THE INTEGRATION OF ROBOTICS IN SOCIETY, STARTING WITH HEALTHCARE

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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 COVID-19 pandemic grips the United States, healthcare systems across the country have been stressed immensely. According to the Centers for Disease Control and Prevention (CDC) website (https://covid.cdc.gov/) 28 million cases and 498,993 deaths have been reported in the United States as of February 23, 2021. 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). Robotics have several inherent qualities that can help with stopping the spread of COVID-19. 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 not spread the virus as easily as human workers ("For robots, it's a time to shine (and maybe disinfect)", para. 5). These benefits extend to healthcare facilities just as much as public spaces.

Although robots have found use in many surgical procedures as well as a utility for disinfection, there are still roadblocks to widespread adoption of robots within healthcare. Robotic disinfection solutions are expensive, often between US $30,000 and $135,000 per unit according to Cresswell and Sheikh (p. 2). These high prices forestall purchases by many facilities. Surgical procedures performed by robotics are similarly expensive, according to Sheetz, Claflin, and Dimick (p. 3). From a legal point of view, regulation of robots is often lacking, and tends to lag behind implementation leaving innovators with little guidance.

Simshaw et al. reported back in 2016 that "current medical device regulation and data protection laws will present legal challenges for the emergence of these robots that must be addressed in the very near future if innovation is going to continue to thrive." (p. 36). Likewise, the United States needs a strong robotics initiative to properly fund new robotic solutions. When comparing the United States to other countries in their adoption of new robotics to fight COVID-19, Murphy, Gandudi, Amin, Clendenin, and Moats (2021) found that "…a national robotics initiative appears helpful in terms of prior availability of existing robots and enabling a breadth of applications. In addition, it may be helpful in creating end-user awareness and acceptance of robotics." (p. 14). It is also apparent that robots such as the one seen in Figure 1 below, can displace certain workers such as some janitorial roles in hospitals within healthcare and medicine, as they have done in other fields such as manufacturing.

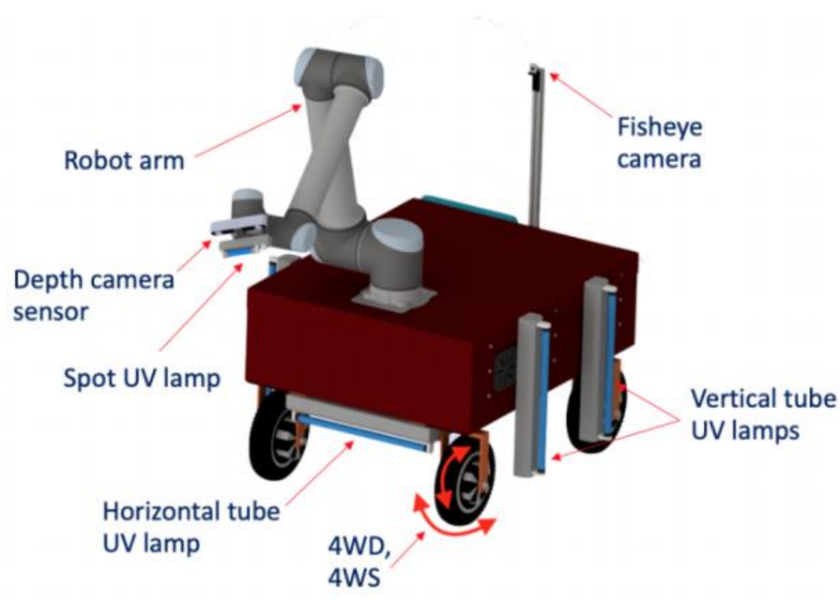


Figure 1: The Prior Disinfection Robot. A CAD rendering of the UV disinfection robot developed last year. The new design will have several changes, but the core design elements will remain the same. (Adapted by Daniel Helmus (2020) from Conte, Leamy, Furukawa 2020).

