Wearable Upper Limb Exoskeleton Robotic Device for Muscular Motion
(Technical Paper)

Prosthetic Abandonment: A Sociotechnical Analysis
(STS Paper)

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 1, 2021

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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

Advancements in medical technology within the past century have prolonged the average human life expectancy from 45 years to 80 years (Boudoulas et al., 2017). Medical devices are commonly used to address an array of needs. For example, modern technology may assist individuals who are dependent on devices to live, monitor daily health data, or ultimately allow individuals more autonomy. The proposed technical project will focus on designing and constructing an upper limb muscular assistive device. The proposed STS project will focus on patient identity, prosthetic features, and medical field factors and the predictability of prosthesis success and patient re-integration in everyday life.

The technical project entails designing a wearable upper limp exoskeleton device for motor control. Wearable technology, or wearable devices, are technologies that provide medical assistance through "monitoring, recording, and transmission of physiological signals" (Rutherford, 2010). Modern wearable technology has become incorporated into accessories and clothing such as fabric patches, watches, or jewelry (Wright & Keith, 2014). Applications for everyday life include fitness monitoring or increased motor control. Engineers are finding new ways to develop devices and finding new applications to employ devices in both the medical field and everyday life. The goal for the capstone team will be to design a wearable exoskeleton device in the upper limb for motor control, construct the robotic exoskeleton, iterate the design based on customer feedback, and write a paper discussing the findings from the study.

Although medical technology has prolonged the average human life span, there are flaws in the medical field which prevent patient satisfaction. The proposed STS research paper will discuss factors of identity and prosthesis technology that cause devices to be successful and used in daily life or rejected. Outcomes of the prosthesis will be examined from the diagnosis, fitting, rehabilitation, and recovery periods. Individuals face adversity based on underlying bias in the system, predisposed health factors, accessibility to specialized health institutions, and factors influencing reintegration into society post-operation. Understanding why some individuals have more success with a prosthesis than others in medical technology will improve interactions between patient and medical personnel, human and device interfaces, and engineers and developing new technology. The potentials in the medical technology field are limitless and based on engineering accomplishments. Researching the factors influencing a patient's prosthesis helps create awareness for disparity factors in the healthcare system.

Technical

The technical portion the fourth-year capstone design course involves constructing a functional, wearable, upper-limb exoskeleton robotic sensor on the arm for continuous arm motion. Modern wearable technology incorporates electrical, computer, and mechanical components for fitness, health, or medical purposes (Iqbal et al., 2016). Wearable technology devices can be used in daily life to track and monitor health or assist with fine motor skills. The concepts in this wearable robotic arm require understanding of mechatronics, programming, circuits, biomechanics, actuators and motors, wearable systems, transformations, and kinematics. The capstone project requires both electrical and mechanical sub-teams to design, develop, manufacture, and examine a wearable robotic exoskeleton arm to provide motor movement for the user.

The electrical sensors team will have three main tasks, two of which will be completed at the end of the fall semester and the last will be completed during the spring semester. First, the sensors team will focus on choosing sensor type and location. The team will use both electromyography (EMG) and inertial measurement unit (IMU) sensors to detect the muscular current position and intended motion for the five degrees of freedom upper limb model. An 8-sensor array will be used to detect the muscle electrical activity in the arm. One EMG sensor will be placed on each of the following muscles: anterior deltoid, lateral deltoid, posterior deltoid, pectoral muscle, bicep, triceps, pronator teres, and supinator. Three total IMU sensors will be placed on the shoulder, elbow, and wrist to detect muscular acceleration and act as a gyroscope. Second, the sensors team will design the printed circuit board (PCB) layout for the EMG and IMU sensors. Essentially, the design and layout of the EMG and IMU sensors will connect the sensors and organize connecting wires. Third, the sensors team will develop a unique algorithm that uses a filtering process to control the exoskeleton. The algorithm will consist of a data driven model from the EMG sensors and employ forward kinematics to combine the mechanical muscular movements.

