Design and Creation of an Upper-Limb Wearable Exoskeleton
(Technical Paper)

Potential Applications of Exoskeleton Suits in the Armed Forces
(STS Paper)

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Introduction

As the first quarter of the 21st century comes to a close, we've seen new technologies that have infiltrated every aspect of our lives. Improving everything from our cars to our homes, there is almost nothing left untouched by today's rapidly improving and expanding technology. Perhaps the next logical step in our development then would be to use technology to further improve the human body. While creating a perfect human body may be possible through pure genetic manipulation sometime in the future, for now we'll have to focus on improving what's already there. Since the 1960's, scientists have begun to develop human exoskeleton limbs to improve the strength and motor control of the human user. One of the first successful prototypes for an exoskeleton limb was the HARDIMAN I, which was developed in 1969 by the Specialty Materials Handling Products Operations of General Electric Company (Croshaw, 1969). This model, although primitive by today's standards, was a crucial first step into opening the door to a future where an individual's strength could be directly improved with technology.

Exoskeleton prototypes like the Hardiman were put on the backburner for decades, as the designs were simply far too heavy and costly to manufacture for them to be of any practical widespread use. But with the advent of lighter, more mobile, more energy efficient systems, the world is seeing a boom in the number of exoskeleton designs available in the marketplace (Gull, 2020). Additionally, the capabilities of exoskeletons have broadened immensely in recent years, ranging from motion amplification to medical rehabilitation. As shown in Figure 1, there are now nearly a dozen commercially available upper limb exoskeletons, that each specializes in a specific motion or function.

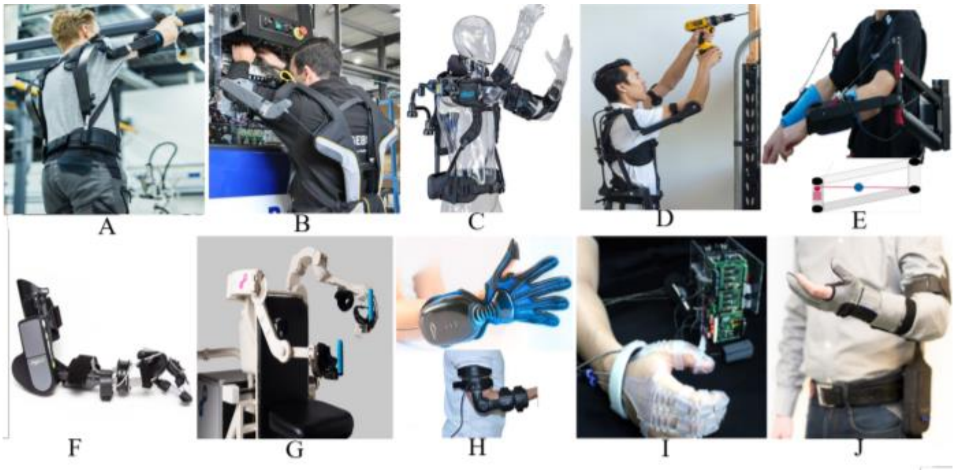

Figure 1: Commercially available upper-limb exoskeletons: (A) Skelex; (B) Egrosquelettes by GOBIO-robot (Gobio is the brand of Europe Technologies that promotes exoskeletons); (C) EksoVest by Ekso Bionics; (D) Modular Agile eXoskeleton (MAX) by SuitX; (E) Robo-Mate; (F) MyoPro Orthosis by Myomo, Inc.; (G) Alex exoskeleton by Kinetek Wearable Robotics; (H) Hand and Arm tutor by MediTouch; (I) Exo glove poly; and (J) Soft extra muscle glove by BioServo.

(Gull, 2020)

Generally speaking, most practical applications of exoskeleton suits can be sorted into one of 3 categories. The first category is exoskeletons designed for human performance augmentation, which includes things such as increasing strength and endurance for already able-bodied individuals. This category of exoskeletons is usually seen in use by the military, or factories and warehouses that require demanding manual labor. The second category is exoskeletons used as assistive devices for individuals with permanent disabilities. These exoskeletons are designed to help the user walk, perform arm movements, or complete motions they otherwise could not. The last category of exoskeletons are devices that exist to help rehabilitate a user's muscles through therapeutic exercises. The difference between the 2nd and 3rd categories is that devices in the 3rd category are intended to be a temporary measure to help the user regain normal function, while devices in the 2nd category are likely to be permanent additions to the user's body (Young, 2017). While the applications of each type of exoskeleton are different, the underlying science and technology that make them possible are consistent across the board, meaning that gaining an understanding of how one works will provide valuable insight into how all others work.

