USING EMG SENSORS TO CREATE A FLEXIBLE UPPER LIMB EXOSKELETON

HOW ROBOTS CHANGE THE PATIENT-CAREGIVER RELATIONSHIP

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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There has been a vastly growing research interest in both the cause and cure of Amyotrophic Lateral Sclerosis (ALS) since the 1990s (Keirnan et al., 2011, p. 942). According to the ALS Association, ALS is “a progressive neurodegenerative disease that affects nerve cells in the brain and the spinal cord” (Understanding ALS section). Because ALS causes a disconnect between the brain and the muscles, a wearable upper limb exoskeleton would be useful in assisting with everyday tasks. While there are multiple upper limb exoskeletons already on the market, most of them are heavy and bulky and therefore uncomfortable to wear, especially for persons with disabilities. Combining EMG sensors, pneumatic actuators, and feedback control will produce a wearable upper limb exoskeleton that is more natural feeling and will provide rehabilitation and motor control for people with ALS. The use of exoskeletons in patient care will hopefully lead to better-quality relationships between patients and caregivers.

The technical project tightly couples with the STS research project to analyze how a wearable exoskeleton will affect the relationship between patients and caregivers. During the Fall 2021 semester, a flexible upper limb exoskeleton will be designed, and during the Spring 2022 semester, the exoskeleton will be printed and tested on human subjects at the University of Virginia hospital. The STS research discussing the use of exoskeletons and robots for elderly health care will be carried out during both semesters. As health care for the elderly becomes a more prevalent topic and a “gray tsunami” of older individuals outnumbering children approaches, it is important to recognize the impact that technologies like exoskeletons will have on different social groups (Engelhart, 2021).

USING EMG SENSORS TO CREATE A FLEXIBLE UPPER LIMB EXOSKELETON

The objective of this technical project is to design a 5 degree of freedom, flexible upper limb exoskeleton for patients with ALS. The main purpose of creating an exoskeleton is to assist in performing daily activities by controlling the muscles in an arm more efficiently (Perry et al., 2007, p. 408). While there have been numerous upper limb exoskeletons already created and tested, there is a lack of research on the use of flexible EMG sensors and sensing systems to create wearable technologies that move more naturally with a human arm. Although this flexible exoskeleton will be more comfortable and easier to maneuver in theory, Ruiz (2006) highlights that with lighter robotic parts comes the tradeoff of less powerful designs (Conclusions section).

This project will be conducted in the two semester capstone classes, ME Design I and II, under the guidance of Sarah Sun in the department of Mechanical and Aerospace Engineering at the University of Virginia. Together in a group of 15 students, the technical project will be completed in May of 2022. The technical project will be in the form of a scholarly article with a long-term goal of presenting at various biomechanics conferences. The project will be divided into three sub-groups of five students each, where the first group will handle the wearable sensors, the second group will handle the wearable actuators in the shoulder joint, and the third group will handle the wearable actuators in the elbow joint. Isabella Nazari, Colton Applegate, Joseph Carley, Marvin Lee, and Nazirah Farach Rojo will manage the shoulder joint group. In order to develop the appropriate electrical and mechanical components for a functioning upper limb exoskeleton, both forward and inverse kinematics and dynamics will be needed as well as computer aided designs. It will also be necessary to understand and interpret human kinematics in order to mimic the motions required to carry out daily activities (Jarrasse & Morel, 2012, p. 697).