Two mechanical actuator teams will focus on researching, choosing, and designing the wearable actuator for the shoulder and elbow, respectively. Both actuator teams have similar tasks. The mechanical teams will use Computer-Aided Design (CAD) software to design the external exoskeleton for the shoulder and elbow. Second, the actuator teams will choose the actuator type. Last, each team will develop a unique control code to control the continuous arm motion of the actuators.

During the Spring semester, the shoulder and elbow actuator teams and sensors team will develop a functional physical prototype ready for iteration and improvements. The device will undergo an iterative process of remodeling based on interview and survey responses of patients at the UVA hospital with Institutional Review Board (IRB) approval. The capstone mechanical and electrical design teams will collaboratively write an IEEE paper discussing the findings from the study. Finally, the primary intention of the textile based wearable robot will involve sensors and actuators to give feedback control and system integration through translational and rotational movement. In other words, muscular motion will provide statistical data for understanding the robotic system. Awareness of all functions and methods of the wearable robot will benefit users and engineers.

STS Topic

Prosthesis offer numerous solutions to patients' needs and demands through several applications such as cosmetic appendages or exoskeleton powered devices utilizing mimicry (Biddiss & Chau, 2007). Proof of prostheses in Ancient Egyptian mummies showed crafted wooden prosthetic toes following amputation. The first lower limb prosthetic device dates back 300BCE in Capua, Italy, and was created from copper and wood parts. Today, innovation in technology, materials, and electronics progresses the medical field (Dellon & Matsuoka, 2007). However, the medical field is not without its faults. Several factors contribute to the abandonment of a prosthesis on account of patient dissatisfaction. The proposed STS research paper will discuss technology factors and the influence of the identity factors on the success or abandonment of a prosthesis.

Essentially, upper and lower limb prostheses offer individuals both mobility and independence (O'Keeffe & Rout, 2019). The timeline of receiving a prosthesis has several phases from initial device fitting, training, definitive prosthesis fitting, rehabilitation, therapy, and reintegration into society. Prostheses for upper and lower limbs require upgrades in device design, based on usage and activity level. Patients who have received an amputation experience an initial healing time prior to being fitted for a prosthetic device (Davis et al., 2013; O'Keeffe & Rout, 2019). This additional stage has associated complications based on the level of amputation, location of amputation, and healing time. At any of these stages, something can go wrong for patients to reject and abandon their prosthesis.

Prior to prostheses fitting, the patient should have sufficient health, mobility, and maintenance ability over the limb. Three significant areas surround the device fit and alignment: "(1) socket shape and fitting methods, (2) alignment for stability and swing, [and] (3) selection of components" (Radcliffe, 1977). First, the limb location must be prepared. The residual limb, or stump, should be positioned above the heart in a flat manner for best blood flow to the area. Second, the residual limb and surrounding area should be moved daily. The patient should be trained to bandage and dress the stump and observe for changes in limb size and color. Furthermore, proper stump hygiene must be maintained through regular cleaning of the residual limb (O'Keeffe & Rout, 2019). The sensitivity of any of these factors could result in a patient rejecting a prosthesis. Third, there are various components which are used in the prosthesis fitting phase. The interface material technology between the residual limb and the device help provide more comfort to the patient. Soft foams, gels, and silicones are common materials used for this interface socket lining. The prosthetic socket should be individualized for the patient, meaning the socket design should grip the individual and provide suspension and support. The prosthesis design must accommodate individuals for both dynamic and stationary functions (O'Keeffe & Rout, 2019). Each component requires active participation of the patient, from trying the prosthesis fitting to rehabilitation. These are just a few precautions and components which are recommended for the best possibility of successful prosthesis fitting.

There are numerous factors, services, and professionals influencing the success of an individual's prosthesis. The patients' identity factors impacting prosthesis outcomes are race, gender, sexual identity, age, education, and socioeconomic status. For instance, gender impacts an individual's reintegration into society and their susceptibility to post-op comorbidity such as strokes (Pasquina et al., 2015; Walker, 2020). Age of amputation affects the lifetime costs of prostheses and replacement (Davie-Smith et al., 2017; Dougherty, 2017; Pasquina et al., 2015). Patients experiencing hardships due to identity at any stage of receiving a prosthesis may result in device abandonment. Understanding patient factors of identity influencing the outcome of the prosthesis will help eliminate bias in the medical field.

