USING ROBOTICS TO INHIBIT THE SPREAD OF SARS-COV-2

THE INTEGRATION OF ROBOTICS IN SOCIETY, STARTING WITH MEDICINE

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By
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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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As the coronavirus pandemic grips the world and the United States, new technologies that can help to inhibit the spread of the SARS-CoV-2 virus have been implemented at higher rates. As countries attempt to control the virus, they have "quickly deployed digital technologies to facilitate planning, surveillance, testing, contact tracing, quarantine, and clinical management" (Whitelaw, Mamas, Topol, Van Spall, 2020). According the Centers for Disease Control and Prevention (CDC) website (https://covid.cdc.gov/) 9 million cases and 230,000 deaths have been reported in the United States as of November 1, 2020. The pandemic has stressed healthcare systems across the country and the world, and hospitals are seeking any advantage they can obtain.

Before the pandemic, robotic technology was already being implemented in healthcare at increasing rates, for a myriad of purposes. Sheetz, Claflin, and Dimick studied the increasing implementation of robotic surgery, and found that "the use of robotic surgery increased from 1.8% in 2012 to 15.1% in 2018" (p. 4). Yet, the COVID-19 pandemic has further changed the course of robot's implementation in the healthcare field. Yang et al. (2020) posited in March that "COVID-19 could be a catalyst for developing robotic systems that can be rapidly deployed with remote access by experts and essential service providers without the need of traveling to the front lines." (p. 2).

The technical research and the tightly coupled STS research in this report seek to deliver a greater understanding of the difficulties, benefits, and drawbacks to implementing robotics in healthcare with regards to the coronavirus pandemic. The technical report for this project will involve the design and creation of a semi-autonomous wheeled robot with multiple degrees of freedom that will use ultraviolet-C (UVC) light to disinfect high-occupancy rooms and remove SARS-CoV-2 from surfaces. By developing the robot from the ground up, the team will be able to observe state-of-the-art robotics technology from a highly interdisciplinary point of view that will leverage electrical, mechanical, computer, and software engineering. Tightly coupled to this project, the STS research for this report will attempt to determine to what degree robots can replace humans within healthcare, and what drawbacks and benefits robots will provide.

The team for the technical project consists of the author, five other undergraduate mechanical engineering students (Erin Dubas, Charlie Kellas, Connor Wynkoop, Cynthia Okoye, and Hannah Clark), one graduate mechanical engineering TA (Dean Conte) and the technical advisor, Professor Tomonari Furukawa of the Mechanical Engineering Department. This fall, concept generation will be completed and system level design started, with construction and testing of the robot being conducted in spring 2021.

THE STATE OF ROBOTIC DISINFECTION

COVID-19, among other diseases, is highly contagious, and reducing contact with the virus is critical to slow the spread. Although traditionally performed by support or custodial staff, the possibility to reduce contact with the virus by replacing human workers with robots is an attractive one. Disinfecting robots also have application in airports, train stations, testing facilities, and other public spaces. Prevost (2020) found that companies in charge of cleaning public spaces valued several qualities inherent to robots: they can run 24/7, can clean more thoroughly with the data to match, and can't spread the virus as easily as human workers ("For robots, it's a time to shine (and maybe disinfect)", para. 5) .

Although COVID-19 has spurred the adoption of robotic disinfection, it is not a completely new technology. Yang et al. (2019) conducted a study that proved the effectiveness of UV-C lights mounted on a robot in disinfecting aspergillus (fungus) and nontuberculous mycobacteria from hospital environments, both of which are often responsible for hospital acquired infections (HAIs)

(p. 492). The robot used was a Hyper Light P3, which has a UV lamp standing up from a wheeled base (p. 488). Hospitals have increasingly acquired robots that can disinfect rooms using ultraviolet tube lamps mounted on a wheeled base, which is at this time the most widely adopted design. In 2020, Simmons et al. proved the effectiveness of a standing tube robot developed by Xenex in eliminating SARS-CoV-2 from surfaces (p. 3). Schaffzin, Wilhite, Li, and Finney also proved that 2 Xenex LightStrikeUV-C robots decreased hospital acquired infections by 16.2% following program implementation (p. 904).

Now that the effectiveness of these robots has been proven and the pandemic stretches on, adoption has increased. A Xenex spokeswoman told Lindsey Carnett of the San Antonio Report that "since the start of the pandemic, Xenex has seen its sales increase 600% para. 9). Keutel (2020) found nine disinfection robots created by different companies being utilized in hospitals and other public spaces across the world, with some utilizing disinfectant spray and others ultraviolet light ("9 disinfection robots fighting the coronavirus", paras. 1-11).

