUTONOMOUS DISINFECTION ROBOT FOR HOUSEHOLD ENVIRONMENTS

THE IMPACT OF AUTONOMOUS TECHNOLOGY ON ACHIEVING SUSTAINABILITY

A Thesis Prospectus
In STS 4500
Presented to
The Faculty of the
School of Engineering and Applied Science
University of Virginia
In Partial Fulfillment of the Requirements for the Degree
Bachelor of Science in Mechanical Engineering

By
Cole Lloyd

November 1, 2021

Technical Team Members:

Jacob Adelsheimer
Borah Choe
Christopher Dauber
Dong Wook Kim

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.

ADVISORS

Catherine Baritaud, Department of Engineering and Society

Tomonari Furukawa, Department of Mechanical and Aerospace Engineering

Whether it is drones, robots, or vehicles, autonomous technology, or technology that can operate independently from humans, is growing in frequency each passing day. Transportation, manufacturing, and electronics are just a few of the major areas in which automation is being applied daily. Many major corporations have reached a point in which autonomy is essential in their continued relevancy. According to Dr. G. V. V. Ravikumar, an associate vice president at Infosys consulting company, "if organizations are really serious about staying at the top, embracing autonomous technologies … is extremely critical (Ravikumar, n.d., para. 14). As self-sufficient technology continues to advance, the communal relationship between humans and artificial intelligence continues to evolve as well. For example, the DaVinci robot has become popularized in the medical field as it seems to act "as an extension of the surgeon's hand" (Lamphere, 2018, p. 28). Furthermore, autonomous technology has become especially crucial in the field of medicine due to the recent COVID-19 pandemic. The coronavirus (COVID-19) is an infectious disease and was distinguished as a national pandemic by the World Health Organization on March 11, 2020- causing many influenza-like symptoms such as fatigue, couch, and other respiratory issues (Abolhassani et al., 2020, p. 2). Consequently, surface contamination has become a major issue as "virus-laiden respiratory droplets tend to settle and contaminate surfaces within a 1.8 [meter] distance from the virus source (Belluco et al., 2021, p. 696). Therefore, autonomous technology could be utilized to avoid this risk of contamination.

This concern is directly addressed by the technical project and loosely coupled STS topic described in this prospectus. The design goal for the technical project is to design a light-weight, low-cost, fully autonomous household robot to disinfect surfaces while still remaining safe to perform around humans. Furthermore, the robot will come equipped with a robotic arm to manipulate a UV-C light for disinfection purposes. While the technical project explores the

direct use of autonomous technology in a daily consumer's life, the paired STS research project will explore this matter further-, examining the impact of autonomy towards achieving sustainability. The design work and research will take place over both the Fall 2021 and Spring 2021 semesters and will result in a technical report and thesis.

DESIGN OF AUTONOMOUS DISINFECTION ROBOT FOR HOUSEHOLD ENVIRONMENTS

The use of autonomous technology in the field of medicine continues to grow with examples such as the DaVinci robot mentioned previously (Lamphere, 2018, p. 28). The introduction of the coronavirus has only accelerated this process in the medical field. In response to the COVID-19 pandemic, many hospitals sought an efficient way "to sanitize and sterilize their place of business," leading to the creation of "the first autonomous robot equipped with UV-C light to kill bacteria" in early 2020 (González, 2020, p.33). The issue with this model, and many other current disinfection robots, is that the sheer size and bulk of the robot fails to navigate in smaller, concentrated areas. Thus, the efficiency of disinfection is not maximized. Furthermore, the device would require users to vacate the area during operation due to the large vertical ultraviolet lamps and the subsequent harmful nature of UV-C light. Research has shown that UV-C light that ranges from 100 to 280 nanometers has the greatest chance in fighting the coronavirus (Extance, 2021, p. 10). On the other hand, this spectrum is the most dangerous to humans as UV-C light in the 254-nanometer range "penetrates human skin and eyes, leading to skin cancer and cataracts" (Anderson, 2020, p. 52-53). Therefore, a disinfection robot that is able to perform safely around humans would be extremely beneficial.

The technical project objective is to design a low-cost, portable, and fully autonomous household robot equipped with a UV-C light for disinfection purposes. Since the device must be designed for household use, it is imperative that the robot can perform safely around humans.

Therefore, the UV-C light must be properly shielded from contact with human eyes and skin while still properly disinfecting surfaces, as surfaces can be contaminated anywhere within a 1.8 meter range from the virus source (Belluco et al., 2021, p. 696). Additionally, this robot will improve upon the past team's similar design goal of a disinfection robot for indoor environments which was named the Robot Operating System Infection Eliminator (ROSIE). While the current team on this project is designing an original model from scratch, the goal is also to improve upon the apparent flaws of the previous team's design. As seen in Figure 1, the past robot was much too large and bulky to properly disinfect smaller concentrated areas such as corners and irregular shaped surfaces. Furthermore, the previous model did not achieve total autonomy, thus maneuverability and degree of autonomy are crucial target specifications for the current design model. Using this background information the design process will center around three main objectives- design a robot that is safe to perform around humans, ensure high maneuverability and portability, and maximize efficiency of disinfection via autonomy.

