EEG CONTROLLED ROBOT

THE CAUSE OF COSTLY PROSTHETICS

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

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November 8, 2024

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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

The cost of owning a prosthetic device is recognized as a primary issue behind its accessibility to amputees. While affordability appears to be a larger issue for lower-class patients, amputees in both low and high income settings have limited access to prosthetic and orthotic services (Donnelly, 2021). Accessibility of orthotic services for amputees has a major societal impact, not only benefiting the patients, but rather an entire network of actors. Poor, failed, or no prosthetic care results in long-term negative side effects for amputees, but also long-term and significant costs for insurance companies (Baumann et al., 2020).With the simplest bionic arm costing approximately $5000 (Cutipa Puma et al., 2023), the technical research topic is developing a 3D printed robotic system controlled by electroencephalography (EEG) in order to offer a low-cost solution utilizing affordable materials and eliminating any surgical procedures.

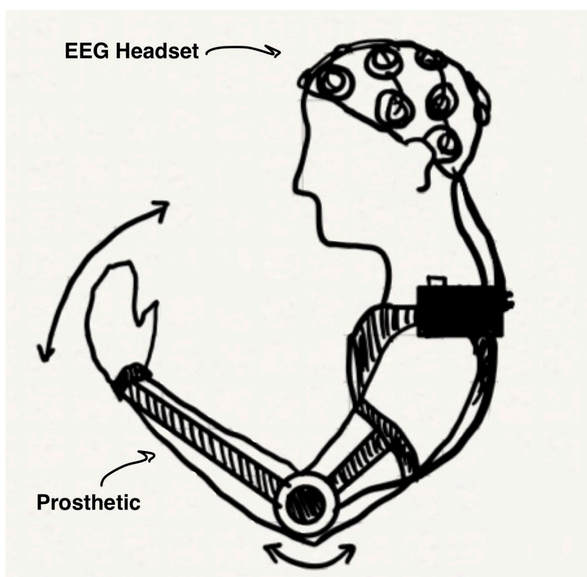

Fig. 1. Rough sketch of the primary components of the project. The EEG headset is on the user’s head, connected to a prosthetic device that moves based on the EEG readings.

The previous group working on this project was able to achieve approximately 60% success rate in distinguishing a user's intent and having an exoskeletal robot perform the task. This year, an 80% accuracy rate or higher will be considered successful for this capstone project. In order to achieve a higher accuracy rate, a different approach using machine learning will be done. Previously, intentions were based on directions (ie. left, right, up, down) and machine learning. This version will use reinforcement learning to move in specific predetermined movements, with a user thinking yes or no as to whether or not they wish to move the prosthetic and the program being rewarded or punished based on its action. OverallThis project will not only examine the causes behind prosthetic inaccessibility through academic research, but will also develop a technical solution through the design of a low-cost, non-invasive (without the need of surgical implants) bionic device.

EEG Headset

The oldest known prosthetic devices are two artificial toes from Egypt, estimated to be between 2,600 and 3,400 years old (*Prosthetics through the ages | NIH MedlinePlus Magazine*).

Fig. 2. Cairo Toe, the oldest prosthetic artifact from approximately 3,000 years ago (*A wooden toe: Swiss egyptologists study 3000-year-old prosthesis* 2017).

Over the years, the capability of these devices has drastically increased, from simple cosmetic wooden prosthetics to brain-controlled bionic arms. The earliest versions of orthotics were typically wooden or metallic replicas of missing appendages or limbs, such as pegs or hooks. Over time, mechanical systems were implemented into prosthetics, creating body-powered devices which were capable of ‘independent’ movement, meaning they could perform a function other than moving in the direction of their base.