The design process for the wearable actuator side of the technical project is described in Figure 1 (p. 3). The first step is to decide on the number of degrees of freedom that the exoskeleton will have. Shoulder joints have three degrees of freedom: abduction-adduction, flexion-extension, and rotation. Elbow joints have two degrees of freedom: flexion-extension and rotation. Combining the maximum number of degrees in both joints yields a total of five degrees for the exoskeleton as a whole. After deciding to design all five degrees of freedom, it is crucial to understand the design requirements for both motion range and force range. Motion range is defined by the Denavit-Hartenberg (D-H) convention parameters. The D-H convention is a useful technique for selecting the frames of rotation for the homogeneous transformations needed for forward kinematics equations (Balasubramanian, n.d.). The D-H parameters and table set up for an arm are described in Figure 2 (p. 4). The next step is to choose the actuators that will be used to mimic the muscles of an arm in the exoskeleton. Unlike traditional exoskeletons that use DC motors, this design will use soft-pneumatic actuators that act as air muscles. The artificial muscles will "actively contract and/or actively expand in length when excited by a stimulus" (Mirvakili & Hunter, 2018, p. 2). In this case, the muscles will react to the pressure from a compressed air source. The final step is to create a prototype for the exoskeleton and test it on individuals with motor function loss such as ALS. The prototype will be developed with a computer aided design (CAD) model and put together using a combination of 3D printing and purchasing other components. The exoskeleton will function with the partnership of the EMG sensor team and the necessary Arduino codes to operate the air pumps.

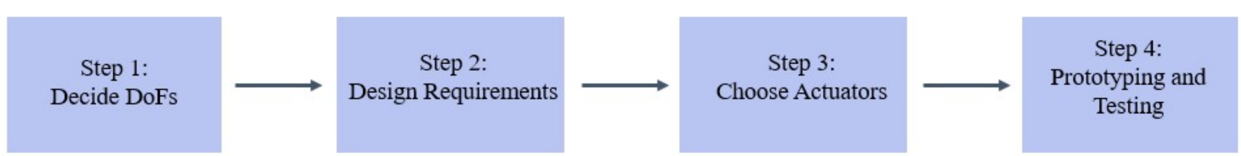

Figure 1: Actuator design plan. Mapping of the steps required for designing the wearable actuators in the exoskeleton. (Nazari, 2021).

Joint	β_i	Number	α_i	a_i	d_i	θ_i
Base	0	$1_{(0\rightarrow1)}$	0	a_0	d_0	0
Shoulder	(−90) medial rotation/lateral rotation (+90)	$2_{(1\rightarrow2)}$	-90°	0	0	β_1+90°
Shoulder	(−180) abduction/adduction (+50)	$3_{(2\rightarrow3)}$	$+90^\circ$	0	0	β_2+90°
Shoulder	(−180) flexion/extension(+80)	$4_{(3\rightarrow4)}$	0	l_1	0	β_3+90°
Elbow	(−10) extension/flexion (+145)	$5_{(4\rightarrow5)}$	$+90^\circ$	0	0	β_4+90°
Elbow	(−90) pronation/supination (+90)	$6_{(5\rightarrow6)}$	$+90^\circ$	0	l_2	β_5+90°
Wrist	(−90) flexion/extension (+70)	$7_{(6\rightarrow7)}$	$+90^\circ$	0	0	β_6+90°
Wrist	(−15) abduction/adduction (+40)	$8_{(7\rightarrow8)}$	0	l_3	0	β_7

Figure 2: D-H parameters for an arm. Table of degrees of freedom for each joint in the arm. (Sun, 2021).

In order to appropriately design the exoskeleton, the technical project group will develop an in-depth questionnaire survey for patients and their providers to complete. Figure 3 below provides a mapping of the design process that will be used for the questionnaire. According to Jenkins and Dillman (1995), visual elements should be consistent so that respondents can easily follow directions, and information should be presented in a clear manner so that respondents do not have to look elsewhere for guidance (p. 71). The results from this survey will give insight into the attitudes of subjects towards this research and their specific measurements needed for the device to fit.