The autonomous disinfection robot will be designed and constructed throughout a two-semester long capstone project led by Tomonari Furukawa, a mechanical and aerospace engineering professor and director of the Virginia Cooperative Autonomous Robotics (VICTOR) lab at the University of Virginia. The first semester consists primarily of planning and research such as reviewing existing technologies, allocating customer needs and related target

specifications, and generating concepts for our design process. Consequently, the second semester will consist of designing and testing the robot- refining the mistakes that arise throughout the process. The testing and development of the disinfection robot will take place at the Observatory Mountain Engineering Research Facility with various resources such as lab computers equipped with Robotic Operating System (ROS) software. The team members on this project consist of Jacob Adelsheimer, Borah Choe, Christopher Dauber, Dong Wook Kim, and Cole Lloyd, all of whom are an undergraduate student in their fourth year studying mechanical engineering at the University of Virginia School of Engineering and Applied Science. The project will be documented in a technical report. The desired outcome from this project is an autonomous disinfection robot that can easily maneuver and operate around humans safely.

THE IMPACT OF AUTONOMOUS TECHNOLOGY ON ACHIEVING SUSTAINABILITY

Despite its growing popularity, many individuals remain skeptical of autonomous technology and question the positive impact it can have. While medical service robots have seen a recent upsurge due to the coronavirus, "there is a heated debate on whether COVID-19 is speeding up the robots' use to replace human workers (Ozturkcan & Merdin-Uygur, 2021, p. 1). There is a persistent fear among society that increase of autonomy in the workspace can lead to economic detriment. Although people may believe that manufacturing jobs will be lost to automation in the years to come, this technology can make workers' jobs safer and easier while simultaneously promoting environmental and social sustainability. Due to climate change reaching an alarming level in recent years, with many nations declaring the issue a global emergency, numerous delivery companies are striving to reduce their respective carbon emissions. In order to reach their goal of carbon neutrality by 2040, FedEx took the following actions:

> The company pledged an initial investment of $2 billion to start electrifying its massive fleet of more than 180,000 vehicles and $100 million for a new Yale Center for Natural Carbon Capture (Butler & Mufson, 2021, p. A18).

Many companies such as FedEx feel a sense of frustration as there is an immediate need to reduce carbon emissions throughout these companies; however, the technology required to achieve this goal of sustainability can only be researched and manufactured in a deliberate manner.

ATTAINING UNIVERSAL TRUST IN AUTONOMY

A possible compromise to address both issues of reducing carbon emissions and gaining universal trust in autonomous technology could be the introduction of autonomy in transportation. Some suggest an entirely autonomous fleet of electric vehicles which would provide "a path to overcome the personal ICV's wasteful energy consumption and emissions" (Martin, 2020, p. 29). This process is understandably complex however, with traffic engineers determining the specific necessary conditions for free flow transportation with little to no accidents (Meyboom, 2019, p. 160). Although the process is undoubtedly difficult to perfect, a systematic public transportation fleet of autonomous vehicles could reduce personal vehicle travel and carbon emissions through optimizing transportation routes all the while ensuring an efficient mode of travel for all people. Additionally, this complete shift in transportation can dramatically reduce the transportation industry's carbon footprint, while allowing time and resources for the research and manufacturing of completely carbon-neutral technology. Furthermore, Thomas Porter, researcher at the Big Data Analytics Research Unit in Dublin, Ireland, conducted several surveys and experiments finding that autonomous vehicles increase efficiency without human error; as shown in Figure 2, surveys reveal that there was an eighty percent relevance in reduction of traffic accident-related costs and a sixty-two percent relevance

in decreased fuel consumption of autonomous vehicles.

Table 8 Autonomous vehicle benefits to the mobility ecosystem (%, relevance)

Traffic safety improvements	82
Reduction of traffic accident-related costs	80
Increased mobility for elderly, disabled	77
Expanding car- and ride-share programs	75
Traffic network efficiencies	73
Decline in vehicle ownership and vehicles per family	67
Decreased fuel consumption	62

Sources: EY; my survey among 4,100 individuals conducted January 2020.

Figure 2: Autonomous vehicle benefits to the mobility ecosystem (%, relevance) (Porter, 2020, p. 34)

The idea of autonomous transportation is just one of many applications of autonomy promoting global environmental sustainability.

