Applied Robotics Ethics:
The Impact of Ethical Considerations In the Context of Pandemics

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Abstract

Academic research projects have been developing solutions to address challenges that were brought about by the COVID-19 pandemic. Through these projects, we question how ethical concerns impacted the development of solutions for COVID-19, particularly looking for solutions made for the healthcare industry. Through semi-structured interview, textual analysis and meta analysis this research was able to address the priorities of engineers in the context of the pandemic. This research helps to highlight the future of academic research, development, and response during and post pandemics.

Authorship

The writing process and development of this report was highly collaborative between Hoang Nguyen and Krystal Grant.

The report was a back and forth discussion as to how to analyze and break up the core question. Hoang Nguyen helped outline and draft portions of the document. Hoang also moved things around and experimented to make the paper as good as possible. Krystal Grant helped to review, edit, and revise the document. Often the suggestion made by Krystal was in the form of suggesting areas of improvement, and highlighting sections not properly sourced.

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Chapter 1: Introduction

SARS-CoV-2, commonly called the coronavirus, is a respiratory illness that spreads through air transmission and contact with infected surfaces. The coronavirus is responsible for the disease known as COVID-19 [79]. The COVID-19 pandemic began in early December of 2019, with first cases indicated in Wuhan, China [79][37]. People infected with COVID-19 were contagious for 12-22 days with symptoms usually appearing between 2-14 days after being infected [79]. People have reported symptoms ranging from coughs, fever or chills and shortness of breath or difficulty breathing. Others are asymptomatic meaning that they do not develop any symptoms at all [79]. More severe symptoms include “respiratory failure, lasting lung and heart muscle damage, nervous system problems, kidney failure or death” [79]. Due to the way in which the virus was transmitted between people, self quarantining, social distancing, and mask mandates were established [79]. As cases rose in the United States, schools and businesses were recommended and issued orders by states to shut down until it was safe to reopen [73][37]. As a result, the general public turned to working remotely [11].

Because COVID-19 can be transmitted through the air or through contact with infected surfaces, measures like constant disinfection and wearing of personal protective equipment (PPE) have become a new normal for individuals who have to work in close proximity with others [60]. There was a frequent use of PPE which soon led to a shortage in protective materials such as medical grade face masks and hospital gowns [37].

On January 9, 2020 the World Health Organization (WHO) published guidance to help inform countries how to respond to the coronavirus, which at the time was starting to emerge as a worldwide pandemic [37]. With this information in mind and minimal data regarding the virus, there were many ways in which America could have responded. Some of the methods used in an effort to reduce the spread of the virus include enforcing social distancing, quarantining, and mask mandates. Even though it was carried out for the health of the public, these policies disrupted the lives of many people. For many, this meant switching from a physical working or learning environment to a remote one. Many social gatherings were put on hold or canceled, and entering businesses now required a mask. Even with all of these requirements in place, there was still no data to suggest that these measures were working as intended. “One of the ethical questions that has to be asked is whether we actually know how to measure the benefits that will come from any of these interventions” [14].

In March 2020 when hospital PPE supplies were limited, not only did the CDC create instructions for making homemade masks as a “last resort”, an image of health care workers using trash bags as surgical gowns went viral [37]. This raised the question of the safety in using lower standard materials during such a shortage. When vaccines became available they were originally limited in supply and there were recommendations made by the CDC as to distribution and prioritizing vaccination in certain groups [6]. These responses to the virus do not represent the full scope of choices that multiple parties, groups, and organizations had to make. With each response, there had to be a level of ethical decision making to determine the “best” choice. If more early planning and discussions were involved, then choices that are made could have been better [48].

Data shows that of the people who were infected with the virus, 20% needed to go to the hospital and 6% of infected individuals would be admitted to the intensive care unit [28]. Around 20% of infected patients would need ventilators during their time in the ICU [28]. Hospitals had to prepare to receive people with similar symptoms to COVID-19 who were not infected with the virus [45]. Health care facilities were recommended by the CDC to follow stricter guidelines in managing and interacting with patients to protect all patients [45]. Following these recommendations staff changed into new PPE attire after helping a patient, "even if only to perform a simple task such as changing a ventilator or dosing medication" [28]. The labor required to handle these new regulations, in addition to a lack of support caused additional stress on health care workers [45]. Many patients and employees showed signs of lower mental health including signs of PTSD, depressive symptoms, and anxiety [15]. As of August 11, 2021 there have been 205 million global cases of COVID-19 with 4 million dead [18]. To reduce the spread of the virus, the CDC suggested methods such as social distancing, quarantining, getting vaccinated, and wearing face masks [19]. Even with these measures in place, hospitals were being overloaded by the resurgence of COVID-19 cases[37][54]. As of August 2020, COVID-19 vaccines were available, with 16.7 Million Americans being fully vaccinated [20], and 4 billion doses administered globally [80]. Measures used to slow down the spread of the virus are still highly recommended by the CDC [68]. Although the spread of the virus is slowing down in some countries, there are many areas still heavily affected by the virus like rural and developing communities [17]. The pandemic has pushed many researchers and engineers toward fields such as robotics as a means to address some problems presented by the pandemic.

Similarly to the response made by hospitals and the government, roboticists also have had their fair share of solutions to address the pandemic. There have been corporate solutions for the pandemic, as well as academic research projects addressing the concerns and problems of COVID-19. For example, Digital Innovations Hubs in Healthcare Robotics (DIH-HERO) received 146 robotics project applications from 30 different European countries [27]. Research teams aimed to develop new solutions to current issues in the world, or improve on current technologies. It's because of these development teams that there has been a spike in different types of projects that are being considered. At Johns Hopkins University a team is using tele-robotics to build remote control functionality for hospital ventilators [38]. Georgia Institute of Technology, Carnegie Mellon University, and Worcester Polytechnic Institute all have ventilator projects of their own [71][1][35]. Massachusetts Institute of Technology helped develop a disinfection robot for the Greater Boston Food Bank [23]. Companies such as Waymo and Nuro are using their existing self-driving car prototypes to provide contactless delivery services [22][41]. Blue Ocean Robotics have been dispatching their UVD Robots to help disinfect schools and hospitals [26].

Previous research into these solutions helped to emphasize that the urgent need for new technologies as a response to the pandemic comes with some ethical concerns [6]. This led to the research question for this report: **How do ethical concerns impact robotic solutions during COVID-19?** This question intends to address ethical issues from the perspective of a researcher, developer, consumer, and investor, as well as to analyze the effects of outside factors on the reception and perception of a robot. Research into these fields and semi-structured interviews were conducted to understand an expert's perspective of these topics, as well as highlight things that may not have been considered.

Three questions were used as guides to help answer the core question:

Question 1: How do roboticists consider the ethical impacts of their designs during COVID-19?

This question is meant to understand what the developer's intention is behind a project. Do they focus on ethical concerns as a priority or is it meant to be a proof of concept idea first and foremost? How do roboticists balance ethical values and design concepts? COVID-19 has presented a lot of challenges for projects as teams are limited in size and many have to work remotely. Considering challenges faced outside of the project itself it led to the question: when creating a robot to combat or prevent COVID-19, are there challenges in trying to adhere to established ethical frameworks, and/or the initial design conception? Have there been any trade offs between design concepts or ethical standards due to the pandemic? These questions aim to look into how roboticists think about ethics in relation to constraints resulting from the pandemic.

Question 2: What are the risks and benefits of deploying simplified standard robotic solutions in the pandemic?

A robotic solution is simplified when features are omitted from a design but the final product can perform the core tasks as the original. Previous research has identified that robots that are already in use have had more of an impact during the pandemic than new technologies [6]. Solutions such as mechanical ventilators may lack complex components and are being newly introduced into the medical field, but is it as impactful as its more complex pre-existing counterparts during the pandemic? While a simplified solution may be impactful, it could also represent safety risks by omitting certain features. What kind of standards are put in place to ensure the safety of new technologies? What context is required to justify the simplification of standardized robotics solutions? This relates to the first question in that if roboticists only consider projects for current situations, how does that impact their development in the future? These questions aim at understanding the role ethics plays in the production and development process of a robot.

Question 3: What do changes in investments toward robotics during COVID-19 mean for future public interests?

The next issue we want to address is the boom in the market of existing robots. Some of the solutions only serve through the course of the pandemic. Once the United States considers itself not to be in a public health emergency, what type of projects will remain post-COVID-19? Will these projects continue development post-COVID-19 or will these projects become obsolete? While some new technologies have emerged thanks to the pandemic, there has also been an increased investment in existing robotic solutions due to needs for contactless interactions such as in food and grocery delivery services. Increased investments in these projects may be important during the pandemic but will these technologies still remain in the public interest in the future? What robotic projects are being funded due to COVID-19? What type of organizations are making these investments? Are there trends in the types of projects being invested in during COVID-19? What are the implications of these investments on the future of their industries? These questions look to compare the current robotic market to past markets to see the effect that COVID-19 had on these industries.