Despite the success of the mounted tube robots, they have drawbacks. Most operate by following a path set by a human operator that the robot cannot deviate from, thus not including any autonomous functionality. And since the tube is mounted perpendicular to the base vertically, the light cannot easily disinfect surfaces above or below the robot that could include high-touch surfaces such as doorknobs, drawers, rails, and sinks. The technical project in question seeks to use a different design basis in order to solve those problems.

A NEW DISINFECTION ROBOT

Namely, the robot developed will have an arm that can rotate at the base, midspan, and at the end where the light is mounted to obtain greater coverage of all surfaces. The robot will likely incorporate side mounted lamps on linear actuators so that walls and the floor can be disinfected faster. The robot will also have semi-autonomous functionality and will use simultaneous localization and mapping (SLAM) to visualize a map of the surrounding environment, understand its position, and plot a map for coverage of every surface. As shown below in Figure 1, the robot will have a wheeled chassis to contain the electronics, a robotic arm with attached camera and spot UV lamp, and front and side mounted UV lamps.

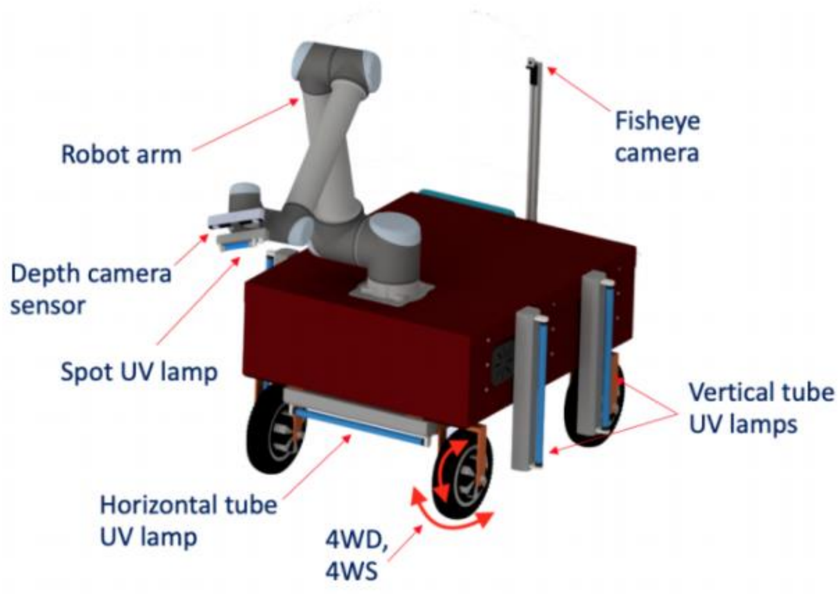


Figure 1: The Prior Disinfection Robot. A CAD rendering of the UV disinfection robot developed last year. The new design will have several changes, but the core design elements will most likely remain the same. (Adapted by Daniel Helmus (2020) from Conte, Leamy, Furukawa 2020).

The above figure depicts a similar robot that was designed and constructed by the graduate TA leading the team, Mr. Dean Conte. The team is currently planning to improve upon the original design in several ways: reducing the size and profile of the robot, mounting front, side, and back lamps on linear actuators and increasing battery capacity. The goal of these changes is to make the robot more adaptable, maneuverable, and better at cleaning. The system level diagram for the robot can be found below in Figure 2, where all the components of the robot and how they are connected can be found. Green lines depict communications connections, while red lines depict the main power line. The robot will incorporate a battery source to provide DC power for the robot, and an AC converter to divert power to the UV-C light, robotic arm, and computer. Green lines indicate communications connections, while red indicates direct power connections. DC power will also be connected to the motors and onto the wheels via an emergency stop condition that will be activated whenever a person enters the room and is detected by the robot.