In addition to environmental sustainability, autonomy can also lead to a dramatic increase in social sustainability such as fair labor practices, social equity, and satisfactory health and safety conditions to name a few. For the example of autonomous transportation, “reducing automobile dependency and encouraging people to walk” could lead to more social encounters in the city, thus improving social relationships and community engagement (Cugurullo, 2021, p. 82). Furthermore, a social divide would be less apparent between different classes of wealth as autonomous bus transportation could be affordable for all parties. Eileen Crist, William J.

Ripple, and Christopher Wolf, three journalists for the scientific journal collection *SpringerLink*, propose six transformative steps for mitigating climate change:

[1] energy—replacing fossil fuels
[2] short-lived air pollutants—reducing methane, black carbon (soot), and hydrofluorocarbons
[3] nature—protecting and restoring Earth's ecosystems for sequestering carbon
[4] food—eating mostly plant-based foods, improving cropping practices, and curbing food waste
[5] economy—shifting from unlimited GDP growth to ecological economics and sustainable monetary practices
[6] human population—curbing population growth in the context of social justice (Crist et al., 2021, p. 1753)

The article highlights that climate change mitigation can be realized while still placing an emphasis on population policies that could promote social justice and gender equity. As seen in Figure 3, social justice and population issues are rarely discussed when dealing with climate change policy. Implementation of autonomous technology such as transportation vehicles could serve as a gateway between environmental sustainability and social sustainability issues that are often undervalued when concerning climate policies.

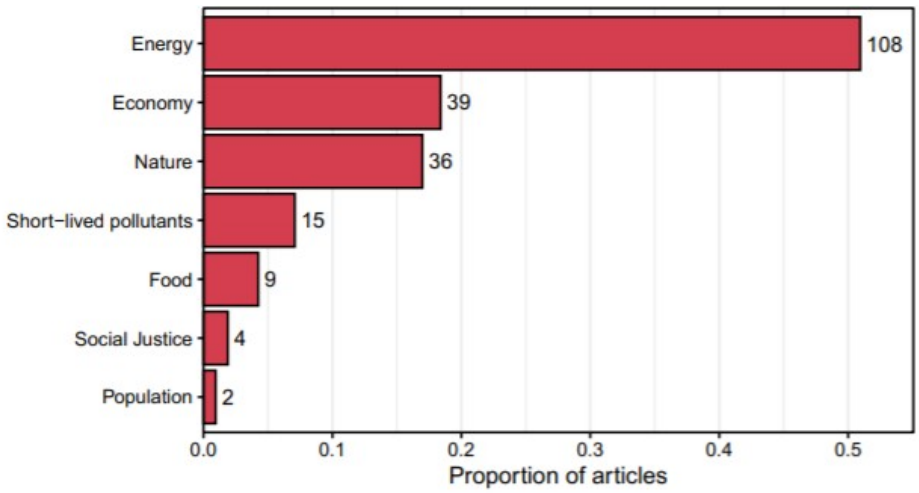

Figure 3: Proportion of the 212 Nature and Science climate change policy articles dealing with each topic (Crist et al., 2021, p. 1754)

The Social Construction of Technology (SCOT) framework introduced by Trevor Pine and Wiebe Bijker will be used to investigate the impact of autonomous technology on environmental and social sustainability (Bijker & Pinch, 1984). As seen in Figure 4, the center party, in this case the engineer, communicates and exchanges information with the other relevant social groups affected by the specific autonomous technology. Therefore, allowing different social groups and societies that will be directly affected by the presence, or lack thereof, of this technology to possibly shape the direction of the technology in the future gives them a sense of agency in the matter. Consumers and normal individuals can have a direct say and impact on autonomous technology. Therefore, their assessments and desires can be well reflected in the eventual product of said technology created by engineers.

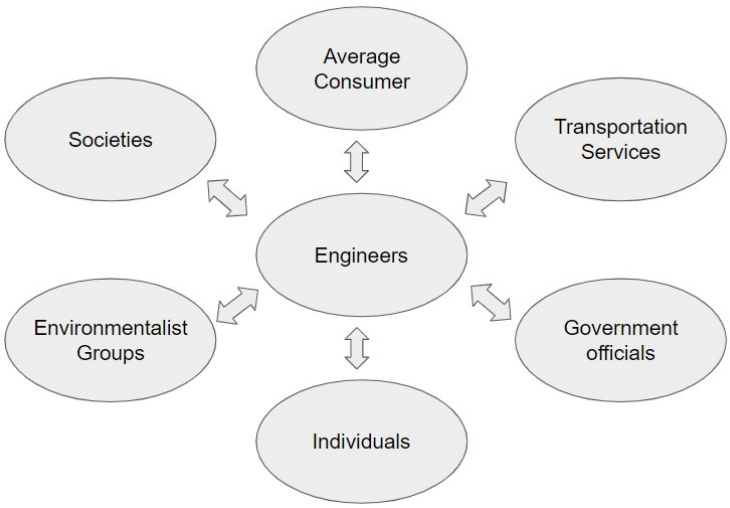

Figure 4: Sustainable autonomous technology SCOT model. The engineers facilitate information among various social groups to shape future technology (Lloyd, 2021)

This STS research project will be a scholarly article detailing the impact of autonomous technology on environmental and social sustainability. The article will also explore the possible

technological solution of achieving sustainability through the implementation of fully autonomous transportation services.

