Soft Robotic Upper-Limb Stroke Rehabilitation Exoskeleton

Understanding the Role of Social Factors and Stakeholders in the Expansion of the Exoskeleton Industry

A Thesis Prospectus

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By

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On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

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Introduction

Each year around 795,000 people in the US suffer a stroke (Virani et al. 2021). A stroke is when something interrupts blood flow to part of the brain. This causes damage to brain tissue and brain cell death. Those recovering from a stroke often experience various levels of disability and stroke is a leading cause of long-term disability in the United States (Belagaje, 2017).

A common rehabilitation strategy is repetitive task training in which the patient undergoes the same simple motion continuously as a means of relearning the motion, gaining muscle, and most importantly reestablishing the mind-muscle connection. Hower, this strategy is limited by the time a patient can spend working with a physical therapist. Physical therapist fatigue prevents extended repetition, and access to a therapist may be limited for individuals who live in remote areas or who have limited insurance coverage.

The purpose of my group's technical project is to build on exoskeleton research with a focus in assisting in upper body rehabilitation following a stroke. Exoskeleton in this case refers to a wearable frame that assists or enhances a person's movements. A common outcome following a stroke is loss of function in the arm and hand. This results in shoulder pain in up to 70% of those who experience it (Belagaje, 2017). Additionally, loss of arm function can severely limit the patient's ability to complete daily activities independently. To address these disruptions in a more accessible way we will develop an affordable technology that will allow repetitive exercise while being soft, lightweight, and affordable.

My STS project seeks to provide context for this approach to rehabilitation by exploring the causes for the expansion of the exoskeleton industry. The exoskeleton market has grown rapidly in recent years. It was valued at $671.6 million in 2021 and was worth $952.5 million in 2022. Growth is expected to continue, with estimates of the market's compound annual growth rate (CAGR), a common method for calculating investment returns, at around 40% (Bogue, 2022). I plan to investigate this by studying economic data and justifications for previous exoskeleton research. I will use what I learn to identify relevant social groups and their motivations regarding exoskeleton development.

Technical Research Project

Stroke rehabilitation aims to improve function and advance participation in daily activities. Rehabilitation may involve adjustments to the patient's environment to assist participation or restoration of previous ability. Restoration can involve medication, electric stimulation, exercise, or a combination of these, as well as other techniques (Belagaje, 2017). Exercise may be assisted by a physical therapist at a hospital or nursing facility, or performed at home. Robotic assistance has the potential to expand the accessibility and effectiveness of this method.

Robotic assisted upper-limb therapy is an effective means of increasing motor function. It has been demonstrated to have greater positive recovery outcomes than traditional therapy and the potential to be more cost effective than traditional physical therapy methods (Franceschini, 2020). Further, robotic assistance reduces the burden on the therapist's muscles and cardiovascular system.

Current forms of wearable upper-limb assistance take a variety of forms. One design used an inflatable support in conjunction with support from a physical therapist. Another used twisted string actuators to enhance elbow movement. Sensing and programming methods are also being explored to smooth movement and improve control response. In spite of these advances, many exoskeletons currently used in the medical industry are heavy, uncomfortable for the user, and expensive.

Our technical project was chosen to address the limits of current robotic exoskeletons in addressing physical therapy needs. Our goal is to create an exoskeleton which can be worn comfortably and will assist the patient with deflection and extension of their arm at the elbow as well as with curling and relaxing their fingers. This differs from previous works by combining fine motor movement with arm extension and deflection.

Our current design consists of a backpack, two arm cuffs, and a four-finger glove. One cuff will be worn above the elbow and the other at the wrist. A Bowden cable will run along the length of the arm, anchored at the cuffs. Another cable will run from the palm side of the fingers, between the finger to the back for the and. Both cables will be retracted using motors controlled by an Arduino.

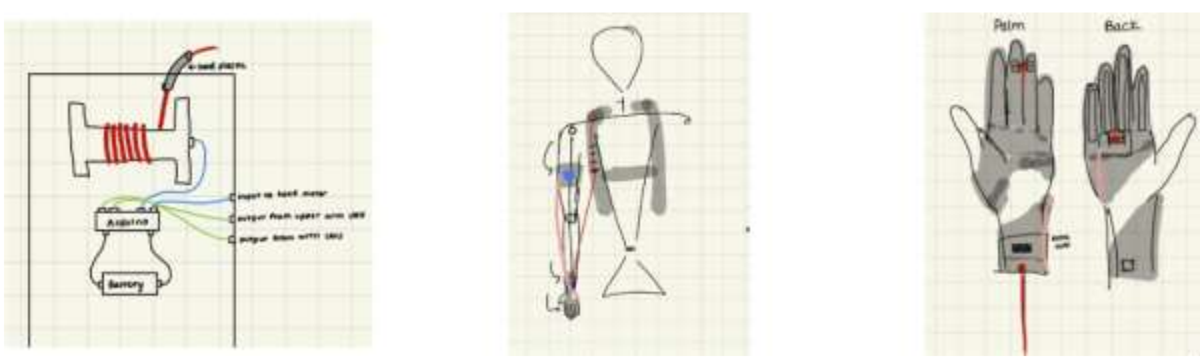

Fig. 1. Sketches of initial design of wearable exoskeleton. The left image is a cross section of the backpack to show the arrangement of the internal mechanisms.