Through textual analysis of articles and semi-structured interviews we aimed to answer these questions and gather additional insights into robotics during COVID-19. We narrowed our focus to a select few categories of robots present during the pandemic: telepresence robots, disinfection robots, delivery robots, and robotic ventilators. Based on the nature of each research project, not all of our questions could be answered by each project. Answers from each project collectively gave good insights on how robotics is affecting COVID-19, and likewise how the pandemic is shaping the robotics industry. We believe that by analyzing these questions further we were able to update and expand our current understanding of how ethics shapes robotics. In addition this allowed us to have a better understanding of other considerations that may be made in regards to robotics in the near future and post-COVID-19.

Chapter 2: Background

2.1: Role of Robotics in COVID-19

Solutions arose out of the robotics sector with ways to automate tasks and aid healthcare workers at the forefront of many technologies. These solutions came in the form of telepresence robots, robotic nursing assistants, disinfection robots, delivery robots and robotic ventilators [49]. These solutions help to address some of the challenges brought on by COVID-19. Robots proposed helped minimize contact between patients and medical workers. Additionally, work that can be assigned to robots allowed medical personnel the ability to tackle more complicated challenges [3].

The pandemic also represents an opportunity for new technologies to be developed and tested. One example of this can be seen in the market of open-source ventilators. Prior to COVID-19 only standard commercialized ventilators were available but due to shortages during the pandemic the market expanded to include do-it-yourself (DIY) and open-source alternatives [75]. Because these technologies were fairly new they required rigorous testing in order to be implemented. The pandemic represented a large testing ground for these projects [3][28]. The experience gained during the pandemic can shape the future of the robotics industry, especially when it comes to robotics response in urgent situations.

2.2: Robotics

The term robot has many different definitions. Some define robots as simple machines while others consider robots to be a combination of mechanical parts and some form of AI [33][32]. Previous research into this field has defined a robot as "... a programmable, self-governing machine capable of carrying out a series of tasks without an external trigger" [6]. The EU is also developing a working definition for a robot based on five key characteristics [52]. These characteristics include: autonomy, self-learning capabilities, physical components, adaptation to the environment, and a lack of biological components [52]. This also led to the further categorization of robots based on their level of autonomy and how much AI they implement [52]. A robot can exist without AI, however, such as industrial robots and remote control toys, and some may possess a weaker form of AI such as a navigation system or digital assistant [8]. More complex AI resembles more human-like intelligence and decision making [8].

Artificial intelligence is another important aspect of robotics. AI is the collaboration of different technologies such as sensors and actuators working alongside programs used to create near human-like responses to various tasks [8]. AI is yet another broad concept in the field of robotics as a project might display weak AI by doing simple tasks like analyzing data and reporting the weather [8]. More complex tasks include emulating human intelligence such as systems seen in chess playing robots [8]. AI is important during COVID-19 as robots that can execute tasks autonomously represent a form of AI, even if there is some human intervention.

When referring to robots in this report, we will be focussing on machines that can move in some way to complete a task either with human intervention or through some sort of autonomy. This is a very broad definition as there are a lot of projects that may be considered a robot, but in the context of the situation robotic cases usually become clear. As we look through various cases the type of robot may change based on what kind of task it is engaged in and the level of autonomy it has. Some of the cases we identified include telepresence robots, automated testing robots, delivery robots, and disinfection robots.

When we talk about the robotics community in this report we are referring to project developers, those involved with the robot's production, and the end users. Additionally, we consider experts who help shape the field of robotics. Experts range from people who are roboticists, computer engineers, mechanical engineers, and AI developers to those who are psychologists, lawyers, and designers [32]. The use of robotics is wide, and thus the majority of people should have a say in how the field of robotics should change.

2.3: Robot Ethics

Robot ethics is a fairly new field and as such a working definition can be hard to identify [33]. One thing that can be more easily identified however are ethical concerns when it relates to robots [33]. In addition to this, the robots analyzed in this report do not represent moral agents of their own but rather machines for which humans are able to manipulate. For these reasons, this report focuses on human centered robot ethics and principles of ethical concerns within robotics. The focus on human centered robot ethics means that we analyzed the ethics of human components to a robot (ie. the developers, investors, and end users) [32]. This also means that the focus is on the robot as an object rather than a subject in these ethical concerns [33].

Another thing to note about these ethical concerns is that they mostly relate to the AI within a robot rather than the robot itself. While the robot has physical components allowing it to interact with the world around it, the driving AI used in some of these systems represent more of an impact to society. [33] AI can be found in technologies like smart cars and digital assistants. With these technologies becoming more common, we as people have more interactions with AI than robots themselves.

The ethical concerns we chose to analyze were based upon previous research into the field of robotics during COVID-19 [6]. These concerns include:

- Privacy
- Safety and Security
- Transparency and Explainability
- Fairness and Nondiscrimination
- Professional Accountability and Responsibility
- Public Interest
- Human Robot Interactions

The following sections go into further detail on what these ethical principles mean in general, during COVID-19, as well as how they can be embodied in a robot.

2.3.1: Privacy

Privacy is the idea that a person's information is protected from those that it is not intended for [62]. For example, if information is exchanged in a meeting, then that information is expected to be kept confidential and in the confines of the people involved and the groups acknowledged. In a similar manner, the discussions a person has in private spaces should only be shared amongst the people involved. Privacy is violated when a person who is not the intended recipient of information, receives that protected content, and information exchanged doesn't need to be in the form of conversations. It could be documentation, health records, or messages just to name a few. As technology has evolved throughout the years, privacy has also been extended to third party platforms.

Privacy is a concept that comes up in robotics and especially in AI frequently. Due to an expansion of information being shared through the internet, questions have arisen regarding what information should be safeguarded and what information should remain anonymous [32]. In addition, with the creation of social media, more information is readily available than before. More and more of our lives are now digitally accessible and smart devices are also more common than before [33]. Third parties now collect data on users, some of which is known to them and some of which is not, and the protection of this information has been a concern [33]. This lends to the possibility of malicious actors interfering with these technologies and invading upon a person's privacy.

2.3.2: Safety and Security

Safety and security represent two very closely related principles in ethics. Safety refers to a feeling of being free from harm and security is concerned with a state of being outside of harm's way [70][67]. In ethics the idea of keeping people safe from harm is very important. Safety and security may not refer simply to a person's physical well being but also things such as their economic status, employment status, emotional well being, and keeping personal information secure [33]. Laws and other policies are often put in place to protect a person's feeling of safety and security.

During COVID-19 these principles of safety and security can be seen in things like mask mandates and social distancing to protect a person's physical well being. There were also emergency policies in the United States that were put in place such as the moratorium on evictions to keep people safely housed during the pandemic where possible [53]. Similarly, stimulus checks were distributed to many in the United States to ensure economic stability during the pandemic [30].

Safety and security are also primary concerns when it comes to robotics. If a system is not safe for interaction with humans then the potential harms it faces may prevent a project from being implemented. Once again these principles relate to how the robot interacts with its human counterparts. This can also be seen in how a person perceives a robot. If a person finds a system unsafe, they are less likely to trust the technology and less likely to interact with it. An example of this occurred with the NYPD's robot dog during 2020. A combination of social unrest, distrust in the police, and the overall aesthetic design of the robot resulted in many people feeling unsafe near this robot [13]. Only a few weeks after being deployed the robot dog was retired as it could not effectively serve the public with such distrust in it [13].

Similarly, concerns of cyber security are prevalent especially in AI. Many technologies that implement AI collect data but this brings up the concern of who is in charge of this data and what kind of data is allowed to be collected. [33] During the deployment of the robot dog in New York, there were concerns about surveillance by the police [83]. Although the company behind the robot dog ensures that the product is safe, these concerns were brought up by end users and in the end impacted how this robot was used [83].

2.3.3: Transparency and Explainability

In a broad sense, transparency and explainability are the principles that speak to how much of a system can be understood by an outside person. If a system is transparent in its workings, a person is able to understand the various processes involved. For example, there are laws regarding transparency in the government in the United states such as the Freedom of Information Act [34].

During COVID-19 examples of this include clear laws and regulations such as those set by the CDC during the pandemic. Two such mandates included social distancing, the act of staying at least six feet apart from others, and wearing a mask while in public [19]. These mandates had their intentions made clear from the beginning to help people understand their importance, which was to slow the spread of the coronavirus.

In the context of robotics the issue of transparency and explainability within a system is very important as it allows for people to better understand what outcomes to expect from a system and how it can be used [74]. Many robotic systems implement AI, however, the logic that leads to a decision may be hidden from the end user or even the programmer [33]. This leads to concerns about possible bias in AI decision making which can have adverse effects on the public [33]. During the pandemic there was a surge in open-source robotics. These projects made their designs and programs for their robots available to the public. Open-source solutions provide the opportunity for reproducibility, and review by other groups and individuals [59].