Two analytical frameworks will be used to develop the discussion between patient identity factors and the prosthesis outcome as successful or rejected. The STS tools are Actor Network Theory (ANT) and Social Construction of Technology (SCOT). ANT was developed by French sociologist, Bruno Latour, along with STS scholars, Michel Callon and John Law. Actors are considered human and nonhuman entities which do things to influence the system, while the network is considered the complex connections and relationships between the entities (Cressman, 2009). ANT will be used to identify the identity factors, device technology, services, and professionals in the medical system and their relationship to one another. However, more context is needed to show the relationship between the factors and the technology.

Second, the SCOT is a social constructivist ideology introduced by British sociologist Trever Pinch and Dutch philosopher Wiebe Bijker in the 1980s. SCOT refers to the interactive social concept of human action shaping technology. SCOT is defined by four main components: interpretive flexibility, relevant social groups, closure and stabilization, and wider context.

Interpretive flexibility describes how the technology outcomes may change based on social circumstances. Relevant social groups are the members in a group who share the same perception and understanding associated to a specific artifact. Closure and stabilization are defined by the need to resolve issues surrounding comprehension such that relevant social groups agree. Wider context refers to the technology development at a larger scale (Klein & Kleinman, 2002). Because SCOT is a social constructivist idea, critics might argue technological momentum is a more applicable analytical framework to society.

The factors associated with the field of prosthetics including identity factors of race, gender, sexual identity, age, education, and socioeconomic status; rehabilitation, training, and therapy; and device components will be examined using SCOT. Because receiving a prosthesis is such a personalized experience, SCOT is an effective analytical tool to show the fluidity associated with the technology and necessity for individualized technology based on social demands. The scientific and medical field is consistently changing based on human needs. Understanding factors and their relationships to prostheses may improve social interactions at medical institutions, patient evaluations, application of devices in context, and device engineering through design and development.

Modern developments in medical technologies have improved many individuals' lives, but some individuals may be predisposed to inferior quality of care and everyday life post-op due to uncontrollable factors in identity. Further explorations in patient identity may examine post-op self-image. Other factors may include changes in health from pre- to post-operation. Examining factors and addressing the unfair influence of factors on success of patient prosthesis fit and use will help create equity in healthcare. Additionally, this research may improve quality of health care, medical practices, and design and development of devices.

Methodologies

Research Question: How do patient identity and technology factors affect the predictability of patients' satisfaction or abandonment of prosthesis based on device component and fitting, rehabilitation, reintegration in society?

In answering the research question, two methodologies will be employed to organize the research. The approach of network analysis will be used to analyze the actor network in the prosthetic field. Network analysis will help determine all possible contributors and responders in the medical field applying to prosthetics. The case studies methodology will be used to organize the primary and secondary research resources to interpret how each actor influences the outcome of a prosthesis. Additionally, case studies will show the necessity of unique, individualized devices for the best probability of success. Google scholar and UVA library research will include keywords such as "prosthesis and equity," "prosthesis and outcomes," and "prosthesis and abandonment."

Conclusion

Just as the health care system is growing, so are the applications and implementations of medical technologies. The technical project will focus on designing and building a wearable upper limb exoskeleton consisting of wearable electronics, actuators, and feedback control. The intent of the exoskeleton will be to provide mechanical movement to individuals. The assignment will be broken into two parts. First, the capstone class will design and develop the mechanical and electrical components through designing parts and layouts, developing unique code for sensors and actuators, and creating a prototype. Second, the capstone class will iterate and modify the protype design based on feedback from interviews and surveys of UVA hospital patients.

Medical technology involves many factors that may limit outcomes. Prosthetics are no exception. The multiple device and care factors involved during the diagnosis, rehabilitation and recovery, and reintegration in society play key roles in determining the patient-prosthesis relationship. The patients' identity factors that will be examined are race, gender, age, sexual identity, education, and socioeconomic status. The actor network theory and the social construction of technology frameworks will expose the roles and relationships of these factors in the prosthesis and medical field. Identifying, understanding, and preventing disparity factors will lead to more equity in the health care system.

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