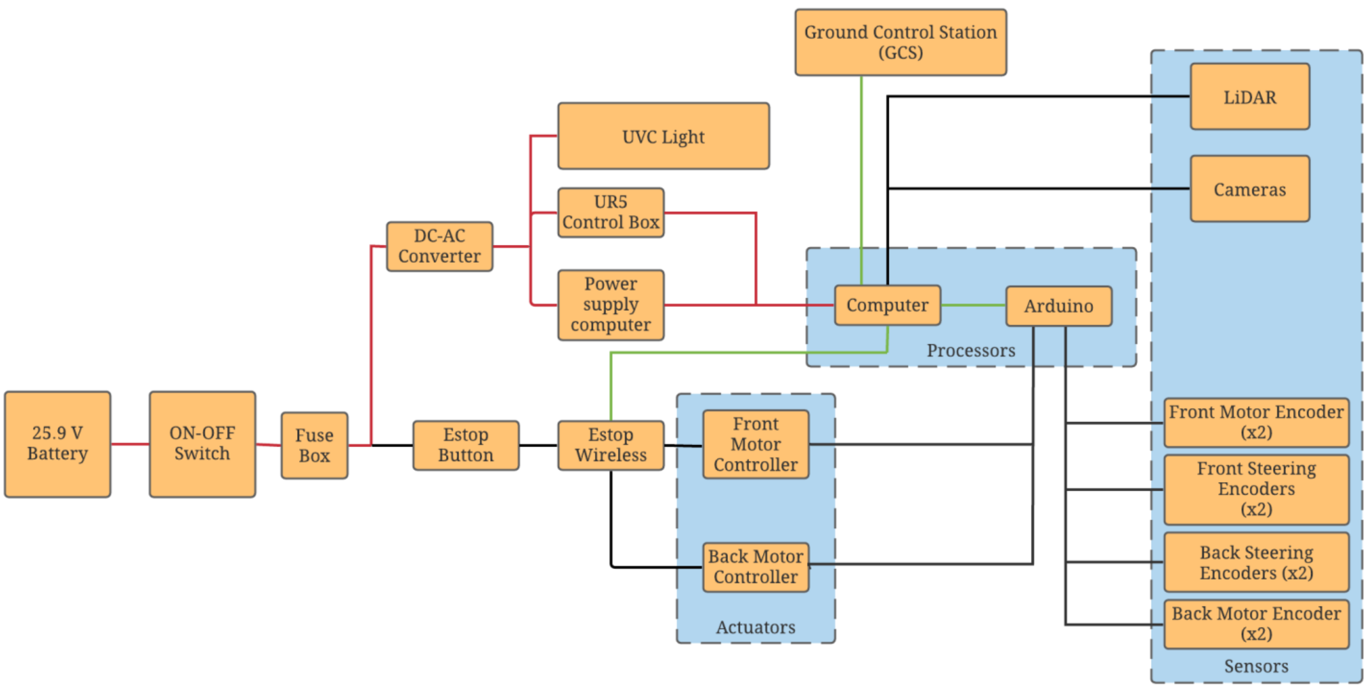


Figure 2: The System Diagram. The current draft of the disinfection robot's system diagram. The battery provides DC power to be utilized by the motors, computer, Arduino, robotic arm, and UV-C lights for successful operation of the robot. (Helmus, Clark, Wynkoop, Kellas, Okoye, Dubas, 2020).

The robot will be designed, constructed, and tested at the Observatory Mountain Engineering Research Facility (OMERF), with funding from the Naval Research Laboratory. The OMERF lab has on hand a great deal of tools and equipment, and whatever other components are needed will be purchased. The goals of the project are for total coverage of a testing area with as little human input as possible. A technical report on the development and testing of the completed robot will be written upon completion.

IMPACTING HEALTHCARE WITH ROBOTICS

The coronavirus pandemic has already changed the world in many obvious ways that are often painful to recognize. But in times of strife, humans often turn to technology to alleviate pain. Unlike prior epidemics such as SARS in 2003, Ebola in 2014 and MERS in 2015, the virus was not contained and can now be found throughout the world easily- creating an opening for new technology to solve new problems in the healthcare field. Yang et al. believed in March 2020 that robotics could automate many key processes in fighting COVID-19, but without global effort, they won't be developed enough to make a significant difference:

> Now, the impact of COVID-19 may drive further research in robotics to address risks of infectious diseases. But without sustained research efforts robots will, once again, not be ready for the next incident. By fostering a fusion of engineering and infectious disease professionals with dedicated funding we can be ready when (not if) the next pandemic arrives. (p. 2)

Hindsight tells us that America has indeed seen a widespread rise in implementation of disinfection robotics. Blake (2020) reported that as of April 15, the company UVD Robots had shipped hundreds of disinfection robots to China in February and hundreds more throughout Europe in March, with the company's sales growing 2,000% by April. This meant that when a 3-figure order was placed in February, "the company had nearly sold more robots that single day than it had during its first full year of commercial viability" ("In coronavirus fight, robots report for disinfection duty”, paras. 3-18). However, the high cost of most solutions (most between $40 and $125 thousand) stops many hospitals and healthcare centers from purchasing them (ECRI Institute, 2015).