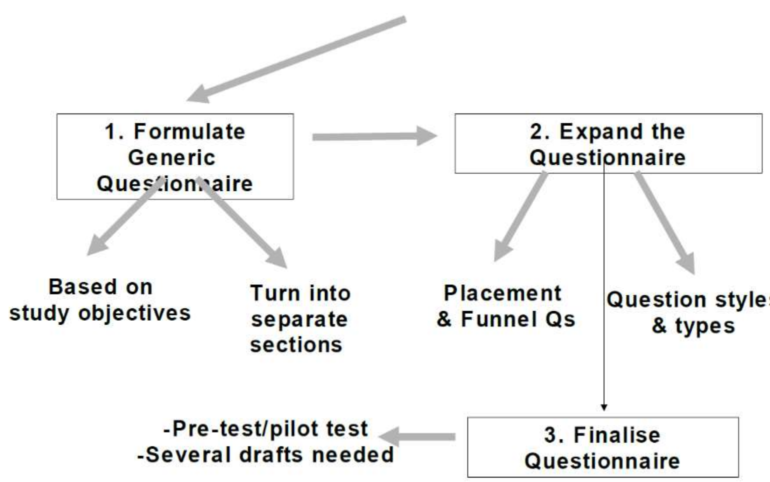

Figure 3. Questionnaire planning/design. Explanation of the steps required for creating an effective questionnaire. (Sun, 2021).

HOW ROBOTS CHANGE THE PATIENT-CAREGIVER RELATIONSHIP

More recently, there has been discussion about the appropriate care for the elderly population. The common interest is to offer health care that is customized for this specific group of people and offers the maximum amount of freedom for elderly people to choose what they want and need (Arnaert et al., 2005, p. 370). The STS topic aims to answer how responsibilities of a caregiver will shift with the addition of a wearable exoskeleton and how this will in turn affect the patient. Similarly, to the technical project, a scholarly article will be written to explore the STS research.

Social robots are now a mechanism for elderly people to receive aid both mentally and physically. Many elderly people often feel lonely, and these robots offer support. The thought behind this idea is to create companions for this population without causing additional stress for caretakers and health workers (Moise, 2018). In this STS discussion, the idea of giving caregivers the opportunity to be more of a companion for the elderly instead of performing tasks for them is under review. With the assistance of an exoskeleton, caregivers will have extra time to focus more on mental health and quality of life in elderly patients. Caregivers also believe that if robots can provide help in certain aspects of patient care, they will then be able to focus on other, more important, parts of their relationships with their patients and even lessen the strain that caregiving can produce on both parties (Wang et al., 2017, p 74).

Caregivers can range from formal hired staff to informal family and friends of the patient. In their paper discussing the types of care for the elderly, Swanberg and coauthors (2006) look at the experiences of employed caregivers. The combined stress of traditional work and taking care of family or friends "leads to a variety of physical, psychological, and financial consequences for the caregiver" (Swangerg et al., 2006, p. 419). While an accommodating workplace and flexible employer can decrease the stress caused from balancing work with caregiving, technologies such as exoskeletons also have to ability to lighten the load on these workers.

In order to analyze the effectiveness of robots, and specifically exoskeletons, on decreasing loneliness and improving the patient-caregiver relationship, it is crucial to include the subjects themselves in the research. Most current research on robots for the elderly fails to include the subjects which causes inappropriate assumptions about the efficiency that technologies provide for the patient (Engelhart, 2021). There is great potential for the use of robots in social and physical care for the elderly, but only if done in an appropriate manner. By including elderly people in their own research studies and asking them what they believe is effective, robots will prove to be an asset in the health care department. While they cannot replace genuine human connections, they can offer support for both the elderly and the caregivers who can then focus on having more meaningful connections with their patients.

The patient-caregiver relationship is an important part of the health of both groups. John Law and Michel Callon's Actor- Network Theory analyzes the complex systems between various actors (1988). Figure 4 (p. 7) describes the network of patient-caregiver relationships, the motivations behind various actors' actions, and the connections that they have with each other. From an STS perspective, the main motivations of motor control technologies are to improve patient-caregiver relationships and reduce stress that arises for both groups. While the caregivers tend to feel overwhelmed from the workload that comes with taking care of elderly and sick individuals, patients tend to feel like a burden on others and do not want to have other people taking care of them (Engelhart, 2021). An exoskeleton can provide the independence that patients desire to feel more themselves all while relieving the caregivers from performing daily tasks including feeding and picking up objects. The goal of this research is to understand how the designed exoskeleton can change the dynamic of caregiving and in turn improve other factors of life including mental health and human connection.

