Soft Robotic Exoskeleton for Elbow Assistance

(Technical Paper)

Dual Use of Medical Exoskeletons in the Military

(STS Paper)

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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

Neuromuscular disorders affect hundreds of thousands of people around the world (Deenen et al., 2015), yet there is currently no cure. This wide variety of conditions disrupts the nervous system and results in progressive loss of muscle control. Treatments include improving the quality of life for the patients and aiding them in their day-to-day lives (Cedars-Sinai, 2021). One such method of helping patients cope with muscle loss is the use of robotic exoskeletons. Robotic exoskeletons are wearable robotic systems that assist the wearer with their motion, with studies showing promising results of their use in rehabilitation (Gorgey, 2018). There are, however, many technical and sociological factors to consider when designing this technology. Ultimately, this paper will be answering the question: How do robotic exoskeletons and humans interact?

The technical project will focus on designing and fabricating a robotic exoskeleton arm for patients with neuromuscular disorders to help the patients regain arm function and mobility. It will answer the question: How can a robotic exoskeleton arm be used to help patients with muscular diseases regain arm functionality and mobility? Successful implementation will improve the standard of living for patients and allow them to move more freely and independently. Since such technology has the power to be expanded to uses beyond healthcare, the sociotechnical section of this paper will explore how this medical technology could be used to harm instead of heal and how this technology could interact with and affect social systems related to the military.

Technical Topic

The technical project seeks to answer the question of how a robotic exoskeleton arm can be developed to help people with neuromuscular disorders regain arm function and mobility. The central design requirements for wearable devices are wearability, lightweight, usability, and ability to understand and comply with the wearer's intended motion. Achievement of these requirements will help the wearers gain independence, self-esteem, and social inclusion (Ambrosini, 2014). The exoskeleton can also be used for rehabilitation by increasing levels of physical activity for patients with extensive loss of muscle control (Gorgey, 2018).

The exoskeleton is a mechatronic system with electronic sensors, actuators, analog and digital circuits, a mechanical structure system, and feedback control. Sensors placed on the wearer's arm will measure electromyographic (EMG) signals from the contraction of the arm muscles and respond with soft pneumatic actuator motion to help the wearer achieve their desired motion. The robot will have seven degrees of freedom in order to enable full range of motion for the wearer and thus will likely include seven actuators. The actuators will be McKibben artificial muscles, which are actuators comprised of an elastic inner tube surrounded by a double-helix-braided outer sheath (similar to a finger trap toy). When air is pumped into the inner tube, the sheath contracts linearly, and conversely when air is pumped out of the tube, the sheath expands (Tondu, 2021). This technology is shown in Figure 1 below.

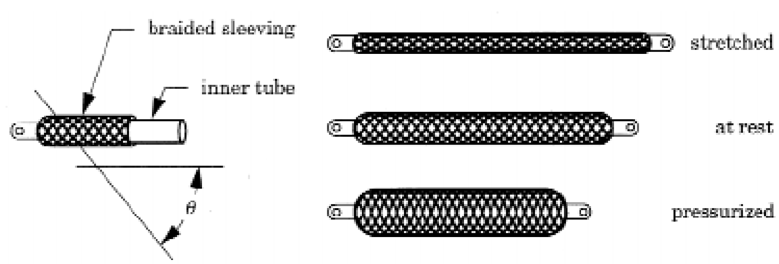

Figure 1. Illustration of pneumatic artificial muscles during expansion, rest and contraction (Daerden and Lefeber, 2002).

We will be fabricating our own McKibben artificial muscles and deriving the control algorithms to be able to accurately model them. The purpose of using these actuators as compared to traditional motors or hydraulic actuators is to make the exoskeleton more flexible, lightweight, and portable (Proietti, 2021), all of which are crucial for patients with neuromuscular disorders. The EMG sensors will be able to detect the amount by which the wearer's arm muscles contract and EMG-to-force estimation models will be used to convert the electrophysiological signals to an estimated force of the arm. The exoskeleton will use this force data to help the wearer complete their anticipated motion. Standard force estimation models are data-driven and have relatively high rates of error, so to make the estimation as accurate as possible, we will likely be considering a model derived from biomechanical muscle dynamics. This type of method has been shown to increase the accuracy of the estimation (Hayashibe, 2013), which is important for wearers with limited muscle use and unique physiology. Once we have a working prototype, we plan to work with doctors and patients at the UVA hospital to iterate and refine the design through patient-cooperative feedback.