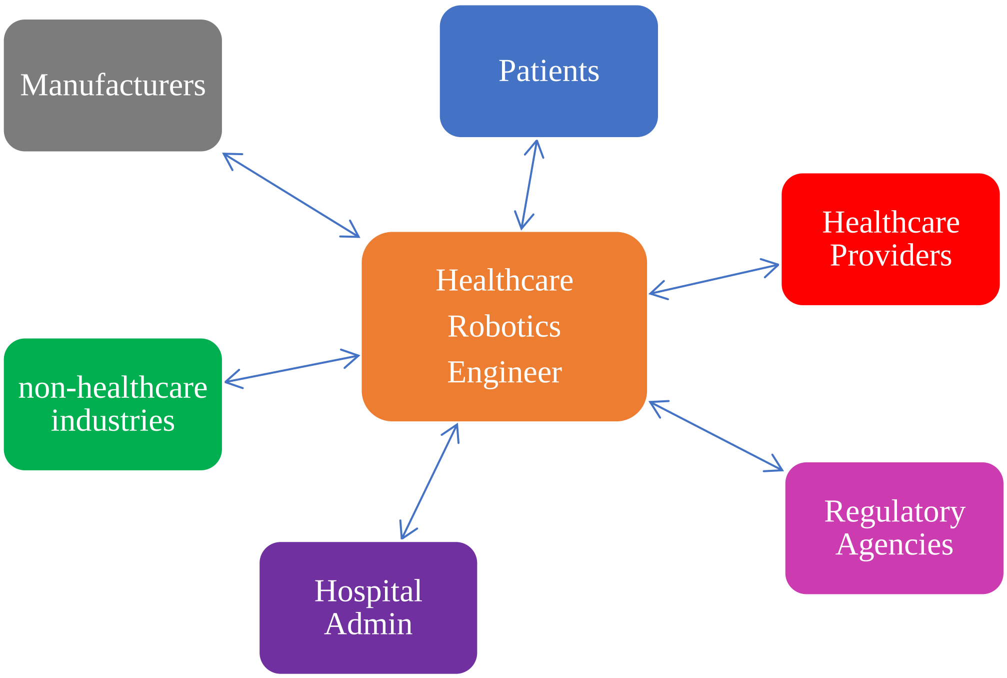
The technical research and the tightly coupled STS research in this report seek to deliver a greater understanding of the difficulties, benefits, and drawbacks to implementing robotics in healthcare with regards to the coronavirus pandemic. The technical report for this project will involve the design 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 work with robotics technology from a highly interdisciplinary point of view that will leverage electrical, mechanical, computer, and software engineering. Making design decisions based on what users of the technology may desire allows for an examination of the factors that could influence further development of this technology. This spring, the design for the robot will be completed, with manufacturing and testing following soon after. Tightly coupled to this project, the STS research for this report will investigate what social groups shape the technology now, and how they may affect further development of healthcare robotics.

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, different social groups will influence the robotics engineer to make specific design decisions, which will affect what form these robotics will take in the future as well as what place in our society they will hold.

The key relationships within the SCOT model of healthcare robotics are patients, manufacturers, hospital administrations, regulatory agencies, healthcare providers including doctors, surgeons, and nurses, the patients themselves, and users of robotic disinfection outside of healthcare.

Figure 2: SCOT Model of Healthcare Rbotics: 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).



Now that these key relationships have been identified, the SCOT model will provide a useful framework for analyzing the effect of robotic disinfection on these subgroups and vice versa. It is important to note that it is unlikely any one group will be completely satisfied with whichever solution is used at any given time. Rather, the engineer at the center will have to design a robot that will maximize the satisfaction of each group.

WHY ROBOTICS ARE HERE TO STAY

It is apparent from Figure 2 that robotic disinfection, like any other technology, will be shaped by the actors that use it. In October 2020, Zemmar, Lozano, and Nelson reported that in order to craft efficient robotic designs, there must be clear communication between the clinical teams, design engineers, and commercial vendors. Continuing development will likely result in overall cost-saving for hospitals and healthcare facilities (p. 5). A clear line of communication between these actors is necessary in order to facilitate the design of these helpful robotic technologies, and to reduce their price in the future.