Although transparency and explainability have positive impact in certain ways, they can also represent a risk to the security of a system. If the inner workings are exposed then someone with ill intent could use the technology for malicious reasons. A common example of this are hacks in systems in which a person identifies a weakness in the construction of a system and exploits it. For this reason AI systems must exhibit some form of robustness in order to ensure the safety of users in the event of some misuse [61].

2.3.4: Fairness and Nondiscrimination

The concept of fairness and nondiscrimination is tied closely to bias. Bias occurs when unfair judgements are made usually based on discriminatory or stereotypical conceptions of a group of people [33]. Bias is not the only form of unfairness that exists. Other forms include equal access to technologies and equal socio-economic opportunities [32].

During COVID-19, thanks to shortages in materials and space, many healthcare workers were forced to make decisions on who received treatments and who could not [56]. Because of this issues of fairness and nondiscrimination were raised in groups such as the disabled, minority races, and those experiencing financial hardships [56]. Organizations such as the US Department of Health and Human Services (HHS) and the CDC created guidelines to ensure equality in receiving testing and vaccine availability in various communities [16]. With the increase in remote communications and learning during the pandemic, internet access for more communities also became a concern of fairness as not all households had access to the internet. This led to the creation of wifi hotspots free to use for anyone in the area provided by companies such as Xfinity [82].

In robotics, one area of focus is bias within automated systems. This can be seen in AI and designer choices that alter the service based on color of skin [33]. An MIT report suggests if AI was created to choose which individuals should receive ventilators, then bias could affect the life and death of certain populations [42]. In regards to AI, bias can be exposed to a system through statistical data [33]. If a dataset is created for one type of situation it may present bias in another thus making the dataset itself biased [33]. Not only would the system not recognize this bias on its own, it would also replicate the data in any output predictions that it makes [33].

2.3.5: Professional Accountability and Responsibility

Professional accountability refers to the individuals and organizations behind new technologies being held accountable for any malfunctions during normal use of the product [2]. In a more general sense this can be seen with corporations and any damages they are made to reimburse due to a failed system [33]. Professional accountability relates to the code of ethics in a given field as it is a guideline for ensuring the safety of the employees, the product, and the customer. In engineering fields associations like the National Society of Professional Engineers have a readily available code of ethics that detail how engineers should act as well as principles they must keep into consideration during the course of their work [57].

In robotics this means ensuring that the robot is safe for humans [32]. In a proposed ethical code for roboticists, responsibility for the outcomes of a robot's use comes first [24]. This idea of accountability and responsibility in robotics is also seen in autonomous systems. In the case of autonomous vehicles there are laws in place to distribute the responsibility in the case of an accident [33].

2.3.6: Public Interest

Public interest is a very vague term but usually refers to doing something that positively affects all people [46]. Although something is in the public interest, it may not be as effective as originally hoped. For example, although policies like masks mandates and social distancing are meant to protect everyone from the further spread of COVID-19, many people still ended up infected and the death toll continued to rise. These policies are still continued, however, because they are meant to benefit everyone. In addition it can be said that not everything that embodies public interest will be of the utmost interest to the public [46].

Roboticists also have to consider public interest when presenting a new technology. Not only should it be safe for the public, but should also represent values that are important for the general public [44]. Without these principles in mind the public are less likely to trust and interact with these technologies.

2.3.7: Human-Robot Interactions

Human Robot Interaction (HRI) focuses on the way that humans and robots interact, as collaborative partners or as assistive technologies for humans [65][33]. Robots, during all stages of development, have the capability to harm individuals physically and emotionally if not well designed and executed. Everyday events can be places in which the interaction can harm a person [39]. It is the job of engineers to assess the type of risk that can befall individuals who use these technologies, and to limit certain types of interactions as necessary. In interactions that intend to exchange private information of the individuals, if the safeguards are not established in those robots, then information could be leaked or used inappropriately [65]. Thus, the need to care for the impact of these systems on the people using them.

One recent concern that is brought about by COVID-19 is using telepresence robots to deliver devastating news to patients. If a prior relationship between the patient and medical staff was not established, then the delivery of the message would be emotionally devastating. Should healthcare professionals use telepresence robots to deliver the news, or should medical personnel walk in personally? [9]. Applying this to the context of the pandemic, interacting with a patient in close proximity means risk for the medical staff.

Chapter 3: Methodology

3.1: Introduction

The purpose of this study is to analyze how COVID-19 has affected the robotics industry from an ethical perspective. To begin our research we gathered a selection of robotics projects from COVID-19 and categorized them based on the robot's use. We then further analyzed these projects through textual analyses and gathered further insights into academic projects through qualitative interviews.

3.2: Objective 1: Categorize robotics projects related to COVID 19

We saw roboticists use robots to solve issues that are presented due to COVID-19. The type of robot research and solutions that are created for the pandemic are vast, however, similar in principle. The categories exist to summarize the problems that are being addressed, and the solutions of those issues. We used their categorization as a basis for organizing research projects relating to COVID 19.

The Institute of Electrical and Electronics Engineers (IEEE) is an organization of experts from around the world that share information collectively. Their March edition of IEEE Robotics & Automation Magazine reports the state of robotic solutions and innovations worldwide in regards to the pandemic. When reporting their findings, they explain the issues from an overall and targeted perspective. An overall perspective gives a general view of what categories exist, while a targeted perspective provides examples of each category. With this magazine, we applied textual analysis to understand the categories/classifications of robotics projects. We used their categorization as a basis for organizing research projects relating to COVID 19. Articles and news outlets outside the IEEE magazine were used to help modify IEEE's classifications.

In the end we decided to focus on the following three categories of robotics projects: telepresence robots, robotic ventilators, and disinfection robots. We selected between 3 and 5 projects within these categories to research further. We found many more resources than this and some were also analyzed further but may not appear in the findings sections due to their overall relevance to the proposed subject questions.

3.3: Objective 2: Researching selected projects

Most reports discussing robotics and COVID-19 tend to focus on technical aspects of the problem and its solution. That does allow for an understanding of potential ethical issues. However, for the purposes of looking at the ethical aspects relating to robotics, we wanted to find projects that would help give deeper insights into the research questions we had considered.

College research studies that were selected were active or have recently concluded within the past year. We used search engines and college databases to find these projects and their advisors. These studies were related either directly or indirectly to COVID-19, but had to be based on robotics, whether that is creating a new robot, modifying existing robots, or working on a feature that is directly tied to a robot. In addition, these projects that we were selecting aimed to target one particular category mentioned by IEEE.

When parsing through project papers, we identified key features that are meant to respond to ethical concerns made by COVID-19 or that align with previously established ethical frameworks. Usually, those features implemented were design goals to improve safety and meet some standard of performance. However, as much as these papers helped highlight certain ideas, it did leave a few of our questions unanswered. Thus, we looked at interviewing advisors to better understand these projects.

Advisors often have industry experience that can play a role in aiding a project. We considered on-campus WPI research as we thought these projects were easier to contact and interview. We also tried to contact people outside WPI, to expand the pool of subjects for this research paper. In the end, we were able to interview 5 project advisors. Of those 5 subjects, 4 of which were current WPI professors and the other a Northeastern University professor.

At the start of these interviews we asked many clarifying questions about the individual project to be able to ground ourselves into what the aim and goal of the project was. From that understanding, we could see the intent of these researchers.

We transitioned over to asking some general questions such as:

- Are there any ethical standards that you use as a guideline at work?
- What technical standards do you adhere to during the research and development process?
- What was the market like for this project pre and during COVID-19?
- How was your project received by the public?

These questions helped establish the relationship between different influences such as society, the pandemic situation, the market to the design choices to these researchers.

Past these generalized questions, we choose to investigate different areas of our interest by these researchers, situations where the ethical situation is handled with care.

<u>3.4: Data Analysis</u>

Within our analysis of these projects, we looked for common themes, considerations, and issues that came across throughout each category. Any ideas that were emphasized and stressed by the advisor also became points to acknowledge. We also thought about issues that we did not consider in our initial research, that may be brought up by our interviews.

We tried our best to answer all of our core questions for each category of robot that we looked into but not all categories could provide an answer for each question. We considered this to be important data as well as this either meant that we lacked sufficient data or that there is not enough research in the field currently in relation to our question.

In the next section, data on the three categories of robots selected was gathered. Similarities between projects and differences were identified and these categories were further analyzed through the lens of the core questions of this report. After the analysis of each category comes an overarching reply to our core questions based on similarities and differences between all three chosen categories. Data and insights gathered during interviews appear in the Appendix of this report.

