Design and Build of an Upper Limb Exoskeleton for Rehabilitation

The Emerging Practice of Relying on Wearable Technology

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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

Wearable technology, or “wearables,” encompasses a wide range of mechatronic devices that can be worn as accessories, embedded in clothing items, or physically attached to (or implanted in) the user itself. These devices all aim to provide feedback to the user about their lifestyle and health through a connected system of sensors, controllers, and actuators. Through the advancements of these components and related systems over the past two decades, the wearable technology industry has grown to become a part of the daily life of millions. The commercially available devices allow users to learn more about themselves and how the decisions they make impact them over time. The research and development of wearable technology in the medical field have the potential to help those with neuromuscular disorders or diseases as well as those with physical disabilities. The ability of wearable technology to track physical activity, measure blood glucose levels, or directly help a patient gain/regain control of their body provides reasons for optimism for the future of this industry.

For my Mechanical Engineering capstone project, the goal is to design and build a wearable upper limb exoskeleton. The exoskeleton will consist of wearable electronics, pneumatic actuators, and feedback control mechanisms. Because our project is to help patients who struggle with arm movement and control, we hope to test our design with patients at the University of Virginia hospital and seek feedback from those whose quality of life could be improved by our exoskeleton.

The STS research paper will focus on the motivation of entrusting external and wearable technology with our choices and actions. Users of wearable devices and technology hand over their responsibility of everyday decisions to the device itself as the technology become more personal and the relationship grows between device and user. In a data-driven society, consumers are increasingly sharing more about themselves through the devices that they buy in exchange for gaining access to personalized information that can help make better choices about their health and lifestyle. I aim to determine the reasoning behind the emerging practice of delegating the responsibility of our actions/choices to technological devices. The customer base for all of these wearables continues to grow year after year knowing that each one is tracking and sharing user health data. While many hear about the risk of voluntarily sharing personal data, consumers often neglect the behavioral aspects contributing to the widespread adoption of wearables into the daily lives of users.

Technical Topic

Unlike joint replacements or biomaterial solutions, an exoskeleton improves the performance of the associated limb of able-bodied patients. Furthermore, the exoskeleton works in tandem with the body and is controlled by the user (Herr, 2009). The exoskeleton includes all of the sensors, controls, and actuators that comprise the entire structure. Because there are multiple elements to designing and building an exoskeleton, there will be two teams focusing on specific elements with specific goals before coming together to build the complete final product in the spring.

The two teams in my capstone course will collectively aim to build an upper limb exoskeleton. One team is responsible for the wearable surface electromyographic (sEMG) sensor design and signal processing. The circuitry will be designed using printable circuit board (PCB) software and incorporate the sEMG sensor data to communicate with the actuator. As a member of this wearable sensor team, I will help to identify the user's intent and communicate it to the robotic system as seamlessly as possible. The other team's objective is to work on the mechanical design of the wearable actuator. The actuator will involve the understanding of pneumatics and the biomechanics of the arm.

The sEMG sensors will be used to provide the control signals to the exoskeleton and essentially communicate the arm's intentions. The electrical signals picked up by the sEMG sensors on the surface of the skin indicate when the user activates the muscles. Because the sensors are on the surface of the skin and not implanted into the user, the signal tends to be noisy, so signal filtering and processing measures will need to be taken by the first subteam. Several signal processing methods include rectification, taking the root mean squared values of the signal, and applying different types of filters such as low and high-pass versions (Kiguchi & Hayashi, 2012). The goal is to generate a smooth signal of the user's muscle activity and use that signal to determine how much force that the actuator will need to generate to perform the intended action. That relationship between the muscle action potential signal and the force applied by the actuator is the ultimate goal of subteam

1 so that they can provide that information to subteam 2 as the structure and design of the mechanical system is developed.

Subteam 2 will draw the design in a computer-aided design (CAD) software including the actuator that acts as an artificial muscle and the power source needed to generate enough torque and force to the exoskeleton. A program will also be needed to take the processed sEMG signal and the relationship (also known as the transfer function of the designed circuit) to activate the actuator appropriately. The hope is that our exoskeleton can provide rehabilitation consistently for a longer duration and reduce the load felt by the patient as much as possible without adding inconvenience (Lo & Xie, 2012).