Zeldovich (2020) examined recent innovations in robotics from surgical teleoperation, personal care robots, and ultraviolet disinfection. She described the future possibilities of robots that disinfect “shopping malls, supermarkets, train stations, offices, assisted living and nursing homes, fitness centers, schools, and prisons”, others that enable doctors to control robotic arms from miles away, and yet more that can perform coronavirus nasal swabs autonomously (p. 34-39).

Although disinfection and surgery are two obvious and well documented uses for robotics, there are other less documented benefits, especially concerning the mental state of healthcare staff. It is possible that robots could help share the burden that nurses and doctors face, especially in a year with such a strain on medical systems worldwide. Schecter et al. reported that of the 657 New York City healthcare workers surveyed during peak impatient admissions (April 9 -April 24 2020), 57% reported acute stress, 48% depressive, and 33% anxiety symptoms (p. 66). Reducing the load on doctors, nurses, and EMTs could help improve their lives as well as the treatment of their patients.

COVID-19 has also presented difficulties by forcing hospitals to freeze elective surgeries and procedures that will present future difficulties in the population. Earlier in 2020, Moawad, Rahman, Martino and Klebanoff suggested the following:

> Robotic surgery decreases the length of stay for patients, thereby increasing the availability of beds for other hospital needs… additionally, robotic surgery allows for the staff and surgeon to be remote from the patient and from each other. These advantages of robotics, combined with the use of appropriate PPE, will allow us to provide safe and

> much needed surgical management of our patients. ("Robotic surgery during the COVID pandemic: why now and why for the future," para. 14).

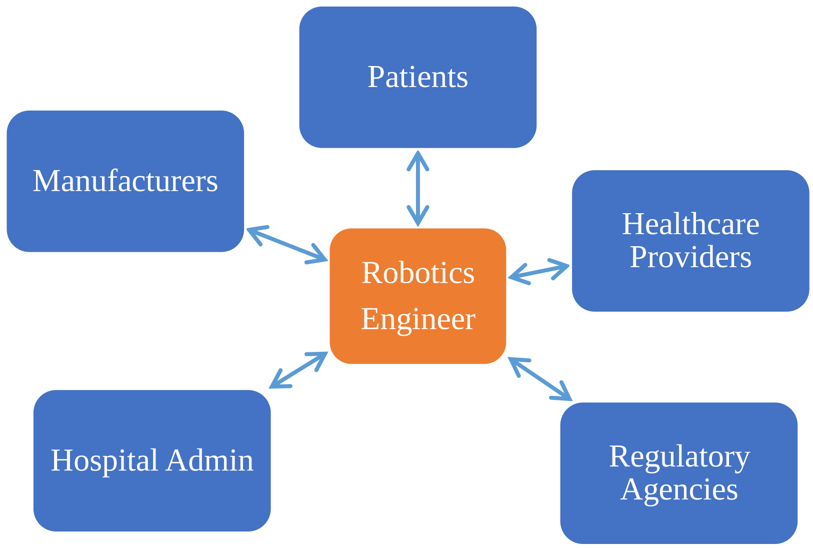
Disinfection robots, although expensive, will not go away once implemented. The coronavirus pandemic has made the users of public spaces well aware of the need for disinfection and cleaning. Many more custodial jobs may be supplemented with or performed by robotics in the following months. These developments will prompt questions that affect their implementation. How will robots displace certain roles that already exist in society? Are robots worth the significant investment required to truly replace certain roles within healthcare and medicine? If robots are implemented in healthcare, will they actually improve the treatment received by patients? If robots are adapted for disinfection purposes, they will be a more common sight for patients and others, which will open up the doors for robots operating in other spheres of society.

ROBOTICS, SOCIETY, AND HEALTHCARE: INSTRUCTIONS NOT INCLUDED

If robots are to be widely implemented successfully across a society's healthcare system, a Social Construction of Technology (SCOT) model should be adopted (Bijker, Hughes, Pinch, 1987). Bijker et al. (1987) also posit that technology does not shape human action alone, but rather that human action shapes and pushes technology to take certain forms. The framework also incorporates the idea of "interpretive flexibility", with different social groups deciding the purpose, use cases, and meaning of technology. With respect to healthcare robotics, humans will shape the technology to best fit their aims, and the technology will be developed in a similar manner to the model depicted below in Figure 3.

The key relationships within the SCOT model are patients, manufacturers, hospital administrations, regulatory agencies, healthcare providers, such as doctors, surgeons, and nurses, and the patients themselves.

Figure 3: SCOT model of healthcare robotics: The engineer at the center of this social construction model is responsible for creating a robot that will satisfy the needs of each group as much as possible. (Daniel Helmus, 2020).