3.5: Flaws in the Study

With our methodology, we could have unintentionally created bias in terms of what areas of robotics we are addressing, and analyzing. We focused our interviews on academic sources in Massachusetts rather than any companies or resources from other regions. Time constraints also affected how many subjects we were able to interview and gather data from. This further narrowed our data set and could have resulted in us missing out on important insights present in other projects.

Chapter 4: Findings

Ventilators

Looking at ventilator projects there were a lot of similarities. Due to the increased need for ventilators during COVID-19, there has also been an increase in the market for DIY ventilators such as those made through 3D printing [36]. As a result, all of the projects that were examined were not from mainstream ventilator manufacturers but rather open-source solutions from non-profit organizations and designs by college research teams.

The main similarity of these projects is that they are not meant to replace the ventilators currently on the market but rather to supplement them in shortages. As a result, most of these projects have been given Emergency Use Authorization (EUA) under the Food and Drug Administration (FDA) allowing for rapid use during the pandemic [75]. While this is good for the pandemic, these do not represent long term solutions as this type of authorization only extends through the end of the global pandemic [76].

Another similarity is that one of the main focuses on these projects is ease and cost of manufacturing the ventilators. For example, The Ventilator Project, a non-profit organization, set a goal to produce at least 1,000 units within the first 30 days after receiving EUA in order to help address the pandemic during its peak in March of 2020 [21]. The cost for these ventilators would be between $1,000 and $2,000 compared to the average $40,000 that other ventilators cost [21]. In addition, Johns Hopkins University's pumpless ventilator is estimated to save costs of production though mass production via injection molding [50].

Throughout these projects some of the most important ethical considerations that stood out were safety and public interest. The safety of patients and being able to address a global crisis in the form of ventilator shortages were the driving force for these projects. In the case of open-source designs, transparency and explainability were also at the forefront as they aimed at allowing anyone with minimal resources to develop these designs. Due to shortages in the early months of COVID, these forms of DIY ventilators were given EAU under the FDA flooding the market with open-source designs and alternatives to ventilators currently on the market. As such, many of these designs were produced within a matter of weeks and could only accomplish the critical actions of providing positive air pressure to patients.

Telepresence Robots

Telepresence robots have been around for at least a decade. For instance, VGo's robot was pre-commercialized to the public in 2010, at a price point of $4,800 for the robot, and an annual service fee of $1,200 [4]. Other companies providing these robots include Beam and Double Robotics [40]. These robots were targeted at people who were unable to be physically present in a space. These robots allowed for a more inviting form of communicating and presence in the space the robot is located in. During COVID-19, these robots served to reduce the use of PPE by health care workers and maintain social distance.

Looking through countless examples of telepresence robots used for the healthcare industry, there is a common form factor, with several of the same features. Commercial telepresence robots have a monitor with video and audio capabilities at eye level to adults. The monitor helps bring the user into the environment. These robots also have a mobile base coupled with obstacle detection for easy navigation. Companies developed desktop and mobile applications for controlling the robot over wifi [63][78][66]. The usability of these robots in COVID-19 were due to the years of research and development of the system, coupled with people's comfort with electronic communication.

Even though these robots and services may keep the confidentiality in the data transmitted across their platform, these systems can violate the privacy of other people in the vicinity. One suggestion to address this issue is for health care staff to maintain confidentiality and privacy while getting permission from patients to use telepresence robots. Additionally, a combination of robot vision masking and muting audio reception can be used while traveling to non-local areas within the facility [55].

Another issue that can be seen with current telepresence robots is the similarity in their form factor. While this does provide a good general solution for the majority of people, specialized forms of communication may be needed for different individuals. Health-care professionals need to assess situations where use of these robots are appropriate [55].

In the future, while the market for telepresence robots in healthcare may be reduced, these robots could aid individuals who are immunocompromised. Additionally, telepresence robots will allow rural communities easier access to health professionals and professionals. While these robots currently are unable to manipulate objects in their environment, research projects such as TRINA may lead to more capabilities for these types of robots in the future [40]. Current research for TRINA involves alternative methods for controlling the robot, such as 3D tracking algorithms.

Disinfection Robots

During the COVID-19 pandemic there has also been a rise in disinfecting robots [29]. These robots take the form of those that spray chemical disinfectants, like XAG, to UV-C robots like Xenex and UVD Robotics. Disinfecting robots have an important role in combating the coronavirus by disinfecting surfaces and the air in various spaces.

For many of these robots, they have been in use prior to the pandemic. Robots like those from UVD Robotics have been used in hospitals to disinfect hospital rooms and reduce the risk of hospital associated infections since 2014 [47]. While XAG has been an agricultural robotics company since 2007, they have been active in helping rural communities with disinfection from January of 2020 [81]. The result of having these robots in place prior to the pandemic meant that they were speedy in terms of providing aid to areas in need of sanitation robots. Because of that many companies who looked at disinfection robots had previous data to go off of when deciding which robot is right for them [25]. Another benefit to these robots being on the market prior to COVID-19 is that there is minimal infrastructure needed to implement these solutions in places like hospitals, schools, offices, and arenas.

There was an overall boom in the market for disinfection robots during COVID-19 which is in part due to government intervention. For example, in the fall of 2020 the European Commission purchased 200 robots from UVD Robotics in order to distribute them to hospitals across Europe [58].

A large focus for these disinfection robots is the safety of patients and users. For UV-C robots like those from Xenex and UVD Robotics, the robot is autonomous and is able to disinfect a room within a short amount of time [58]. Because they utilize UV light they are equipped to assess whether there is a person in the room to avoid possible harm while ensuring 99.99% bacteria removal to the given room [58]. In contrast, chemical disinfecting robots like those used by XAG are used in more open spaces such as by the Thai Armed Forces on their base to disinfect storage areas [64].

Comparing the two types of solutions, chemical disinfecting robots and UV-C robots, the chemical disinfection robots represent more of a simple solution. This is because these types of robots cannot always get into all spaces easily and are more apt to work in large open areas like arenas and in storage areas. Another reason this represents a simple solution is that it focuses heavily on surface disinfection and not on air purification as well. This is different with UV-C robots as they can disinfect both surfaces and the air in more confined spaces like hospital rooms and offices.

While disinfection robots have become more commonplace during the pandemic, no major ethical concerns have seemed to arise from their presence. Disinfection robots typically have minimal interaction with humans and the methods that they use are all human approved and safe and so there are no safety or privacy concerns. In addition, while there is little human robot interaction between these systems, that conforms with their intended goal of safely sterilizing an area to make it safe for humans. Finally the wide range of deployment areas as well as types of disinfection robots shows an acceptance of these robots by the public without a lot of backlash in terms of ethical concerns.

4.1 Market Impact

During COVID-19 there has been a great increase in the market of various robotic solutions. In the case of ventilator robots, the introduction of simple ventilator robots drastically increased the investment into the ventilator market. In 2019 this market was worth just over a billion dollars but it surged to almost five billion dollars in 2020 [77]. With such a big investment in 2020 there was a decrease in investments in 2021, leading to a steady growth leading into 2030 [77].

In the case of disinfectant and telepresence robots the markets also saw a significant increase. Although these products were already on the market prior to COVID-19, they have seen a rise in purchases due to the need for these technologies. Such as with the case of UVD Robotics, rather than catering to just hospitals, they also distributed units to schools and even sports arenas [26]. Similarly other companies like XAG found their machines repurposed to serve various communities during the pandemic [64]. Because of these factors the markets for these robots are expected to grow by 11.5% for telepresence robots, and 34.6% for disinfection robots [29][72].

The reception of these robots also affects the market as greater interest in these technologies imply greater investments in them. The reception to these robots during the pandemic has been varied. In the case of ventilators, while many have been produced and given EUA status, we have not found information to show instances of the deployment of these ventilators in the field. This is in part because they are simply meant to supplement common ventilators on low risk patients rather than those who are at high risk.

Disinfection robots have received a positive reception by its audience by being able to cut the man hours for disinfecting rooms by a significant amount, For example UVD Robotics robot can disinfect a hospital room in 10-15 minutes, reducing the man hours needed to clean a room by 1.5 hours [58]. This frees up staff to work on more pressing matters which, in turn, increases the overall efficiency of the hospital system. These robots also have a wide range of acceptance in the community from use of XAG in the Thai Armed Forces to the use of UVD Robotics in a school in New Mexico [64][26].

Finally, telepresence robots have also seen a positive reception by its communities, but not without some challenges. For example, the telepresence robot from Ava Robotics has received a positive reception from hospital staff though things can get crowded if a room is filled with doctors and robots [3]. This does not, however, detract from the fact that a robot like the one from Ava Robotics is able to navigate obstacles in a hospital setting autonomously, negating the use for a human operator and freeing up more time for doctors and nurses to complete tasks while the robot is in transit [3].