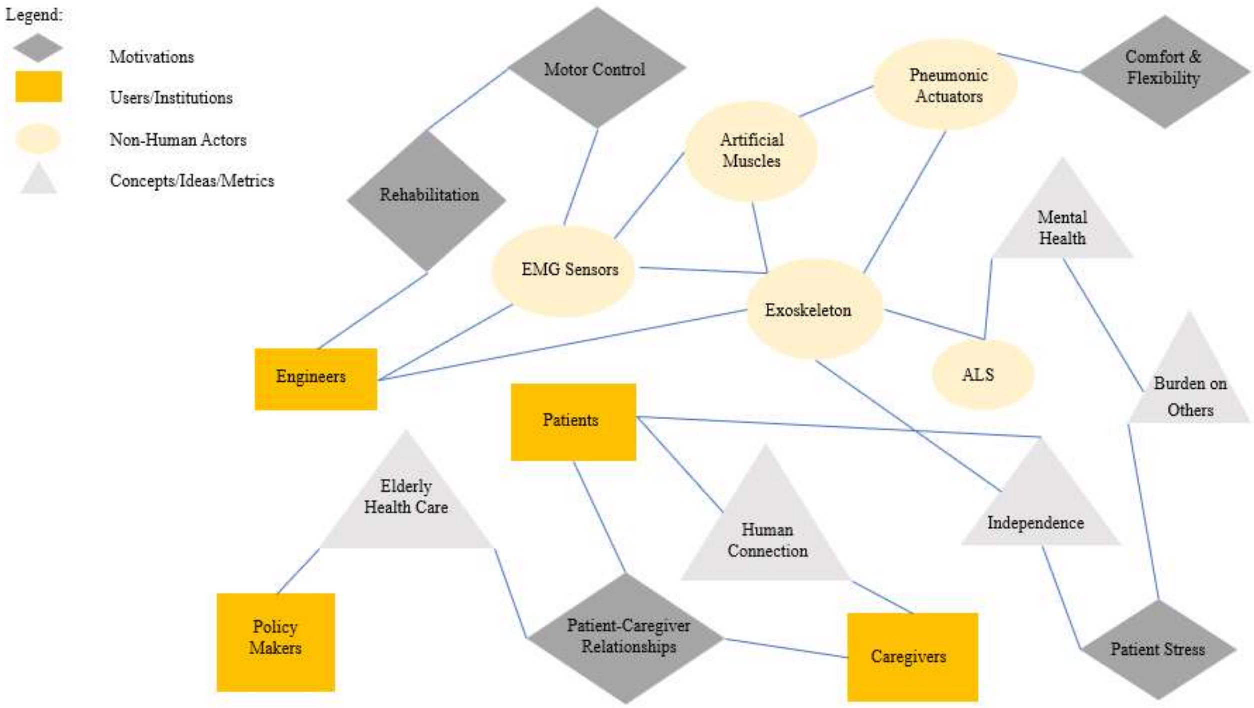

Figure 4. Network of patient-caregiver relationships. Visual representation of the connections between actors and motivations. (Nazari, 2021).

