THE DEVELOPMENT OF LOW-COST, ACCESSIBLE EEG CONTROLLED 3D-PRINTED REHABILITATIVE MEDICAL ROBOTICS

THE ANALYSIS OF THE ETHICS AND ACCESSIBILITY OF MEDICAL ROBOTICS WITHIN LOW-INCOME SOCIETIES

A Thesis Prospectus
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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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***Introduction*:**

Medical robotics is a field that has been on the rise over the past decade or so. Thanks to these robots, numerous surgeries have become less tedious and dangerous to perform, overall improving the lives of those who require their assistance. Recent developments within this field focus on the analysis and development of mechatronic systems to assist in rehabilitating those suffering from numerous muscular and neural conditions. This realm of medicine is often known as the research of rehabilitative robotics. These robots can come in many diverse forms ranging from a stationary, high-powered robotic exoskeleton to a wearable textile, pneumatic-based assistive exoskeleton. No matter what form these devices are developed into, they all employ the use of advanced modern technology to achieve their purpose.

My Mechanical Engineering capstone project deals with the development of an EEG-controlled low-cost 3D printed rehabilitative robotic exoskeleton that patients use to recover from localized, upper body paralysis. The rehabilitative robotic exoskeleton employs the use of numerous mechanical and electro-mechanical devices, such as stepper motors, sensor data analysis from electronic sensor devices, and machine learning to identify and predict potential movements through facial expressions, vocal analysis, or electric signals from the brain. Due to the assistive nature of the technology being developed, we hope to be able to test the robot on patients within the University of Virginia hospital to seek feedback from those who use it. Not only this, but we hope to develop this device through low-cost materials. We beg the question of whether it is possible to develop these brain-controlled, complicated devices with a medium to low amount of capital, allowing those within lower-socioeconomic societies to gain access to these affordable technologies.

For my STS project, I hope to delve deeper into the ethics and processes behind the development of these rehabilitative medical technologies and the gatekeeping that is present within the medical facilities that utilize them. Since I want to make these robots accessible to all, not just to those with a better economic standing, I want to investigate these concepts fully in order to determine why these robots are currently inaccessible to countless individuals. The question that I hope to provide insight on through this research would be how the development of these modern-day rehabilitative technologies allows for this gap in access and how can we, as engineers, change this process to allow for those with lower-socioeconomic backgrounds to gain access to these helpful technologies. Given that my STS project and technical project share a same motive, to prove that low-cost rehabilitative medical robots can be developed and accessed fairly to individuals of different economic standings, I believe that thorough research within the STS project will assist me in the design and development of my over-arching technical project.

Through this prospectus, I hope to first highlight the development plan of my technical project and then dive into the ethics behind the accessibility and development of these technologies.

***Technical Project*:**

For the technical aspect of my Mechanical Engineering capstone project, my team of three engineers is designing, prototyping, and developing a low-cost 3D printed upper body exoskeleton. The exoskeleton uses machine learning to trigger given movements by analyzing electrical activity in the brain. This device would be utilized for patients suffering from partial upper body paralysis as a means of an affordable rehabilitative option. To achieve this, we will plan out three major facets of the project: the design phase, the manufacturing phase, and the overall testing and improvements phase. This will ensure that we can comply with all standards necessary for the timely completion of this project. Within the technical components, the exoskeleton will employ concepts and components from mechanical engineering, electrical and computer engineering, and computer science. To break this down further, I will lay out the general components that will be utilized for each discipline. Currently, this project is in the design phase, so many of these components are subject to change given newly discovered constraints. It is to be noted that we are required to receive an Institutional Review Board (IRB), a board of individuals that determines whether a research study involving humans meets industry specifications, certification in order to fully test the device once it is developed.