Both the reception and the market offer the suggestion that people are interested in the development and deployment of robotic solutions. The promised possibility of what could be in store for the future of healthcare facilities, often discusses the idea of increase in health care quality. The pandemic in part has helped increase that discussion. This means that while ethical implications can help drive the design of a robotic solution, they can also be affected during deployment by shifts in public interest.

4.2 Simplifying Standardized Solutions

The lack of resources makes it difficult to support patients infected with the virus. The major resource acknowledged by several groups is the lack of ventilators. These types of resources that engineers are developing to supply the healthcare industry vary in quality to what is typically used and accepted by the FDA, because researchers are developing a more simplified version. Regardless, the saturation of research into these technologies and their acceptance by both engineers and news outlets helps highlight the positive perception [59] that these technologies can make an impact toward the pandemic.

One technology of concern are open-source ventilators. As previously discussed, open-source technologies are intended to help supply devices such as ventilators during a time in which hospitals lack them. One can argue that current open-source ventilators lack adequate testing, critiques, and documentation [59], which overall affect the safety of those devices. The safety of these resources can deteriorate depending on the people who use these resources to construct their own. Looking at the individual device, there is no certainty the device will perform adequately to meet the needs of those who need respiratory assistance. Typical ICU ventilators are monitoring gas concentration, flow, and pressure to not over-inflate the lungs [5]. Gasses are also being filtered for debris and bacteria to maintain a good quality of air to the patient [5]. These typical features exist to reduce chances of lung related injuries. Looking back to open-source ventilators, most are capable of adjusting oxygen intake and air pressure. The monitoring of these factors does not seem to be included in these devices. The lack of certain features is done to maintain a low cost for the device [59]. This reduction and simplification of design results in a less responsive device. Although the amount of simplified devices make up a small portion of the research initiatives and goals for the pandemic, it can serve as a good example for the challenges of open-source work in the future.

One justification for creating and simplifying standard medical devices is the deployment of these technologies to developing countries. Some developing countries lack access to medical resources. Looking purely at open-source ventilators, even though the technologies themselves do not have the same level of safety as ICU ventilators, it is a better alternative than not having respiratory assistance at all. Consider the status quo of the United States and Sub-Saharan Africa.

In the United States the healthcare industry has access to high quality ventilators that are approved by the FDA. However, the access to these ventilators is limited. With the rise of more simplified ventilators, although it does not have high capabilities as what is typically used, it offers a chance for high risk patients to stay using their ventilator and allow others who did not have the opportunity to get support. As of FDA's recommendation, the simplified versions can be used as emergency options when other ventilators are not available [75][31]. In comparison, developing countries lack these higher quality ventilators [51], and the access to knowledge on how to operate those devices [12]. Providing these simplified ventilators, even though they may not have all the measures to accurately keep someone safe, is still benefiting the community. In some cases it is better to have something than nothing at all. In the case of the WPI open-source ventilator project, the decision to take in these solutions came from the sub-saharan african communities, rather than the project team themselves.

4.3 Ethical Implications

4.3.1 Ethical Considerations During Product Deployment

The consideration of certain ethical issues are based on the current stage and intended end goal of the project. During the early stage of development, most projects will have some level of preconceived and foreseeable risk that could occur if not handled well. Often these risks are considered because of previous and known ethical issues that have arisen. These considerations are part of the standards for ethical designing of robots and AI. After this initial thought, we have seen that projects can go into two different directions.

Projects such as automated testing PPE robots developed by Northeastern University, or open-source ventilator projects; projects that are intended to be applied immediately while COVID-19 is still occuring stress the importance of many of their features. These features are correlated to a larger scope of ethical considerations that involve safety, and professional responsibility.

On the other hand, projects such as TRINA that are being used to explore new ideas without the intention of being implemented often consider ethics minimally. Based on our interviews, most of the focus of early development is dedicated to developing the functionalities of the project. If the technology being developed is not being used, there is less stress on addressing those issues. Part of the reasoning comes from the idea that those projects are not being deployed and interacting with a diverse set of users. Once the core functionality is completed to a satisfactory degree, other aspects of the robot can be discussed and its impact on users.

4.3.2 Safety is Paramount

When engineers are considering ethical concerns to address, many of the factors boil down to identifying issues that could lead to the highest magnitude of risk. The most frequently considered and reviewed ethical consideration is the physical safety of the technology. For instance, one concern during the pandemic was how to make sure the robot can be kept clean [3][40]. Although most surfaces on a robot can be cleaned through UV light [3], areas such as, "electronics, joint seals, vents for fans, and wheels" are often difficult [40]. If the robot cannot be cleaned, then the robot can pose as a vector for spreading the virus. One potential solution was the use of robot PPE [40]. The robot has to be determined to be safe by tests to indicate its performance. An additional priority for engineers is the consideration of the level of autonomy that the robot should have, and the decisions that these robots are allowed to make for the user [24][32][33]. This is stressed heavily in the automated testing PPE robot in which, by limiting the robot's performance to tests based on set parameters and report test results, humans are making the most important decisions. If issues occur due to those choices, there is a human who will be held accountable. Lastly, is considering the potential areas that the project can be deployed to help communities who have a lack of access to these technologies.

4.3.3 Impact of Industry and FDA Regulations

COVID-19 gave rise to a need to help push new solutions out to the general public to better handle, and mitigate the spread of the virus. One initial concern that might have had an effect on people's adherence to established ethical frameworks was the overall pressure of COVID-19 to increase development of solutions at a fast pace. However, from interviews it seems as though the situation of the pandemic only increased the desire to follow these established standards as much as possible.

The requirements and engineering standards used to assess the safety of each of these projects have been based on what is considered by the FDA and WHO, with these two providing recommendations for what should be accomplished. The risk-benefit analysis carried out to determine these new requirements for designs for Emergency Use Authorization (EUA) was deemed to be more beneficial, maximizing the safety of devices while reducing time of testing in the pandemic situation. This action does bring some potential for lowered safety standards for robots seeking FDA EUA approval compared to typical FDA approval. In the case for creating automated systems for PPE testing, Professor Taskin Padir suggested that some of these previous requirements were omitted after the pandemic began because there was not enough data to support the benefit of the requirement during the pandemic. For instance, in the project mentioned previously, data gathered from testing related to flammability and fluid resistance provided more information than that of the tensile strength test. This project would have taken longer if automated testing of PPE tensile strength was included.

These lowered requirements mean easier ability for different solutions to be approved by the FDA for use. By following these minimum requirements established by the FDA, many of these engineers seem to agree that they are carrying out their professional duty. Any risk that can be caused by their project can be reviewed by the FDA. If anything, some are considering making these regulations by the FDA more defined, to make it easier to quantify the safety of these projects.

4.3.4 Developing Projects for Developing Countries

One common pattern that can be seen for research in COVID-19 is the development of technologies for developing countries, creating simplified devices to help supply developing countries with better resources. In particular, two projects in our research have directed their work toward sub saharan Africa.

Each country follows different standards for how to handle and maintain medical devices similar to how the United States is following FDA guidelines. In our interviews, the policies and regulations that were followed were based heavily on the locations the research was conducted in. From our understanding, choosing which regulations to follow stems from convenience, and access to that information. Even though these projects are following foreign regulations relative to the intended users, regulation between different countries follow similar patterns. Transferring these projects over to other countries means shifting the device to meet those different standards. The researchers of our study heavily stated that the responsibility for those changes are in the hands of the community members, rather than in the hands of the engineers.

Chapter 5: Recommendations for Future Research

In our research, there were many different questions that were raised by not only our case studies, but also through the different types of projects that we investigated. Some of those questions arose from a few of the ethical pillars that were established very early on.

Although the FDA and roboticists do try to promote privacy and security with technologies such as telemedicine and telepresence systems, the discussion of integrating security into the design of these systems is lacking. Often in research the Robot Operating System(ROS) library has been used as a development platform for research, however it lacks standard security measures against cyber attacks [69]. ROS has no protocols that verify information that is received [69]. Recently, two more secure versions of ROS, the Secure Robot Operating System project (SROS), and R0S2.0 are under construction with the main advantage of handling actions by malicent agents [69]. Development of SROS currently involves “securing communication between nodes" [69]. At the moment SROS and ROS2.0 are not industry standard. As such, future research into thinking about ethical concerns of robotics should consider and identify potential issues of transferring over to SROS or ROS 2.0, and how that will affect development as a whole for crisis situations. If the benefits of such change do outweigh the potential risk of implementation, discussion on ways to integrate these libraries into research development might help promote security and privacy in these systems.

In our research, we noted the way that both the government and research groups have responded to the COVID-19 virus. Their response and changes in behavior changed the workflow of projects to some extent. It seems like these responses have actually provided many good opportunities to uphold the ethics standards and practices. In this way, we question the types of precautions that were made because of the pandemic. Of those responses, should any of those be maintained regardless of the state of the pandemic?