A useful tool to open that line of communication is regulation, performed by the United States government. The United States is no stranger to regulation in healthcare, and the Food and Drug Administration (FDA) has had great success in keeping the American public safe from dangerous substances. In order to have continued success with regards to robotics in healthcare, a similar stance should be used. Simshaw, Terry, Hauser, and Cummings stated in 2016 that the FDA regulates most healthcare 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, as new innovations come about (p. 16). Unfortunately, regulation of these robotics cannot wait until it is forced to be written through accidents or mistakes. Robotics in healthcare often perform critical functions. Surgical robotics make incisions that could be life-threatening if performed incorrectly. Similarly, robotic disinfection typically uses ultraviolet-C light that can cause skin and eye damage to users in large enough doses, according to the FDA, which oversees the production of lamps that generate UV-C light (Food and Drug Administration, 2021). If patients or healthcare providers are harmed by this technology, there will be more significant barriers to adoption.

Continuing regulation on healthcare robotics will also separate out the tools that are not thought out well enough to be used in critical, life-threatening situations or in every-day use.

In a similar manner, hospital administrations are the ones making the ultimate decision to use robotics in certain roles, by deciding what technology a facility will purchase by observing its effect on patient outocmes. Unfortunately, the high cost of robotic solutions (most between $40 and $125 thousand USD) stops many hospitals and healthcare centers from purchasing them (ECRI Institute, 2015). Continued testing and use of robots will however improve their function and pricing. Increased competition on the robotic surgery market will render lower purchasing prices in the near future, according to Casarin et al. (p. 3). Nonetheless, robotic disinfection has had positive effects on patient outcomes even before COVID-19 thanks to their effectiveness in preventing hospital-acquired infections. Schaffzin, Wilhite, Li, and Finney proved that 2 Xenex LightStrikeUV-C robots decreased hospital acquired infections by 16.2% following program implementation (p. 904). A picture of a Xenex LightStrike UV-C robot can be seen on the next page in Figure 3. Further implementation of these solutions could make hospital acquired infections a much less common occurrence, especially for high-risk, immuno-compromised patients. Hospital administrations shape the market for disinfection robotic technology by requiring effective disinfection, easily used solutions, and a low logisitical footprint. Hospital administrations need to weigh the costs of these robots from multiple angles, and an effective solution would have to have satisfactory answers to those demands.

Figure 3: Xenex LightStrike Disinfection Robot. This robot created by Xenex has been proven to be effective at reducing hospital-acquired infections. Similar designs have been created throughout the robotic disinfection industry, with many (including the one pictured) requiring a human operator. (Retrieved from https://xenex.com/).

Robots can also reduce the load that healthcare providers such as doctors, nurses and other professionals might face. Although global pandemics do not happen every day, the COVID-19 pandemic's effect on the mental and physical wellbeing of healthcare professionals is well-documented. 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). Indirectly reducing the load on doctors, nurses, and EMTs by decreasing their chance of exposure to COVID-19 could help improve their lives as well as the treatment of their patients. If robotic disinfection is proven to be effective in helping healthcare providers improve the quality of care that they can provide, there could be a much stronger push for adoption of the technology in facilities that have yet to incorporate it.

Each of these social groups has a direct impact on what shape robotic disinfection technology will take. Patients and their outcomes play a role by providing direct evidence of the effectiveness of disinfection, with regulations from the government mandating safe implementation. Hospital administrations then have their own demands by focusing on effectiveness, ease of use, as well as logistical and financial costs.