To begin with, when analyzing the mechanical components needed for this exoskeleton, we see that the device utilizes a stepper motor and flexible supports as a replacement for muscle fibers. The outer shell, housing, and internal components consist of cheap parts ranging from 3D printed materials to lightweight metals and fabrics. For background information, stepper motors are electro-mechanical mechanisms that employ voltage and written motor code to determine specific actuations or movements. These stepper motors will be light in weight and wearable, allowing the patient to equip this device for rehabilitative purposes whenever needed. Also, to power these motors, a cheap rechargeable battery is employed and mounted to the back housing of the exoskeleton. The fabric serves to fasten the exoskeleton to the patient.

In terms of the electrical components to be utilized, we plan that this exoskeleton will employ the use of a Raspberry Pi in conjunction with an electroencephalograph (EEG) device. An EEG device allows for synchronized data collection between the patient's motor cortex and muscle activity as one's motor cortex controls muscle activity (Nakano, 2020). Simply put, EEGs are electro-mechanical devices that allow for the reading and recording of electrical activity within the user's brain. By employing the use of this device, the user would be able to utilize electrical signals from the motor cortex and translate the taken data into perceived muscular movements. To mount this device onto the patient's skull, electric-sensitive pads or electrodes are to be spread around the scalp and head region to allow for accurate measurements to be taken. These electric signals and components would be set, limited to mechanical constraints.

On the computer science facet of this project, my team is going to utilize Raspberry Pi python to develop and optimize machine learning algorithms that will allow for proper data tuning and collection. This will enable us to interpret the given electrical signals to determine exactly what action is to be done. Note that the accuracy of these methods can be limited due to high levels of complexity in the data collected and overall overlap between specific movements.

***STS Project*:**

With new developments emerging for wearable robotic rehabilitative systems and the reliance on robotic systems increasing within society, questions begin to arise over the ethics of the development, distribution, and potential uses of these technologies. With respect to these worries, I hope to discover how the development of these rehabilitative technologies allows for a gap in access between societal classes and how we, as engineers, can change this process to make it more accessible.

To investigate further, I must fully understand why these wearable technologies are being developed and utilized around the world. In developing countries, physical injuries that impair one's ability to move around or complete everyday chores make up roughly 20.2% of all disabilities within the given country (Ullas et al., 2021). Within the United States, a fully developed superpower nation, the CDC estimates that roughly 18.0% of adults over the age of 20 experience physical impairments that limit mobility and functionality (CDC, 2022). Given this high population of individuals seeking assistance in regaining the full functionality of their bodies, we must continue to develop these rehabilitative technologies. These rehabilitative robots are in high demand as current medical devices tend to be limited in their workspace which, as a result, limits the regaining of upper body and lower body functions (Xie, 2016). This encourages us to rethink and investigate the development of rehabilitative devices.

For this study, I will focus on individuals requiring physical rehabilitation who lack the proper resources to afford the current systems set in place. Since current rehabilitative treatments for physical impairments require highly skilled trained professionals, expensive machinery, and the fact that a high percentage of individuals within both developing and developed societies require some sort of physical aid, it is important to develop a technology that is accessible to all

(Ullas et al., 2021). This pertains specifically to those in lower-income regions that tend to struggle to deal with the financing of expensive medical treatments. That means that, for this study, I am not considering individuals without physical impairments or those in wealthy environments that can afford such treatments without any worries. Although this product would also be applicable to these individuals, it sets an unfair bias for pricing the developed technologies, potentially allowing for a skewed cost to be concluded.

To better understand the factors contributing to the unequal access to rehabilitative technologies, I will investigate the manufacturing and distribution methods used by current leaders in the field. I will examine the materials and processes used in the production of these technologies, as well as the distribution channels and insurance policies that may impact their accessibility. Through this analysis, I hope to identify potential areas for improvement and make recommendations for increasing the availability and affordability of these technologies for individuals in lower-income regions.