Works Cited

Abolhassani, H., Arjmand, S., Bashiri, G., Fatemi, F., Ghassemlou, A., Ghiasi, B., Poodeh, S. H., Haji-Yousefi, A. M., Nejad, Z. H., Kouchakzadeh, H., Masoudi, H., Montazeri, M., Rahmandoust, M., Rezaei, S., Sariolghalam, M., Sefidbakht, Y., Shojaosadati, S. A., Siadat, S. E. R. (2021). *COVID-19*. Springer. https://doi.org/10.1007/978-981-16-3108-5

Anderson, M. (2020). The Ultraviolet Offense: Germicidal UV lamps destroy vicious viruses. New tech might put them many more places without harming humans, *IEEE Spectrum*, *57*(10), 51-55. https://doi.org/10.1109/MSPEC.2020.9205549

Belluco, S., Mancin, M., Marzoli, F., Bortolami, A., Mazzetto, E., Pezzuto, A., Favretti, M., Terregino, C., Bonfante, F., Piro, R. (2021). Prevalence of SARS-CoV-2 RNA on inanimate surfaces: a systematic review and meta-analysis. *European Journal of Epidemiology*, 685-707. https://doi.org/10.1007/s10654-021-00784-y

Bijker, W. E., & Pinch, T. J. (1984). The social construction of facts and artifacts. Social Studies of Science, 14, 399–441. https://doi.org/10.1177/030631284014003004

Butler, D, & Mufson, S. (2021, March 8). Can the market save the planet? FedEx and other firms say they're trying. *The Washington Post,* A18. https://www.washingtonpost.com/climate-environment/2021/03/05/more-than-50-companies-have-vowed-be-carbon-neutral-by-2040/

Cabling, M. L., Hurtado-de-Mendoza, A., Sheppard, V. B. (2015). Rethinking agency and medical adherence technology: applying Actor Network Theory to the case study of Digital Pills, *Nursing Inquiry*, *22*(4), 326-335. https://doi.org/10.1111/nin.12101

Clark, H. (2021). Final assembled version of ROSIE [Figure 1]. *Technical Report* (Unpublished research paper). School of Engineering and Applied Science, University of Virginia. Charlottesville, VA.

Crist, E., Ripple, W. J., Wolf, C. (2021). Human population, social justice, and climate policy, *Sustainability Science*, *16,* 1753-1756. https://doi.org/10.1007/s11625-021-00951-w

Cugurullo, F. (2021). *Frankenstein Urbanism: Eco, Smart and Autonomous Cities, Artificial Intelligence and the End of the City*. Routledge. https://doi-org.proxy01.its.virginia.edu/10.4324/9781315652627

Extance, A. (2021). Putting UV Covid-19 disinfection under the spotlight. *Electro Optics*, 311, 10-14. https://bit.ly/3nqYAzo

González C. (2020). Cleaning with UV Light, *Mechanical Engineering*, 32-33. https://doi.org/10.1115/1.2021-JAN2

Lamphere, C. (2018). The dawn of a newish era: How AI, robotics, and everything in between shapes our world, *Online Searcher*, *42*(4), 27-30. https://bit.ly/3nLf2e7

Martin, G. (2020). A sustainability interrogation of the autonomous vehicle at its society-technology interface, *Bulletin of Science, Technology & Society*, *39*(3-4), 23-32. https://doi.org/10.1177/0270467620965466

Meyboom, A. (2019). *Driverless Urban Features: A Speculative Atlas for Autonomous Vehicles*. Routledge. https://doi-org.proxy01.its.virginia.edu/10.4324/9781351134033

Ozturkcan, H. & Merdin-Uygur, E. (2021). Humanoid service robots: The future of healthcare? *Journal of Information Technology Teaching Cases*, 1-7. https://doi.org/10.1177/20438869211003905

Porter, T. (2020). The design, regulation, and adoption of autonomous driving systems in smart sustainable urbanism. *Contemporary Readings in Law and Social Justice*, *12*(1), 30-36. https://bit.ly/3vHaRDy

Ravikumar, G. V. V. (n.d.). Autonomous technologies to power tomorrow's enterprises. *Infosys*. https://www.infosys.com/insights/ai-automation/autonomous-technologies.html