Armed with that piece of knowledge, my technical project will consist of the buildup of a prototype exoskeleton arm, with the goal of taking the time to understand how and why the exoskeleton works. In tandem with this project, I will be taking the concepts learned through the development of the exoskeleton, and researching present and potential applications this technology has for the United States Military. The goal of this would be to gain an understanding of how exoskeletons impact our world today, and what we should expect to see from them in the future.

Design and Creation of an Upper-Limb Wearable Exoskeleton

According to the Annual Disability Statistics Compendium, in 2019 there were around 20.9 million individuals in the United States alone that suffered from some sort of ambulatory disability (Paul, 2020). That means that about 6.5% of the US population had serious difficulty walking or climbing stairs. While things like prosthetics exist for individuals that have lost limbs entirely, there are not many solutions that exist for those with muscle or nerve damage. This is where exoskeletons could come into play and serve a major role in the medical community. However even with recent advancements in exoskeleton technology, most modern designs still face shortcomings when it comes to being useful to patients that need it.

The main shortcomings of modern designs are the size, weight, and stiffness of the exoskeletons (Proietti, 2021). These issues stem from the fact that many current exoskeletons are inherently rigid by design. The easiest way to make an exoskeleton is to encase the user's arm in some sort of rigid brace, and then use external hard actuators such as DC motors to then control the motion of the arm. This not only results in a bulky and heavy model, but it also significantly reduces the range of motion that can be achieved. Additionally, these designs are visually unappealing, and uncomfortable to wear (Zhao, 2021).

The most promising new development in exoskeletons for medical purposes is the idea of what's called a soft actuator. Essentially, soft actuators are made of soft, flexible, and stretchable materials that can better mold to the human contour (El-Atab, 2020). Using flexible materials allows the user's arm to remain as the base structure for the exoskeleton, resulting in a more natural and comfortable feel. However, the reason these types of exoskeletons have not exploded into mainstream use yet is because they require a higher complexity of compliance between the user's arm and the actuator (Proietti, 2021). If these challenges are overcome, the resultant exoskeleton will not only be softer, lighter, and more comfortable, but it will allow the user to have a higher range of motion than previously possible. Therefore, the goal of my technical project will be to pursue the concept of using soft actuators to develop a prototype for an upper limb exoskeleton that meets the shortcomings of modern designs.

As previously stated, working with soft actuators brings its own set of challenges to the table, specifically when it comes to communicating between the user and the exoskeleton. Presently, there are many different ways to go about establishing this communication, but the most popular are Electroencephalography (EEG) and Electromyography (EMG). Both are non-invasive, and use external sensors to read electrical signals given off by the human nervous system. The difference is that EEG uses scalp electrodes to read the signals given off by the brain, and EMG uses muscle electrodes to directly read the signals given off by muscles (Gao, 2018). Both come with their own set of advantages and disadvantages, and both should be accurate enough to suffice for this technical project. Therefore, EMG will be used in this project, which allows for an easier placement of the electrodes on human subjects, and confines the whole exoskeleton system to just the limb region of a user.

The easiest way to break down this project will be to think about how a normal human arm works. When you decide to move your arm for example, your brain sends a signal to your muscle, telling it to either expand or contract, which then moves your arm in the desired motion (Pineda-Rico, 2016). Therefore, we can use EMG to directly read the signals that are sent to the muscles by the brain, and then write an algorithm that converts these signals into motions that can be performed by external actuators. These signals that travel throughout your body are usually still present even if you have weakened or damaged muscles, so the exoskeleton system designed here should work for all of the desired applications.

Under the guidance of Dr. Sarah Sun of UVA’s department of Mechanical and Aerospace Engineering, my capstone group has divided into 3 sub teams, each in charge of a specific aspect of the prototype exoskeleton arm. 2 teams will be focused on the physical build up of the exoskeleton arm, which includes the design for the novel soft actuators. My sub team will be focused on the physical buildup of the shoulder joint of the exoskeleton, and the other team will focus on the elbow joint. The 3rd team will be in charge of creating the control algorithm to read, amplify, and process the muscle signals into usable information that can be sent to the external actuators. Once we have completed the first prototype of the exoskeleton limb, we have the intention of performing trials within the UVA Health System, to get real patient feedback on the design. From this, we hope to gain valuable insight on what patients actually want to see improved with exoskeletons, and the goal is to iterate the design several times until we have a satisfactory prototype.

Tackling this problem will be a several month endeavor, and through this process I hope to learn the most cost effective and efficient way to design an exoskeleton limb, as well as figure out how to overcome some of the problems that most modern exoskeleton limbs have. At the end of the time frame for the project in the spring of 2022, the deliverable will be a polished exoskeleton arm design that functions effectively and is comfortable to wear.