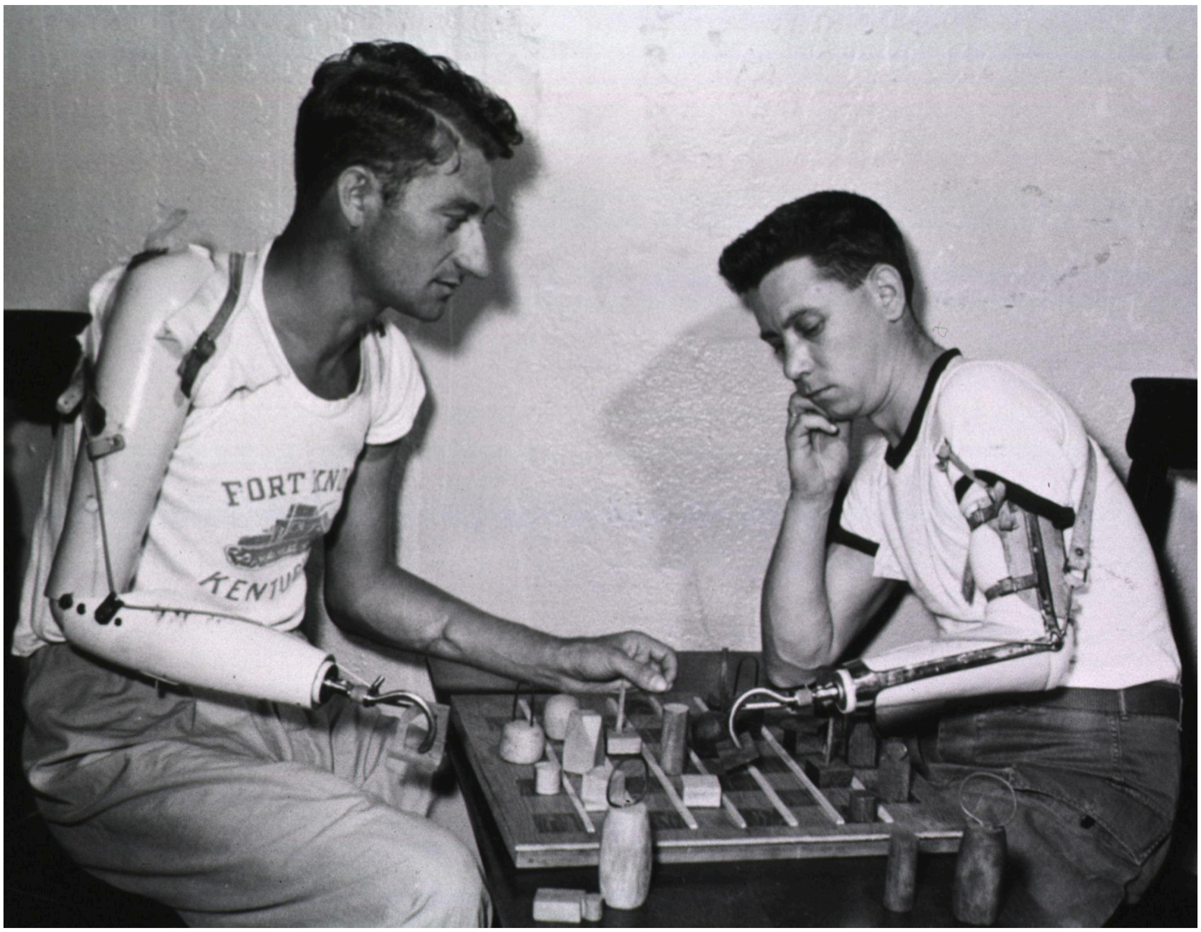

Fig. 3. Two men, each with a body-powered prosthetic arm, sit at a table and play checkers (*Prosthetics through the ages | NIH MedlinePlus Magazine*)

As prosthetic capabilities have increased, orthotic accessibility has seemed to decrease, becoming a major difficulty for amputees globally. Though a big factor has been cost due to the advanced technology integrated into modern prosthetics, after a few millennia an affordable option for amputees deserves to be available.

This EEG headset project has a goal of retaining much of the capabilities in modern, costly prosthetics, costing over $5000 while being affordable for the average consumer through the use of open source brain control interfaces (BCIs) and 3D printing. While a previous capstone group has attempted to implement a solution, the 60% accuracy rate was unfortunately not considered successful when compared to academic journals. This group used an EEG headset purchased from OpenBCI and recorded brain activity from users.

Fig. 4. OpenBCI EEG biosensing headset used for the project (*Ultracortex "Mark IV" EEG headset*).

This data was then fed into a deep learning algorithm which would decipher what a user's intentions were and subsequently actuate an exoskeleton. The algorithm worked by recognizing patterns in specific intentions, such as certain frequencies when a user thought to lift their arm, and another when moving it to the left or right. Due to the amount and complexity of brain signals along with interference from the skin and hair, the group was only able to achieve a 60% success rate at interpreting a user's thoughts and controlling a robotic system.