Once the pandemic has subsided and normal life is able to resume, part of the discussion that can be started is the lingering effects of COVID-19 on the robotics industry. For example, looking into the reception and integration of the promised solutions, and help identify why those solutions came to be standardized.

Hopefully in the near future, these questions will be tackled and considered by other groups that want to explore these ideas.

Chapter 6: Conclusion

With a mixture of textual analysis and semi structured interviews we were able to investigate the ethical considerations of roboticists and how ethical concerns manifested themselves into the design choices and implementation of these research projects.

We found that the market for these types of solutions were great, with both the investment and reception of these technologies highly wanted and accepted in the context of the pandemic. The future public interest seems to be promoting robotics within the healthcare industry, with services to handle the immediate pandemic, and devices that will continue to be used once the world has come to some degree of normalcy. These investments also suggest more forms of better healthcare in developing countries, and access to healthcare personnel across the globe. Suggestions as automation of many pre-operative procedures are expected to be implemented.

Investigating one type of case, of simplifying FDA approved ICU ventilators, often the justification to continue the development was to make systems that can be utilized in communities who do not have access to these devices normally. Although there are more chances harm can occur with these more simplified ventilators, because these communities were given access to something not available initially, development of these technologies were justified.

Based on overall examination of projects done, the core concern usually addressed is the physical safety of their device, making sure that harm to humans is minimized as much as possible. There's a mix between developers who are primarily still fascinated about the functionality of their device, and those that want to deploy their device. Projects that are going to be deployed often have a more detailed level of considerations of ethical concerns compared to projects used for solely research purposes. Although projects that are focusing on the functionality are only thinking about the ethical applications of the design from a limited standpoint, because the project is not going to affect a large group of individuals, from a researcher's perspective, it is more justifiable.

With research and our findings, we had clarity in terms of the effect the ethical concerns brought about by COVID-19 towards development of medical devices in the research setting. Engineers are able to consider ethics during all stages of development in their robots. Additionally, ethical considerations from the community further affect the robots implementation and interaction with people. Above all seem to be the interests of safety and that of the public. With this data, the insights exposed about ethical considerations could be used to validate and express how researchers will react to future pandemics.

Appendix:

Case Study 1: Automated Systems for Testing PPE

The goal of this project is automating the process of analyzing materials for PPE use. The standards followed by these researchers were based on standards of PPE material set by FDA for EUA. They are using AI to help analyze sample data to report to an expert the status of materials. After 2 hours of analyzing data, the team was able to achieve a 92% accuracy in the assessment of a material. This team aims to make contributions to the manufacture of safe PPE during the current pandemic. Afterward, they are headed to analyze materials for the military.

When learning more about this project one central concern is the possibility of receiving a false positive test result through these automated testing systems.

Taking a step back, consider the situation in which automated testing systems for COVID-19 diagnosis send out a false positive result, versus a false negative result:

False positives in the case of these diagnostic systems that test for COVID-19 can cause stress for the individual. They may seek to self-quarantine for 2 weeks. The risk that this poses for the individual is higher, as they are being isolated from their daily activities, and receiving some level of emotional stress. This does not impact the safety of people around this individual.

On the other hand, what happens when an individual receives a false negative? In those cases, they have a higher potential to spread the virus. Not only will the individual not seek treatment for the disease earlier, but they will also be a vector of the spread of the virus. Considering the harm posed to all people due to the false positive result, the magnitude of harm to society, and the individual is much higher.

If there is a material that produces a false positive result through their system, giving the suggestion that the material is suitable for use as PPE, it would leave individuals vulnerable to the virus meaning that people trusting these materials can become vectors for the virus as well. On the other hand, if the material provides a false negative result that would mean that the material would be tested again, or revised. There would be no safety risk caused by this error but the potential risk is delaying the release of this product to the groups waiting on this evaluation. The challenge then is how to mitigate or prevent these types of situations from occurring.

One place of consideration is the test itself. Are the testing procedures carried about by the robot enough to provide good data on the quality of the material and its safety for PPE? And similarly in the case of automated testing systems; is the test good enough to make good assertions?

As previously mentioned, this research project chooses these testing procedures to be automated because they were the minimal required test suggested by the FDA. The testing procedures that are being followed by this project is not as extensive as what would be carried out normally. For example: in a standard testing facility a test known as a sheer stress analysis is conducted, however, this project does not automate this process because it is not part of the minimal testing requirements for PPE. The choices for what test the FDA suggest carrying out for PPE analysis carries with it some level of ethical considerations and tradeoffs:

On one hand, reducing the types of tests needed to evaluate PPE materials reduces the information provided to experts to make the best possible choice. However, this also reduces the time for testing, to allow individuals to get results sooner.

Another point of consideration was when to allow humans to make choices in this automated system. For this project, Professor Taskin Padir indicated two areas where human choices were made when materials were being processed:

1. The ability to change parameters for which the automated system should check
2. The final decision in deciding whether the material in question was safe enough as PPE

The ability to change parameters make tests more rigorous and adaptable to change. Allowing the final decision of a product be based on an informed expert provides a level of responsibility in case anything goes wrong.

So, why not automate these choices? Why not let AI modify these parameters in the justification to improve the evaluation of the material? And why not let AI make the final call in the safety of the material?

As Professor Padir puts it, "The world isn't ready for [machines] to make decisions for us." People trust experts to make the final choices in any process. Additionally, it also allows these individuals to be responsible in case any issues occur.

Case Study 2: RoboPuppet / TRINA

TRINA is a tele-nursing robot that is intended to work in remote biohazardous spaces. This robot took inspiration from the 2014 Ebola Crisis as the initial cause to keep working on tele-nursing robots. This project that was started at Duke University is now shared amongst 3 universities. TRINA is composed of a MOX upper robot, sporting 2 arms with 7 DOF, compliant joints and gripper mechanisms and a mobile base. The robot also has a monitor to help provide an interface for an interaction between operators and partners of the robot.

As COVID-19 became more prominent, this project transitioned over to tackling issues in the context of the pandemic. However, the shift in context has not changed the overall choices of what areas of focus the robot is undergoing. Research projects such as RoboPuppet, consider making the controlling of the robot more intuitive.

One highlight of this discussion was the potential to be had from insecure systems. Insecure systems allow malicious hackers easier access to data and permissions and manipulate systems in a harmful manner.

Robot Operating System or ROS is a structure used for research and development. ROS by the design structure is not secure. ROS lends itself to allowing information to be shared within these closed systems very openly. One concern of the way that ROS shares information between Nodes often comes in the form of the situation of a malicious hacker being able to access that data. Professor Gernert was able to corroborate by highlighting a story in which a student was able to do just that, assess ROS a robot was using remotely, and read information that was being shared in that system. One change has been the development of Secure Robot Operating System 2, SROS2. This does offer some more protection of data between Nodes; however, it is not as widely used.

In the context of TRINA, because ROS is widely used to control individual robotic systems, the controller robot and follower robot there is a potential vulnerability in terms of data security and access if TRINA is sent out as a commercial project.

As much as these ethical concerns were important, most research projects are focused on functionality, with some levels of ethical concerns in place. Ethical concerns play a minor role in the development of these kinds of projects. Part of this is due to the goal of the project. The project is not intended to be a system that is deployed. In the next few years, that possibility is there, but not at its current stage.

Sources:

[1] 11alive.com. “Father, Son Team Up to Help Establish Low Cost Emergency Ventilators.” *11 Alive,* 13 May, 2020, https://www.11alive.com/video/news/health/coronavirus/father-son-team-up-to-help-establish-low-cost-emergency-ventilators/85-17f2b8e1-b7df-4ca8-9525-3b0ff99b532b

[2] “Accountability (Principle 1.5)” *OECD.AI*, 2021, https://oecd.ai/dashboards/ai-principles/P9

[3] Ackerman, Evan. “Telepresence Robots Are Helping Take Pressure Off Hospital Staff > Ava Robotics’ Autonomous Telepresence Robots Are Helping Doctors See More COVID-19 Patients While Avoiding Infection.” *IEEE Spectrum*, 15, Apr. 2020, https://spectrum.ieee.org/telepresence-robots-are-helping-take-pressure-off-hospital-staff

[4] Ackerman, Evan. “Vgo Telepresence Robot: The $6k price of the Vgo telepresence robot makes it cheap enough, almost, to actually be worth buying.” *IEEE Spectrum*, 2 Jun. 2010, https://spectrum.ieee.org/vgo-telepresence-robot

[5]Agarwal, Krishna Mohan, et al. “Concept Design of the Physical Structure for ICU Ventilators for COVID-19 Pandemic.” *Sensors International*, Elsevier, 28 Apr. 2021, https://www.sciencedirect.com/science/article/pii/S2666351121000139