Potential Applications of Exoskeleton Suits in the Armed Forces

Wherever there is a discussion of subjecting the human body to an unnatural change, there will always be controversy. This is especially true when those augmentations have the potential to change life as we know it. While many exoskeleton suits on the market today are used for either medical or research purposes, there are exoskeletons in use today that are used for much more ethically ambiguous purposes. The clearest examples of this are the first military adaptations of exoskeleton suits for the US Army. Since early 2018, the United States Military has been interested in a new generation of exoskeletons suits designed to increase both the strength and endurance of its soldiers, as well as potentially help them fight better in close quarters (Keller, 2018).

Companies like Lockheed Martin have already begun to develop some very promising prototypes that have been able to successfully reduce the strain on soldiers who have to carry heavy loads long distances. One of their earliest successful prototypes, the HULC, has allowed soldiers to carry loads of up to 200 lbs. across all terrains for extended periods of time without causing the soldier any additional fatigue (Alexander, 2010). Most other successful prototypes have achieved very similar feats, such as assisting soldiers in climbing up steep ascents or descents, and helping them to move heavy equipment or machinery when stationed at a base. Most current applications of military exoskeletons have the primary goal of simply easing the physical toll that being in the army takes on the human body, such as reducing fatigue or strain on muscles. There have already been studies that have proven that using an exoskeleton suit to assist with daily tasks can reduce the likelihood a soldier will suffer from chronic injuries later in life (Gibson, 2017). So, while most of the prototypes developed so far aren't specifically designed to be used in combat, soldiers augmented with exoskeletons can do things like cover more ground, complete more tasks, and operate more heavy machinery, which gives a huge advantage to the military that implements them.

War is something that has been constantly evolving and growing deadlier since the stone age. At this point, technology has changed almost every aspect of warfare, and now it's beginning to change the soldiers themselves. While it's true that the role of standard "boots on the ground" soldiers has been steadily decreasing in the past 2 decades, there will always be a need for soldiers to fight battles and complete missions. Because of this, it's only a matter of time until we see exoskeleton suits that are explicitly designed to improve combat performance, such as the B-Temia/Revision Prowler Exoskeleton, which is specifically intended for military personnel in combat (Young, 2017).

Despite having several potential working prototypes that exist only to reduce fatigue and strain on their soldiers, the US Army has been hesitant to deploy these exoskeletons for widespread use. The technology itself is still very new, and it's likely going to take several more years development before it's at the point where we have an exoskeleton suit that's fit to be worn by the average soldier in the army. There's also the question of how much it would cost to outfit regiments of soldiers, even if a prototype arises that is mass producible. The decision then has to be made if it's even worth it to spend all the time and money developing the next generation of exoskeleton suits just to make the daily lives of soldiers a little bit easier.

Generally, this topic will be somewhat loosely coupled with the topic of my technical project. As previously mentioned, the technical project will be focused on the buildup of one exoskeleton limb for medical research purposes, and the research portion will cover the potential future applications of such a technical project. Additionally, my research will focus on the capabilities of half and full body exoskeleton suits, which goes far beyond the capabilities of a single limb exoskeleton. However, many of the underlying principles which make any exoskeleton possible are consistent across all applications, so there will still be a fair overlap between the research conducted and the technical project.

Research Question and Method

With all that being considered, the question this paper will aim to answer will be 2-fold. First, based on the current state of exoskeleton technology, when should we expect the US army to deploy the first exoskeleton suits that directly enhance the combat ability of their soldiers, and second, will we ever see a widespread deployment of exoskeletons suits in the army, whether it be for ethical or economic reasons? This topic will be pursued by taking a deep look into the current state of exoskeleton technology, and exploring where experts think this technology will go in the future. Furthermore, I intend to review military spending documents, ethical concerns, and research papers to come to a conclusion on the likelihood we will ever see mass deployment of exoskeleton suits. Unfortunately, the scope of the research will likely not be completely indicative of the current state of military exoskeletons, as much of the research and product developments are kept internal to the government for national security reasons. That being said, I do believe there is enough publicly known information to accurately portray the current state of military exoskeletons, which can then be extrapolated from to form predictions about the future.

Conclusion

When we think of using science and technology to increase the physical strength of a person, many of us would envision some kind of elixir or serum that increases the muscle size of a human, much like one of our childhood super heroes, Captain America. In today's world a story like that is still nothing more than a tale of science fiction, but pursuing the technology behind exoskeletons may get us the closest we'll ever get to a real-life super soldier. But whether or not we should even be pursuing such a concept deserves a discussion of its own. The ethics of the tactics employed by certain parts of the US military have been a hotspot for debate for decades, and this subject is no different. I believe this makes the topic very important to address, as whatever is decided in the next couple years has the potential to change warfare as we know it. Regardless of if we use this new technology to improve the lives of everyday people, or use it to enhance the physical strength of our military, exoskeleton limbs are on the horizon and coming up fast.

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