The wellbeing of patients is at the forefront, with the robots being utilized in disinfection and surgery in order to provide better outcomes and keep the patient safe. Healthcare providers will utilize the robots to perform surgery, reduce hospital acquired infections and disease, and to keep themselves safe from diseases such as COVID-19. Hospital administrations, however, are the ones making the decision to adopt specific technologies in the end, as they are the final group in charge of what technology their facility can afford and how it will be used.

Regulatory agencies in health systems and governments will decide on a nationwide level how robotics can be used, and they may lag behind early adopters of the technology. For example, the FDA will regulate many robots as medical devices, subjecting them to premarket review. like all new technology, regulation will tend to lag behind implementation. In the future, new regulation specific to these robots may have to be adopted as well.

Finally, manufacturers of healthcare robotics have valuable input to the engineer; although many advanced software and hardware solutions are possible, they will not be utilized until they can be more efficiently and cheaply produced in order to create profit for the companies producing the technology. At this point, the high cost of most approved robotic systems is a significant barrier to widespread adoption.

The engineer at the center will provide new technology to be used by all of these different groups, and each group will have an interpreted, flexible definition of the technology and how it should be used. Although the goals and requirements of each group may not completely align, the outward facing affect to society must be the same for the technology to have widespread adoption. That is, the healthcare robotics must improve the wellbeing of patients and staff in hospitals and health systems. Without this outcome, the technology will not be used over traditional methods, such as cleaning and disinfection by human workers. However, tradeoffs must be made between each group, compromising on issues such as patient-facing solutions or regulatory demands.

Another part of SCOT is that “various solutions to these conflicts and problems are possible- not only technological ones but also judicial or even moral ones.” (Bijker, Hughes, Pinch, 1987, p. 121). Thus, the multiple problems implicated by COVID-19 can have multiple solutions, of which robotic disinfection provides a strong solution within healthcare, as shown in Figure 4 on page 12.

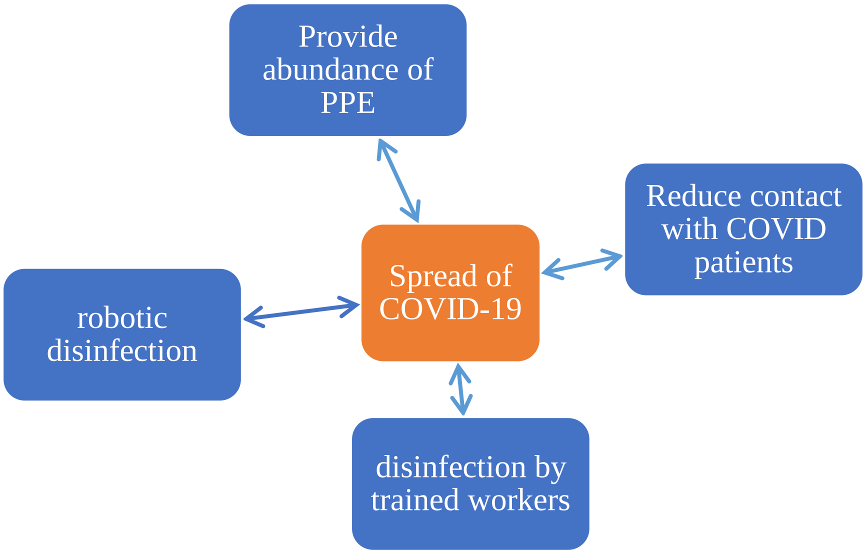


Figure 4: Problem-Solution Framework: The problem at the center of this social construction model has several solutions, that can be performed separately and/or in conjunction with one another. (Daniel Helmus, 2020).

The diagram shows several solutions to slowing the spread of COVID-19 within healthcare locations. The most clear and obvious is to reduce contact staff has with COVID-19 patients, and make sure that staff are equipped with appropriate personal protective equipment (PPE). Neither are always possible, especially in times where there is a heavy strain on the local health system such as at the beginning of the pandemic. The other solutions include robotic and human worker disinfection of shared spaces. At this point in time, most robots utilize UV light which must be performed in conjunction with human workers utilizing chemical disinfectant. The various solutions will require cohesion to achieve the best result. If robotic disinfection does not mesh well within that framework, then it will not have successful adoption.

My STS research project will be a scholarly article that will outline the benefits, drawbacks, and impedances to widespread adoption of robotics in healthcare. The article will also attempt to model how and why this technology will be adopted by society, and what effects it might have in the future.

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