SOCIAL CONSTRUCTION OF TECHNOLOGY ANALYSIS

The Social Construction of Technology (SCOT) developed by Pinch and Bijker (1984) is an approach to understand the exchanges between technologies and their relevant social groups (p. 414). When applied to the issues in patient-caregiver relationships developed from degeneration of muscle control, a clear image of the importance of social groups can be displayed. Figure 5 (p. 8) relates the engineer that designs an exoskeleton to the social groups of caregivers, family and friends, patients with lack of motor function, and policy makers. The arrows are pointed in both directions to depict the mutual exchange of information. For the patient, engineers are creating exoskeletons that will assist with muscle control. In order to customize the exoskeleton for the patient's needs, they will need to give feedback to the engineers. The engineers provide family, friends, and caregivers some relief from the tasks they perform to assist patients. In turn, the caregivers will help engineers understand what type of tasks are most important and how they can be replaced with the technology. Finally, policy makers work with engineers to make the technology readily available. By highlighting the importance of quality health care for the elderly, policy makers have the ability to push the technologies made by engineers through the design process. In order to address the problems that the STS research is attempting to solve, the engineers must listen to feedback and meet the requirements of the various social groups.

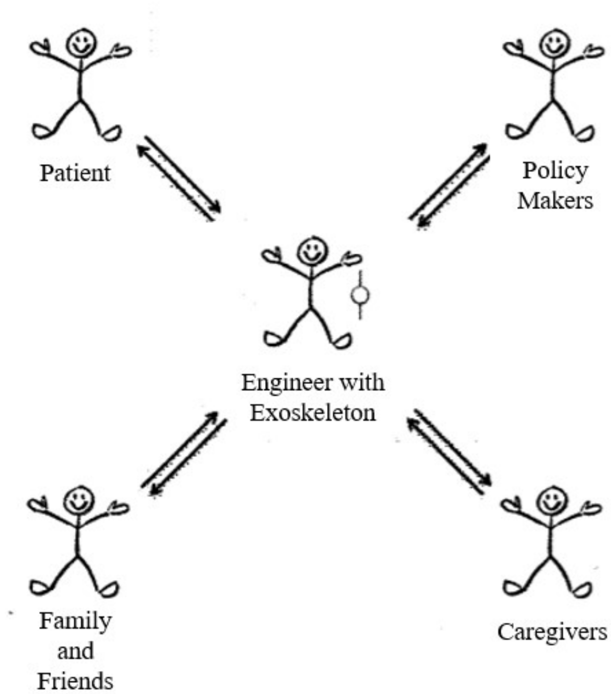

Figure 5: Social construction of exoskeletons. Diagram of the relationships between the engineers and other social groups. (Adapted by Nazari (2021) from Carlson, 2009).

THE ROLE OF EXOSKELETONS IN ELDERLY HEALTH CARE

The STS topic and the technical topic are closely coupled together. One objective of the technical project is to create a new advanced technology for ALS patients. This will help to better the relationship between caregivers and patients through improved communication and ability to develop more meaningful connections. By developing a flexible upper limb exoskeleton to assist people with ALS, caregivers will have more time and energy to have conversations and form bonds with their patients as opposed to solely performing tasks for them.

The goal of the STS research is to determine the role of exoskeletons in elderly health care. While there is research discussing the effects that social robots have on both patients and caregivers (Engelhart, 2021; Moise, 2018), there is a lack of research covering the effect that physical robots can have on these groups. Although the obvious purpose of exoskeletons is to aid in motor control and rehabilitation, they also have the ability to improve the patient-caregiver dynamic in a way that will benefit all parties involved. Without this research, there will be a lack of information regarding the effects that assistive devices can have on elderly health care.

REFERENCES

Arnaert, A., Van Den Heuvel, B., & Windey, R. (2005). Health and social care policy for the elderly in Belgium. *Geriatric Nursing, 26*(6), 366-371. https://doi.org/10.1016/j.gerinurse.2005.09.019

Balasubramanian, R. (n.d.). *The denavit hartenberg convention*. Carnegie Mellon University.

Nazari, Isabella. (2021). *Social construction of exoskeletons*. [Figure 5]. *Prospectus* (Unpublished undergraduate thesis). School of Engineering and Applied Science, University of Virginia. Charlottesville, VA.