We will address the need for comfort by using compliant materials (soft robotics) and limiting the weight of the design. Points where the exoskeleton makes contact with the wearer (the backpack, the arm cuffs, and the glove) will be made from fabric and adjustable to fit patients with a variety of arm sizes and body types. The desired movements will be achieved using a system of motors and cables.

Our design will be activated manually and will receive feedback from IMUs, or Inertial Measurement Units, to track the movement of the arm and fingers. This will allow us to use open loop programming, a method that will allow the device to adjust to unexpected changes in the process or environment.

In order to advance our design, we plan to speak with physical therapists to increase our understanding of stroke patients' needs. We will also be performing kinematic chain calculations to determine the strengths required from our materials and the torques needed for our motors. This will narrow down our component selections. We will test our work at several points during the design process. Arduino code will be run on the motors before assembling the exoskeleton to identify problems with speed and continuity or errors in the program concepts. We hope to test the design on a model to ensure its safety before finally testing on our own arms to ensure comfort and effectiveness.

Approaching the project in this manner should allow us to explore what considerations are important to medical exoskeleton design. Working on a project that emphasizes different types of mobility and sensing will provide insight into how these elements of wearable robotic design interact. We hope what we learn from this project will promote advances in exoskeleton technology and identify areas of interest for future research.

STS Research Project

The concept of human exoskeletons has been around since the 1960s. Since then, the idea of wearable technology assisting or enhancing human capabilities has remained prevalent in popular culture. Although research on wearable robotics also quietly continued during this time, it is only in recent years that the exoskeleton industry has begun to draw attention and significant investment. Developments in hardware are allowing exoskeletons to become lighter and more practical, while the integration of artificial intelligence is improving the interpretation of sensor data and supporting more stable movements (Bogue, 2022). However, there are still many obstacles to the widespread adoption of exoskeleton technology. Designs are often bulky and complicated, or have a limited range of motion. Additionally, there is limited research of potential negative repercussions of exoskeleton usage and how to mitigate these. (Howard, 2020) Because of these restrictions, I believe there are other factors driving the rapid growth of this industry. The goal of my STS project is to identify the social groups that have a stake in this industry and evaluate which of them make the largest contributions to its expansion. How is the global exoskeleton industry differentiated by the variance in investor goals? I hope this project will provide insight into the motivation behind design developments in different areas of the industry. This will contribute to the design considerations of my technical project by broadening my understanding of how our research will serve different groups.

I plan to approach this research project by conducting a literature review. I plan to apply the Social Construction of Technology (SCOT) approach described by Pinch and Bijker (1984) to my research in order to analyze the interactions between prevalent exoskeleton designs and the demands they seek to fulfill. SCOT maintains that to understand the success of a technology it is necessary to examine what relevant social groups play a role in defining the criteria for its success. A relevant social group is a group of people or an organization that attributes the same meaning to an artefact. The SCOT method describes the development of a technology as an alternation between variation and selection. By studying the various enterprises in the exoskeleton industry, identifying their relevant social groups, and evaluating their levels of success, I will be able to identify key actors and motivations behind the expansion of this industry.

Because of its efficacy and the availability of data, I will focus primarily on economic analysis. To obtain a comprehensive view of the American exoskeleton industry, I will investigate the industry's largest companies, top investors, and most notable advances for the past three years. I will then synthesize what I learn in the SCOT analysis.

Exoskeleton designs can take a variety of forms. Some are passive, while others have mechanical actuators. They might support different parts of the body or different kinds of movement depending on their intended usage. They have also been proposed for a plethora of applications, from medical rehabilitation to relief from fatigue and injury prevention for warehouse workers, to enhancing the strength of soldiers. By studying the largest companies in the exoskeleton industry, I hope to identify what other industries are most served by the products they produce. I will achieve this by considering not only the current products offered by these companies but also areas where they are conducting research. I will also look into the origins of these companies to identify what motivated their entry into the exoskeleton industry.

Investigating top investors and notable advances will supplement the perceptions on economic drivers I gain from studying major companies. In addition, looking at the justifications for the research that lead to these advancements will help me identify other factors that may not be evident from a purely monetary analysis. For example, economic analysis might tell me exoskeleton production has expanded because of increased usage in the medical industry, but it might not identify this increased usage may be due in part to the increase in musculoskeletal conditions as the baby boomer population ages (Yelin, 2016). Getting to this deeper level of causality will allow for more specificity as I identify factors contributing to the growth of the exoskeleton industry. This will make my findings more instructive as I pursue my technical project.

Conclusion

Because of the magnitude of the human and economic impacts of stroke and its consequences, it is important to improve the outcomes and accessibility of rehabilitation. Making robotic physical therapy assistance easier to adopt for both patients and providers could increase the health and quality of life for many people impacted by this condition. Determining relevant social groups in the development of this technology will assist identifying possible conflicts with the interests of the users. Understanding drivers of the exoskeleton industry and how designs for this technology are altered and implemented will allow for more conscientious design practices in the scope of the upper body and fine motor assistance proposed by my technical research group, as well as for future works.

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