THE FUTURE AND WHERE ROBOTIC DISINFECTION FITS WITHIN IT

The COVID-19 pandemic has created a problem for the entire world. Like all problems, people work together to try and find a solution. Certainly, an effective solution would find strong traction among our society and perhaps remain in the aftermath of the pandemic. In a similar way, this public health emergency has created a more lucrative market for robotic disinfection, as different companies and nations attempt to find effective solutions through robotics. **“**The Coronavirus outbreak has highlighted use cases for mobile robotics to successfully disinfect, monitor, surveille, and handle and deliver materials. These proven use cases will propel the overall mobile robotics market to US$23 billion by 2021” says global tech market advisory firm, ABI Research, in a press release from April 2020 (p. 1). Another May 2020 forecast from Verified Market Research claims that the market for UV disinfecting robots will grow to more than $5.5 billion by 2027 (Verified Market Research, 2020). These large market increases are intrinsically linked to the COVID-19 pandemic and its affects on many aspects of our society, not just healthcare. However, only the future will tell exactly what place robotic disinfection will have and how it may affect the United States economy.

A large part of the reason for such a large market proportion comes from the various industries that can use robotic disinfection to great effect- but some of these are less obvious than others. For exampe, the easily transmissible SARS-CoV-2 virus has made would-be tourists and travelers more aware of the necessities of disinfection. According to Shadel (2021), some hotels now feel the need for a highly visible and marketable method of disinfection to encourage travelers that they will be safe at their place of stay. This role has been satisfied in some cases by automatic, robotic, disinfection (p. 2). This new wave of robotics performing in customer-centric industries such as hospitality and tourism may have a strong impact on service related workers.

Specifically, a 2017 report by the spatial economist Johannes Moenius, a professor at the University of Redlands in California that found that “more than 60 percent of jobs in hospitality-dominated cities like Las Vegas could be automatable by 2035” (Semuels, 2017). If this were the case, new robotic designs would have to incorporate more complicated automatable tasks that range from as simple as vacuuming to as difficult as cleaning windows.

Fortunately, as vaccines are deployed across the United States, COVID-19 case numbers will recede, and desire for robotic disinfection may subside. However, public health emergencies are always possible. Robotics need continuted development so that they can be prepared to help in the next healthcare emergency. Yang et al. believed in March 2020 that robotics could automate many key processes in fighting COVID-19, but that “…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) . The prior projected market size increases paired with continuing development shows that this technology will contintute to be used once COVID-19 recedes.

Part of the reason that these robotics were ready for retooling and use in disinfection is the strong stance on robotics development the United States has. The government should continue to maintain strong robotics initiative with a specific focus on using robots in healthcare contexts as well as instituting policies that encourage such development. Fortunately, the National Science Foundation recently issued a new National Robotics Initiative (NRI) request for proposals. It will make available 15-30 awards to innovators between $250k and $1.5 m for up to 4 years. This will provide a large amount of funding to creators that work on robotics- of which many will likely be solutions to COVID-19 (p. 2). The United States has been responsible for great innovations in technology in many different fields, with robotics being only one highly visible example. Continued encouragement of research and development is greatly important to maintain and increase the benefits of this technology. National robotics initiatives also provide a way to encourage students to study related subjects in STEM fields, helping manufacturers to have a skilled workforce that can create the technology needed to solve today's and the future's problems.