[6] Andigani, Razan. “Urgency Ethics in Robotics.” *Worcester Polytechnic Institute: Electronic Projects Collection,* 19 Aug. 2020, https://web.wpi.edu/Pubs/E-project/Available/E-project-081920-112502/

[7] “Are Ventilators Helping or Harming COVID-19 Patients?” *WedMD*, 2020, https://www.webmd.com/lung/news/20200415/ventilators-helping-or-harming-covid-19-patients#3

[8] “Artificial Intelligence.” *Accenture*, 2021, https://www.accenture.com/us-en/insights/artificial-intelligence-summary-index?c=acn_glb_brandexpressiongoogle_12088819&n=psgs_0321&gclid=Cj0KCQjw6s2IBhCnARIsAP8RfAhLqXsVzlifPDqAb7dQuV4N1842yVlo14mC9dhndMhsRrfW7z12xrYaAomCEALw_wcB&gclsrc=aw.ds

[9] Becker, Rachel. “Why Hospitals Shouldn’t Use Telepresence Robots to Deliver Devastating News.” *The Verge,* 11 Mar. 2019, https://www.theverge.com/2019/3/11/18256929/telepresence-robot-hospitals-patient-information-medical-news-ethics-kaiser

[10] Beitler, Jeremy R., et al. “Ventilator-Induced Lung Injury.” *Clin Chest Med,* 14 Oct. 2016, https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5131805/

[11] Béland, Louis-Philippe, et al. “The Short-Term Economic Consequences of Covid-19: Exposure to Disease, Remote Work and Government Response.” *SSRN*, 27 Apr. 2020, papers.ssrn.com/sol3/papers.cfm?abstract_id=3584922

[12] Bruce Compton, David M Barash. “Access to Medical Devices in Low-Income Countries: Addressing Sustainability Challenges in Medical Device Donations.” *National Academy of Medicine*, 1 Sept. 2020, nam.edu/access-to-medical-devices-in-low-income-countries-addressing-sustainability-challenges-in-medical-device-donations/.

[13] Bushwick, Sophie. “The NYPD’s Robot Dog Was a Really Bad Idea: Here’s What Went

Wrong." *Scientific American,* 7 May, 2021, https://www.scientificamerican.com/article/the-nypds-robot-dog-was-a-really-bad-idea-heres-what-went-wrong/
[14] "Chapter 4: Ethical Issues in Pandemic Planning and Response." *Ethical and Legal Considerations in Mitigating Pandemic Disease: Workshop Summary*, 2007, https://www.nap.edu/read/11917/chapter/6#171
[15] Chatzittofis, Andreas, et al. "Impact of the COVID-19 Pandemic on the Mental Health of Healthcare Workers." *National Library of Medicine*, 3 Feb. 2021, https://pubmed.ncbi.nlm.nih.gov/33546513/
[16] "Civil Rights and COVID-19." *U.S. Department of Health and Human Services,* 5 Aug. 2021, https://www.hhs.gov/civil-rights/for-providers/civil-rights-covid19/index.html
[17] "Coronavirus (COVID-19)" *World Health Organization Regional Office for Africa*, 2021, https://www.afro.who.int/health-topics/coronavirus-covid-19
[18] "Coronavirus Resource Center." *Johns Hopkins University of Medicine,* 2021, https://coronavirus.jhu.edu/
[19] "COVID-19: How to Protect Yourself and Others." *Centers for Disease Control and Prevention*, 2021, https://www.cdc.gov/coronavirus/2019-ncov/prevent-getting-sick/prevention.html
[20] "COVID Data Tracker." *Centers for Disease Control and Prevention,* 2021, https://covid.cdc.gov/covid-data-tracker/#datatracker-home
[21] Crowe, Steve. "Robotics startups collaborating on low-cost ventilator for COVID-19 patients." *The Robot Report,* 25 Mar. 2020, https://www.therobotreport.com/the-ventilator-project-robotics-startups-COVID-19/
[22] Crowe, Steve. "Waymo Suspends Some Self-Driving Programs Due to COVID-19." *The Robot Report*, 18 Mar. 2020, www.therobotreport.com/waymo-suspends-self-driving-testing-covid-19/.
[23] "CSAIL Robot Disinfects Greater Boston Food Bank." *Robotics @ MIT*, https://robotics.mit.edu/csail-robot-disinfects-greater-boston-food-bank
[24] Davis, Charlotte. "The Importance of Professional Accountability." *Nursing Made Incredibly Easy,* Vol. 15, Issue 6, Dec. 2017, p. 4, https://journals.lww.com/nursingmadeincrediblyeasy/fulltext/2017/11000/the_importance_of_professional_accountability.1.aspx
[25] Demaitre, Eugene. "Coronavirus Fight in China to Get a Boost from UVD Disinfection Robots." *The Robot Report,* 21 Feb. 2020, https://www.therobotreport.com/coronavirus-fight-china-gets-boost-uvd-disinfection-robots/
[26] Demaitre, Eugene. "UVD Robots Supplies 37 Disinfection Robots in Largest U.S. School District Deployment to Date." *Robotics 247*, 26, Mar. 2021, https://www.robotics247.com/article/uvd_robots_supplies_37_disinfection_robots_in_largest_u.s_school_district_deployment_to_date/mobile_robots
[27] "Digital Innovation Hubs in Health-Care Robotics Fighting COVID-19: *Novel Support for Patients and Health-Care Workers Across Europe*." *IEEE Magazine*, vol. 28, No. 1, Mar. 2021, pp. 40-47
[28] Di Lallo, Antonio, et al. "Medical Robots for Infectious Diseases: *Lessons and Challenges From the COVID-19 Pandemic*." *IEEE Magazine*, vol. 28, No. 1, Mar. 2021, pp. 18-27
[29] "Disinfectant Robot Market - Growth, Trends, COVID-19 Impact, and Forecasts (2021

- 2026)" *Mordor Intelligence,* 2021 https://www.mordorintelligence.com/industry-reports/disinfectant-robot-market

[30] "Economic Impact Payments." *IRS*, https://www.irs.gov/coronavirus/economic-impact-payments

[31] "Enforcement Policy for Ventilators and Accessories and Other Respiratory Devices During the Coronavirus Disease 2019 (COVID-19) Public Health Emergency." *Guidance for Industry and Food and Drug Administration Staff,* Mar. 2020, https://www.fda.gov/media/136318/download

[32] "Ethics in Robotics" *International Review of Information Ethics,* Vol. 6, Dec. 2006, http://www.i-r-i-e.net/inhalt/006/006_full.pdf

[33] "Ethics of Artificial Intelligence and Robotics." *Stanford Encyclopedia of Philosophy*, 30, Apr. 2020, https://plato.stanford.edu/entries/ethics-ai/?TB_iframe=true&width=370.8&height=658.8

[34] "FOIA.gov" *United States Department of Justice,* https://www.foia.gov/faq.html

[35] Gaudin, Sharon. "WPI Researchers Developing Open-Source Designs to Speed Creation of Low-Cost Ventilators." *Worcester Polytechnic Institute,* 1 Apr, 2020, https://www.wpi.edu/news/wpi-researchers-developing-open-source-designs-speed-creation-low-cost-ventilators

[36] GlobalData Healthcare. "The future outlook of the ventilators market post-COVID-19." *Medical Device Network,* 10 Dec. 2020, https://www.medicaldevice-network.com/comment/future-outlook-ventilators-market-post-COVID-19/

[37] Goodman, Ryan and Schulkin, Danielle. "Timeline of the Coronavirus and U.S. Response." *Just Security,* 3, Nov. 2020, https://www.justsecurity.org/69650/timeline-of-the-coronavirus-pandemic-and-u-s-response/

[38] "Hopkins Ventilator Robot Wins Top Prize at UK Robotics Week Challenge." *Johns Hopkins Whiting School of Engineering*, 5 Feb. 2021, https://me.jhu.edu/2021/02/05/hopkins-ventilator-robot-wins-uk-robotics-week-challenge/#.YNA2WWhKiUm

[39] Haring, Kerstin S., et al. "The Dark Side of Human-Robot Interaction: Ethical Considerations and Community Guidelines for the Field of HRI." *IEEE Xplore*, 25 Mar. 2019, https://ieeexplore.ieee.org/document/8673184

[40] Hauser, Kris, and Shaw, Ryan. "How Medical Robots Will Help Treat Patients in Future Outbreaks: Teleoperated robots can help perform patient care tasks while keeping healthcare workers safe." *IEEE Spectrum*, 4 May 2020, https://spectrum.ieee.org/medical-robots-future-outbreak-response

[41] Hawkins, Andrew J. "Nuro Is Using Delivery Robots to Help Health Care Workers Fighting COVID-19." *The Verge*, The Verge, 22 Apr. 2020, www.theverge.com/2020/4/22/21231466/nuro-delivery-robot-health-care-workers-food-supplies-california.