Thus far we have all gained a solid background understanding of each of the elements needed to build an upper limb exoskeleton. We all have experience using PCB software that will be used by our subteam to connect the sEMG sensors to the microcontroller that will relay that information to the pneumatic actuator. In MATLAB, we have processed several actual sEMG signals such that we could clearly see where muscle activation occurred. The goal for this semester is to finish the prototyping design for the wearables sensors and the pneumatic actuators so that the teams can build the first iteration of the physical exoskeleton in the spring for patient testing. A participant survey will be created to analyze patient feedback and measure the success of the product.

STS Topic

The advancement in wearable technology in the past two decades has reached the point where the data being collected has become so personal and tuned to the user that we trust these devices to look out for our health via 'nudging technology' (Caraban et al., 2019). There has been a significant shift in how we make decisions about our health on a daily basis. Living in an era where there are countless alternatives to healthy choices, it makes sense that the public would see the benefit of wearables that display user-health constantly. With added diagnostic features and smarter devices, we are relying and delegating more and more on external and wearable technology to give us feedback on how to take care of ourselves.

The reality is that nudging is not new to society and can be seen all over without people taking the time to realize that they are being influenced to make better decisions for both themselves and everyone else. Many retirement plans have become opt-out rather than opt-in such that employees do not have to worry about missing out, and they can easily opt-out if choose to do so. The same can be said for organ donation in European countries where it is the default option. There is more caution, though, when technology-mediated nudging is discussed because of the potential for an over-reliance on products that can be tapped into by those with bad intentions.

Technology-mediated nudging changes user behavior over time, leading to more reliance on wearables in regulating user decisions. It was mentioned that we do not make rational decisions in the present about choices that will impact our future (Schull, 2016). There is also a notion of simply gaining knowledge that comes with having all this data about oneself. Users have a better understanding of their health in real-time based on actual quantifiable evidence. The idea of trusting the numbers and not just a perception of what is going on is certainly playing a role as well (Lupton, 2013). For most who do not participate in high-level physical activity on a daily basis, the incorporation of achievements, or 'medals' for reaching certain goals relating to exercising. These "objectified measures of achievement" and "gamification" have led to further adoption of wearable devices and the expanding role it plays in the decision-making of our health (Till, 2014). The sense of fulfillment and accomplishment of being physically productive is a powerful emotion that these devices can provide each and every day.

After some time, healthier habits develop from users, and further advancements to tune those habits on a person-to-person basis allow for more we rely on wearable medical devices. It is interesting to think that perhaps users don't actually care about the data or about self-knowledge, but rather the users want these subtle nudges to help them live a healthier life. The devices have become a guide to the users, but not every device employs a nurselike feature (Singer, 2015). That is not to suggest that the users have stopped thinking for themselves because the device is teaching its user healthier habits and gaining more self-awareness.

This is a research project on a new social practice regarding the user referring to a wearable device to make healthy choices (Hess & Sovacool, 2017). This particular practice begs the question if we should replace thinking and self-care with wearables (“think for” users) or should we be encouraging "thinking with" wearables as an augmentation to our thinking? The danger with the former is that users risk being taken over blindly by automated decision-making and overtrust in numbers. The companies releasing these products are studying the relationship between consumers and personalized technology, so it would be prudent to do the same as a user.

Next Steps

In regards to my capstone work, I will need to continue to do a literature review on recent studies on exoskeletons focusing on the implementation of sEMG sensors. Specifically for my subteam, I will need to look at current techniques done to filter sEMG data to obtain a smooth curve and reduce the noise as much as possible because a clean signal is crucial for proper interaction between the user and the robotic exoskeleton (Bi et al., 2019). Once the literature review is complete, the team will need to develop a PCB drawing of all the sensors and associated circuits so it can be manufactured and tested.

I plan to look at more specific examples of wearables that are intended to change the user’s behaviors and act as a guide rather than displaying the data of the user’s activity. In a study done with 50 users of wearables, the authors concluded that in the use pattern of following leadership strategies provided by the wearable, “users let themselves be guided by the wearable instead of their own bodily feelings.” The interviewees mentioned how they would complete their daily goals provided by the device because the feeling of earning badges and closing the rings was satisfying to the user. For other interviewees who had set goals in mind, “they moved on their own initiative after a certain amount of time (i.e., self-cueing), even before the wearable prompted them to do so” (Lehrer et al., 2021, p. 11). This use pattern involved the user gaining self-leadership and the device was a source of positive reinforcement rather than a guide. Further exploration will continue to look at users’ behavior and adoption of medical wearables through studies similar to this one. Consumer interaction with the devices is valuable research evidence to explain the new practice of wearable-induced behavior change.

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