This technology, however, is not limited to healthcare. Another major application of robotic exoskeletons is in the military. Military exoskeletons can allow soldiers to carry heavier loads, decrease fatigue (Yeem, Heo, Kim, & Kwon, 2019), and improve weapons aiming. Though the technology for full deployment of exoskeleton-wearing soldiers has not yet been fully developed, certain features of military exoskeletons already exist. The U.S. Army has developed a robotic exoskeleton arm that increases weapons aiming accuracy significantly using tremor-cancelling technology originally developed for people with Parkinson's disease (New Army Exoskeleton, 2015).

Sociotechnical Topic

The sociotechnical section of this paper will explore how medical exoskeleton technology could be used in the military and how this technology could interact with and affect social systems involving the military. To do this, the Interactive Sociotechnical Analysis (ISTA) framework will be applied to dual use of exoskeleton technology. ISTA is a model for sociotechnical systems that includes workflows, culture, social interaction, and technologies. It analyzes recursive technological feedback loops and unintended consequences of technology, based on the idea that sociotechnical organizations are dynamic and interconnected. ISTA is built upon several research areas and underlying theories. Sociotechnical systems (STS) research contributes the concept of dynamic interactions between social subsystems, technical subsystems, and environments. Ergonomics and social construction of technology studies examine the interconnection of technologies, individuals, and physical environments, with the former analyzing the effect of technologies and environments on individuals and the latter analyzing how technology users help change or create technologies. Technology-in-practice shows how technologies mediate use within a society, demonstrating the recursive nature of STS systems. Social informatics, the final research field from which ISTA draws its basis, acknowledges the embeddedness of technologies both within specific organizations and in broader social contexts (Harrison, Koppel, & Bar-Lev, 2007).

This model will be used in conjunction with dual use studies, which analyzes technologies that have both intended and unintended uses, both often dissimilar or contradictory. It informs debates for engineers and administrators about morals and responsibilities when developing a technology (Forge, 2010). Dual use studies can be broken into four groups: political, security, intelligence, and military (Mahfoud, Aicardi, Datta, & Rose, 2018). Since most exoskeleton uses are and are projected to be in military, this is the subsection I will be focusing on in this paper. Also, because exoskeleton technology has not yet been developed to the point at which it can be used widely in militaries, this paper will largely analyze anticipated rather than observed social interactions of the technology.

The ISTA model involves looking at several types of interactions between social systems, the technology-in-use, the new technology, and technical and physical infrastructure. The first type of interaction is new technology changing the existing social system. For medical exoskeletons, this could mean more social inclusion of persons with neuromuscular disabilities due to greater autonomy and mobility (Ambrosini, 2014), but it could also mean a shift toward ableism and stigmatization of exoskeleton-wearing groups (Kapeller et al., 2020). For military exoskeletons, this could mean dehumanization of exoskeleton-wearing soldiers (Greenbaum, 2015). The second type of interaction is technical and physical infrastructures mediating technology use. Insurance infrastructures could dictate who receives rehabilitory exoskeletons and who does not (Greenbaum, 2015). Advances in direct-fire weaponry infrastructure could prompt further development and use of military exoskeletons (Kott, 2019). The third ISTA interaction is social systems mediating technology use. The fourth is technology-in-use changing social systems, which for medical applications could involve a change in societal opinion or use of data tracking due to monitoring devices in the exoskeleton. Military exoskeletons could result in changes in legislation and regulation regarding wearable robots and weaponry definition (Harrison and Kleffner, 2016). The final interaction is technosocial system interactions resulting in technology redesign. I will be discussing each of these interactions with regards to both medical and military uses of exoskeleton technology and comparing the results.

Research Design

The question that this paper intends to answer is how the medical technology of rehabilitation exoskeletons used in military settings could interact with and affect social systems using the frameworks described in the previous section. This is a particularly significant topic when considering the unintended physical and sociological consequences of technology development, which could have serious and unchecked impacts in the world. The research method I will be using to answer this question is case study research. Case study research is an observational study that investigates a concept within real-life context using empirical data to help develop theories. Multiple case design, as compared to single case studies, contributes to forming a theoretical framework for a wide variety of variables (Ridder, 2012). The sources I will be using for data collection include prior literature, historical data, expert interview reports, agency reports, and legal cases, examples of which are shown in the previous section. All data collected will be analyzed through the ISTA and dual use frameworks and will contribute to a final conclusion about STS impacts of military exoskeletons.

Conclusion

The technical project will be answering the question of how a robotic exoskeleton arm can be developed to help people with neuromuscular disorders regain arm function and mobility. The creation of this technology could, however, have unintended consequences in military applications, so the technical topic seeks to understand how rehabilitory exoskeleton technology used in the military could interact with and affect social systems. The completion of these objectives could provide a holistic, sociologically-minded solution for an improved standard of living for individual with neuromuscular disorders and answer the question of how robotic exoskeletons and humans interact.

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