Bijker, W. E., & Pinch, T. J. (1984). The social construction of facts and artifacts: Or how the sociology of science and the sociology of technology might benefit each other. *Social Studies of Science*, 14, 399–441. https://doi.org/10.1177/030631284014003004

Engelhart, K. (2021). What robots can-and can't-do for the old and lonely. *The New Yorker*. https://www.newyorker.com/magazine/2021/05/31/what-robots-can-and-cant-do-for-the-old-and-lonely

Jarrasse, N., & Morel, G. (2012). Connecting a human limb to an exoskeleton. *IEEE, 28*(3), 697 709. 10.1109/TRO.2011.2178151

Jenkins, C., & Dillman, D. (1995). Towards a theory of self-administered questionnaire design. In L. Lyberg, P. Biemer, M. Collins, E. DeLeeuw, C. Dippo, N. Schwarz, & D. Trewin (Eds.). *Survey Measurement and Process Quality* (pp. 165-196). New York: Wiley-Interscience. https://doi.org/10.1002/9781118490013.ch7.

Kiernan, M., Vucic, S., Cheah, B., Turner, M., Eisen, A., Hardiman, O., Burrell, J., & Zoiny,

M. (2011). Amyotrophic lateral sclerosis. *The Lancet, 377*(9769), 942-955. https://doi.org/10.1016/S0140-6736(10)61156-7.

Law, J., & Callon, M. (1988). Engineering and sociology in a military aircraft project: A network analysis of technological change. *Social Problems*, 35(3), 284–297. https://doi.org/10.2307/800623

Mirvakili, S., & Hunter, I. (2018). Artificial muscles: Mechanisms, applications, and challenges. *Advanced Materials*, 30(1704407), 1-28. https://doi.org/10.1002/adma.201704407

Moise, I. (2018, May 28). For the elderly who are lonely, robots offer companionship. *Wall Street Journal.* https://on.wsj.com/3kvnYDU

Nazari, Isabella. (2021). *Actuator design plan*. [Figure 1]. *Prospectus* (Unpublished undergraduate thesis). School of Engineering and Applied Science, University of Virginia. Charlottesville, VA.

Nazari, Isabella. (2021). *Network of patient-caregiver relationships*. [Figure 4]. *Prospectus* (Unpublished undergraduate thesis). School of Engineering and Applied Science, University of Virginia. Charlottesville, VA.

Nazari, Isabella. (2021). *Social construction of exoskeletons*. [Figure 5]. *Prospectus* (Unpublished undergraduate thesis). School of Engineering and Applied Science, University of Virginia. Charlottesville, VA.

Perry, J., Rosen, J., & Burns, S. (2007). Upper-limb powered exoskeleton design. *IEEE/ASME Transactions on Mechatronics, 12*(4), 408-417. doi: 10.1109/TMECH.2007.901934.

Ruiz, A., Forner-Cordero, A., Rocon, E., & Pons, J. (2006, February 20-22). *Exoskeletons for rehabilitation and motor control.* International Conference on Biomedical Robotics and Biomechatronics, Pisa, Italy.

Sun, Sarah. (2021). *D-H parameters for an arm*. [Figure 2]. *Prospectus* (Unpublished undergraduate thesis). School of Engineering and Applied Science, University of Virginia. Charlottesville, VA.

Sun, Sarah. (2021). *Questionnaire planning/design*. [Figure 3]. *Prospectus* (Unpublished undergraduate thesis). School of Engineering and Applied Science, University of Virginia. Charlottesville, VA.

Swanberg, J., Kanatzar, T., Mendiondo, M., & McCoskey, M. (2006). Caring for our elders: A contemporary conundrum for working people. *Families in Society: The Journal of Contemporary Social Services, 87*(3), 417-426. https://doi.org/10.1606/1044-3894.3547

Understanding ALS (2021). ALS Association. https://www.als.org/understanding-als

Wang, R., Sudhama, A., Begum, M., Huq, R., & Mihailidis, A. (2017). Robots to assist daily activities: Views of older adults with Alzheimer's disease and their caregivers. *International Psychogeriatrics, 29*(1), 67-79. doi:10.1017/S1041610216001435