[42] Howard, Ayanna and Borenstein, Jason. "AI, Robots, and Ethics in the Age of COVID-19." *MIT Sloan Management Review*, 12 May, 2020, https://sloanreview.mit.edu/article/ai-robots-and-ethics-in-the-age-of-covid-19/

[43] Hyzy, Robert C. and Slutsky, Arthur S. "Ventilator-Induced Lung Injury." *Up To Date*, 29 Jul. 2021, https://www.uptodate.com/contents/ventilator-induced-lung-injury

[44] "Inclusive Growth, Sustainable Development and Well-Being." *OECD.AI*, 2021, https://oecd.ai/dashboards/ai-principles/P5
[45] "Interim Infection Prevention and Control Recommendations for Healthcare Personnel During the Coronavirus Disease 2019 (COVID-19) Pandemic." *Centers for Disease Control and Prevention,* 10 Sep. 2021, https://www.cdc.gov/coronavirus/2019-ncov/hcp/infection-control-recommendations.html
[46] "Is It in the Public's Interest." *Ethical Journalism Network*, 2021, https://ethicaljournalismnetwork.org/the-public-interest
[47] "Italy: Abano Hospital Veneto" *UVD Robots*, https://www.uvd-robots.com/italy
[48] Jennings, Bruce and Arras, John D. "Ethical Aspects of Public Health Emergency Preparedness and Response." *Emergency Ethics: Public Health Preparedness and Response*, Apr. 2016, https://oxfordmedicine.com/view/10.1093/med/9780190270742.001.0001/med-9780190270742-chapter-2?print
[49] Leidner, Daniel. "The COVID-19 Pandemic: An Accelerator for the Robotics Industry?" *IEEE Magazine*, vol. 28, No. 1, Mar. 2021, pp. 116
[50] McLean, Linda. "Hopkins Engineers Develop A Promising New Ventilator." *Johns Hopkins University Hub,* 23 Apr. 2020, https://hub.jhu.edu/2020/04/23/engineers-develop-pumpless-ventilator/
[51] McMahon, Devon E., et al. "Global Resource Shortages during COVID-19: Bad News for Low-Income Countries." *PLOS Neglected Tropical Diseases*, Public Library of Science, journals.plos.org/plosntds/article?id=10.1371/journal.pntd.0008412.
[52] Molyneux, Cándido G., and Oyarzabal, Rosa. "What is a Robot Under EU Law?" *Covington*, 4 Aug. 2017, https://www.globalpolicywatch.com/2017/08/what-is-a-robot-under-eu-law/
[53] "National Moratorium." *National Low Income Housing Coalition,* 2021, https://nlihc.org/coronavirus-and-housing-homelessness/national-eviction-moratorium
[54] Neuman, Scott and Doubek James. "Arkansas Has Only 8 Empty ICU Beds, As COVID-19 Cases Resurge." *NPR*, 10 Aug. 2021, https://www.npr.org/sections/coronavirus-live-updates/2021/08/10/1026409785/arkansas-hospital-bed-icu-shortage-covid-19-surge
[55] Niemelä, Marketta, et al., "Towards Ethical Guidelines of Using Telepresence Robots in Residential Care." *ResearchGate*, Jun. 2021, https://www.researchgate.net/publication/331288848_Towards_Ethical_Guidelines_of_Using_Telepresence_Robots_in_Residential_Care
[56] "Non-Discrimination in Medical Treatment Guideline." *Illinois Department of Public Health*, 10 Jul. 2020, https://www.dph.illinois.gov/covid19/community-guidance/non-discrimination-medical-treatment-guidance
[57] "NSPE Code of Ethics for Engineers." *National Society of Professional Engineers*, Jul. 2019, https://www.nspe.org/resources/ethics/code-ethics
[58] Odense. "Press Release: UVD Robots Deploys the #100 Robot Ordered by EU in Hospitals Across Europe." *Blue Ocean Robotics,* 29 Jun. 2021, https://www.blue-ocean-robotics.com/news/deploys-100-robots
[59] Pearce, Joshua M. "A Review of Open Source Ventilators for COVID-19 and Future

Pandemics.” *F1000 Research*, 30 Apr. 2020, https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7195895/
[60] Perez, Guillermo I., Abadi, Amin. “Ongoing Challenges Faced in the Global Control of COVID-19 Pandemic.” *ScienceDirect*, 3 Apr. 2020, https://www.sciencedirect.com/science/article/pii/S0188440920304574
[61] “Principle on Robustness, Security and Safety.” *OECD.AI*, 2021, https://oecd.ai/dashboards/ai-principles/P8
[62] “Privacy.” *Merriam-Webster*, 2021 https://www.merriam-webster.com/dictionary/privacy
[63] “Products - Technology.” *Beam*, 2020, https://suitabletech.com/products/technology
[64] “R150 Supports Thai Armed Forces Disinfecting Against COVID-19” *XAG*, 20 May, 2021, https://www.xa.com/en/news/application/101
[65] Riek, Laurel D. and Howard Don. “A Code of Ethics for the Human-Robot Interaction Profession.” *We Robot*, 2014, https://robots.law.miami.edu/2014/wp-content/uploads/2014/03/a-code-of-ethics-for-the-human-robot-interaction-profession-riek-howard.pdf
[66] “Robots - VGo” *Robots - Your Guide to the World of Robotics*, 2021, https://robots.ieee.org/robots/vgo/?gallery=video3
[67] “Safety.” *Merriam-Webster*, 2021, https://www.merriam-webster.com/dictionary/safety
[68] Schuchat, Anne. “Summary of Guidance Review.” *Agency Guidance Review*, 10 Mar. 2021, https://www.cdc.gov/coronavirus/2019-ncov/downloads/communication/Guidance-Review.pdf
[69] “Secure Communication for the Robot Operating System.” *IEEE Xplore*, ieeexplore.ieee.org/abstract/document/7934755.
[70] “Security.” *Merriam-Webster*, 2021, https://www.merriam-webster.com/dictionary/security
[71] Spice, Byron. “Carnegie Mellon, Pitt Researchers Launch Ventilator Project.” *Carnegie Mellon University,* 6 May, 2020, https://www.cmu.edu/news/stories/archives/2020/may/roboventilators.html
[72] “Telepresence Robots Market - Growth, Trends, COVID-19 Impact, and Forecasts (2021 - 2026)” *Mordor Intelligence*, 2021, https://www.mordorintelligence.com/industry-reports/telepresence-robots-market
[73] ‘The Coronavirus Spring: The Historic Closing of U.S. Schools (A Timeline)” *Education Week*, 1 Jul. 2020, https://www.edweek.org/leadership/the-coronavirus-spring-the-historic-closing-of-u-s-schools-a-timeline/2020/07
[74] “Transparency and Explainability (Principle 1.3)” *OECD.AI*, 2021, https://oecd.ai/dashboards/ai-principles/P7
[75] “Ventilators and Ventilator Accessories EAUs.” *FDA,* 15 July 2021, https://www.fda.gov/medical-devices/coronavirus-disease-2019-COVID-19-emergency-use-authorizations-medical-devices/ventilators-and-ventilator-accessories-euas
[76] “Ventilators and Ventilator Accessories for COVID-19.” *FDA*, 9 Feb. 2021,

https://www.fda.gov/medical-devices/coronavirus-COVID-19-and-medical-devices/ventilators-and-ventilator-accessories-COVID-19#enforcement
[77] "Ventilators Market to Reach $1.6bn by 2030 After the Downturn in 2021" *GlobalData*, 15, Jan. 2021, https://www.globaldata.com/ventilators-market-reach-1-6bn-2030-downturn-2021/
[78] *VGo*, VGo Communications Inc., 2021, http://www.vgocom.com/?utm_source=robots.ieee.org
[79] "What is Coronavirus." *John Hopkins Medicine*, 2021, https://www.hopkinsmedicine.org/health/conditions-and-diseases/coronavirus
[80] "WHO Coronavirus (COVID-19) Dashboard." *World Health Organization*, 2021, https://covid19.who.int/
[81] "XAG Introduces Drone Disinfection Operation to Fight the Coronavirus Outbreak." *Health Europa*, 5 Feb. 2020, https://www.healtheuropa.eu/xag-introduces-drone-disinfection-operation-to-fight-the-coronavirus-outbreak/97265/
[82] "Xfinity WiFi Hotspot Access Opened Nationwide in Response to Coronavirus." *Xfinity*, 2021, https://www.xfinity.com/support/articles/open-xfinity-wifi-hotspots
[83] Zaveri, Mihir. "N.Y.P.D. Robot Dog's Run is Cut Short After Fierce Backlash." *The New York Times,* 28, Apr. 2021, https://www.nytimes.com/2021/04/28/nyregion/nypd-robot-dog-backlash.html