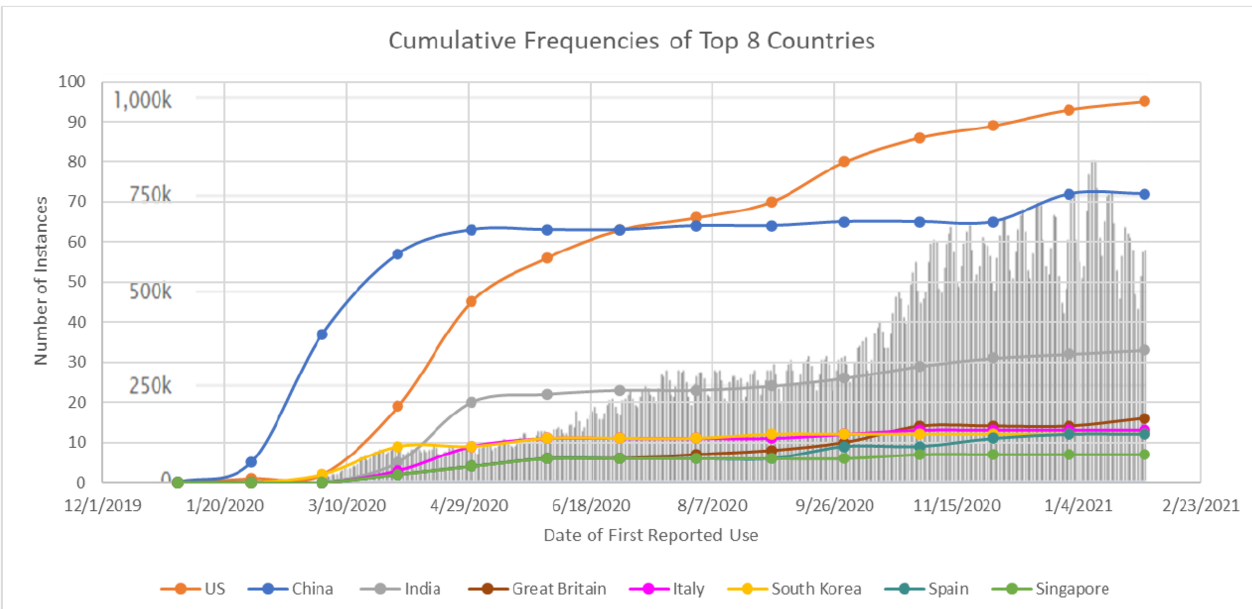


Figure 4: Robotics in 8 Countries. This graph shows the cumulative number of reports of robotics used to work against the spread of COVID-19 recorded from 1 January 2019 to 23 February 2021, in eight different countries. These reports described robotics being used in domains such as public safety, clinical care, laboratory and supply chain automation, and non-hospital care. (Adapted by Daniel Helmus from Murphy, Gandudi, Amin, Clendenin and Moats (2021)).

An analysis of internationally reported use of robotics against COVID-19 from January 2019 to February 2021, published by Murphy, Gandudi, Amin, Clendenin, and Moats (2021) found that the United States, India, and Singapore began deploying robots before the worldwide surge of case counts (p. 9), in the manner depicted on the prior page in Figure 4. The plot also shows that the US was able to continue sustained development and deployment of robotics as the number of case counts tilted strongly upwards during the winter of 2020 through 2021. It is likely that prior and continued national robotics initiatives were at least partially responsible for the high use of robotics in the United States and China, as these initiatives ensured that there were existing robots at manufacturing capacity that could be easily retooled for COVID-19 related tasks, as well as a public willingness to utilize the technology (p. 14).

National robotics initiatives are only one factor relating to robotics being used in this manner, as discussed before. Healthcare robotics must be complicated machines in order to perform their jobs correctly and with enough benefit to be considered worthwhile, and should have new regulation to more carefully develop this technology as well as ensure that they can be available in new emergencies. Each group that interacts with the robotics, from nurses to administrators, have different requirements for robotics, and they all will shape future designs in different ways. The current use of healthcare robotics with proven effectiveness as well as market analysis leads many experts to believe that healthcare robotics will grow to be a large industry in the future, with far-ranging impacts for our economy and society.

The actors described in this paper have affected the development of this technology, and will continue to in the future. Considering the actions and influence of each social group, economic factors, current events, political legislation, and regulation has allowed some insight into the future of robotics in our society. As the world contends with the COVID-19 pandemic, robotics have become more common in our world and they are likely here to stay. It is possible that robotics performing tasks such as cleaning and disinfection in locations as varied as hospitals, train stations, malls, airports, and hotels may be a common sight in the near future.

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