Since EEG is inherently non-invasive and must use surface contact electrodes, skin and hair interference is unavoidable. As a result, a different approach must be used in order to successfully utilize EEG to control a prosthetic or exoskeletal device. This year, a reinforcement algorithm will be used as brain activity is fed into the software as the data. The idea is for a user to think of controlling a robotic system through thinking yes or no; It could be that the action is to open or close, move up or down, or move side to side. By restricting the amount of intentions an algorithm would have to categorize, the learning process would be more efficient and reliable. In addition to a reinforcement algorithm, an anomaly detection algorithm will be implemented to ensure the accuracy of the output. This would identify outliers in the categorized data (the signals that have been sorted into a yes or no category) and clean them out so that the labels would be better predictors once new data is inputted. Once the algorithm has been thoroughly trained, the output will be sent to a Raspberry PI board, a commercial microcontroller, connected to the prosthetic. There the Raspberry PI will actuate the device accordingly based on the output of the algorithm, whether or not the algorithm interpreted the user’s thought as a ‘yes signal’ or ‘no signal’.

The Cause of Costly Prosthetics

The topic of this STS research study is examining the reason why prosthetic and orthotic services and devices are globally inaccessible to amputees and similarly impaired individuals. Access to both these services and devices impacts an array of actors beyond just the patient, with research suggesting that it is societies benefit for the above to be available to amputees.

Although birth defects such as Amelia exist and cause affected individuals to be born without one or more limbs, creating a need for prosthetic and orthotic services, only approximately 1000 people in the United States have the disease (U.S. Department of Health and Human Services, 2024). The primary demographic of individuals who are missing limbs are people who have undergone an amputation. Currently there are 35 and 40 million amputees around the world and 185,000 annual amputations that occur in the United States primarily caused by diabetes. In underdeveloped countries, the major cause for a significant increase in amputations are humanitarian crises, natural disasters, and motor vehicle accidents, such as with the Haiti earthquake or the civil war in Sierra Leone. (Cabrera, 2022).

For amputees, there is both a financial and physical benefit for the utilization of prosthetic services. Individuals who lack access to prosthetic care tend to live more sedentary lifestyles which can lead to complications such as diabetes, also leading to increased medical expenditure (Dobson et al., 2016). Additionally the consequences of a lack of prosthetic care extends to insurance companies as the side effects of poor, failed, or no prosthetic care creates an increase in medical expenditure in the long-term (Baumann et al., 2020).

Economic analyses of prosthetic devices and services conclude that out of the annual 1 million amputations that occur globally, amputees in both low and high income settings have limited access to prosthetic and orthotic services. Even in comparatively modern and high income countries with prosthetic services in place, the demand for these outweighs the resources available. In low income countries, access is limited due to the lack of established prosthetic services and high delivery costs, and since these countries are already in a financial struggle, resourcing these services has not been prioritized. (Donnelley et al., 2021) Additionally, the amount of amputees in need of services far outweighs the prosthetists available. An important figure is brought up stating that over 100,000 prosthetists would be needed to address the needs of the 30 million people in need of orthotic services in developing countries. (Johnson et al., 2012).

By analyzing academic journals and research studies focusing on individual aspects behind prosthetic inaccessibility, this STS project will compile the combined reasons for why prosthetics are so costly. In doing so, an Actor Network Theory will map out the relationships between the various causes for the expenses of prosthetics, from the reasoning behind why amputations occur to the different parties at stake by not having access to orthotic services. In order to analyze these relationships, the data collected will be from research studies that perform quantitative analysis based on statistics or relevant qualitative experiences such as time spent in undeveloped countries examining the effects that prosthetic care had on amputees, or both. Through these methods of analysis, the network of actors that influence or are influenced by costly prosthetics will be examined.

Conclusion

A low-cost EEG robotic system will be designed in order to provide a solution to the expensive prosthetic devices on the market. At the same time, the STS component will examine the causes of inaccessible orthotic services and the reason for why bionic devices are expensive beyond the physical cost of materials. The combination of both makes for a product that addresses the needs of the actors involved, being both capable and affordable. Its importance lies in the diversity and magnitude of its actor network, with many human and nonhuman actors and artifacts impacted by the topic. The hope of successfully completing this project is a movement towards more affordable prosthetic devices having the final product as an adequate proof of concept.

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