From this established importance, I hope to use personal stories to illustrate the financial challenges faced by people with these neuromuscular conditions. I also want to be able to gain insight into the lack of accessibility by interviewing those who are unable to afford the given treatments. This would allow me to develop a diverse view on the overall accessibility of these devices and how the current costs of these treatments may lead to potential financial hardships as the years progress. Given the fact that numerous corporations are profit driven in the modern era, I hope to investigate the current processes and materials that are being utilized to develop commercial and medically distributed rehabilitative devices. This would allow me to gain insight into the potential biases that could arise when determining what materials to utilize and the overall pricing of the product. Finally, I will be looking into current policies pertaining to medical services within the United States, allowing me to determine whether there is an internal issue on the governmental level that may potentially lead to a division in fair access between people.

My next steps to investigate this project would be to first investigate the ethics behind assistive robotics and the potential ethical conundrums that may arise from their usage. Once determining the core argument within the ethics and providing a solution, I can then begin to investigate the costs of development for these robotic systems as well as investigate potential policies that may be leading to an overall divide in access between societies. After collecting the preliminary data and developing a strong understanding of the current standings of public policies and pricing behind these rehabilitative robots, I then plan on interviewing those relevant to the issue. With this background knowledge in hand, it would allow me to ask more meaningful questions that these individuals can sympathize with, allowing for a more productive conversation to be had.

***Key Texts*:**

In the article *Roboethics - making sense of ethical conundrums* by Majeed, the author dives into the ethical issues relating to the application of rehabilitative robotics on children. This issue derives from the fact that in many cases, these rehabilitative robots may take control over an aspect of one's body making it difficult to tell whether it would be ethical to allow children, a group viewed as being vulnerable, to use these devices. Majeed argues that by considering the ethical principles that come with the use of rehabilitative robotics on children and applying them to medical practice, these robots would be considered acceptable within an ethical scope. As my STS topic deals with the accessibility of rehabilitative robotics to the public, it is important for me to fully understand that these devices must be ethical and applicable to all, regardless of race, age, disability, or class. Having this understanding of the full ethical issues that could potentially arise when testing and distributing my device would allow for me to be more considerate when making design choices, ensuring that the product is safe to distribute.

In the article *A systematic review of access to rehabilitation for people with disabilities in low- and middle-income countries* by Bright et al., the author investigates the accessibility of rehabilitation for those with disabilities from varying socioeconomic backgrounds. Bright et al. argues that there is evidence to suggest that uninsured patients with physical disabilities generally have little to no access to assistive devices used for the purpose of rehabilitation. This relates to my STS topic as it investigates the causes across numerous countries that can potentially lead to this general lack of accessibility in rehabilitative devices. As I am investigating the root cause of this gap in rehabilitative accessibility, this article plays an important role in providing potential explanations as to what is propagating this issue.

In the article *Access to health insurance, barriers to care, and service use among adults with disabilities*, Sommers examines the accessibility of health insurance and medical services for those with disabilities, uncovering gaps in access to rehabilitative programs. Sommers argues that it is not those with disabilities that lack access to health care and rehabilitative services, but those in low-income communities that do, pushing for more policy attention to mitigate this issue. Being that my STS project investigates the lack of accessibility in these rehabilitative technologies, this article is essential to understand. By learning of the groups lacking access to these technologies and determining a cause as to how they are being discriminated against, as was done in the article, I am better able to discuss how this gap has been able to be propagated throughout the years.

In the article *Budget impact analysis of robotic exoskeleton use for locomotor training following spinal cord injury in four SCI Model Systems* by Pinto et al., Pinto et al. investigates the current budget of hospital spendings on rehabilitative technologies dealing with spinal cord injuries. Pinto et al. argues that by implementing low-cost robotic exoskeletons into hospitals' rehabilitative technologies, hospitals would be able to mitigate costs on expensive machines while maintaining the effectiveness of the treatment plan. This article is essential for my STS topic, as it deals with methods of mitigating medical costs of rehabilitative devices. By fully understanding these methods of mitigation, I can develop a broader design that is able to be distributed at a low-cost while retaining its efficacy.

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