Minimally Invasive Low-Cost Soft Exoskeleton to Help with Sitting and Standing

The Improvement of Life due to Lower Limb Exoskeletons on Human Users

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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

Over time, the human body begins to deteriorate and weaken making daily activities become more and more strenuous with older age. One of the many things' humans take for granted is the ability to sit and stand, but like many other basic human functions, aging makes this much more difficult (Laporte et. al). As people age, not only does their muscular strength decrease but the range of motion in their joints does as well. Additionally, the reaction time of elderly people worsens and the risk of injury due to falling increases. Many factors of aging result in elderly people living sedentary lifestyles, however this has several worsening health effects that become more detrimental with time (Yen et. al, 2017).

The invention of exoskeletons is an assistive technology that are newly able to be found in the rehabilitation field. The implementation of this technology will assist elderly people as they are wearable and easily usable for the full duration of the day whilst causing no physical damage to them. The newly proposed creation that my technical team and I are developing provides a low cost, minimally invasive, lightweight exoskeleton to assist the human users, especially elderly people, with sitting and standing. Surprisingly, despite muscle deterioration with age, elderly people tend to retain ankle mobility, which has allowed us to develop a solution limited to assisting the hip and knee joints (Laporte et.al). Due to exoskeleton creation being in its infancy, the cost of these devices is very expensive, and the weight of these devices are extremely high due to their bulky designs (Chen et. al).

The existing lower-limb exoskeleton designs are not the most user friendly in terms of comfortability and design structure. Most of these designs are unfortunately inducing pain onto its users due to discomfort and misalignment as suboptimal fitting is consistent in multiple designs; many of these different exoskeleton designs in practice have caused bone fractures on test patients (Chen et. al). The main sociotechnical goal in the new technical design of our mechanical system will be to reduce weight and improve the interactions between human users and the exoskeleton by not inducing pain or any severity of injury. With this implementation, the optimization of the design will enhance the user's physical abilities at a low cost and will weigh the least amount possible whilst still being the most effective.

A New Rigid, Lightweight Structure

Exoskeletons designed to assist lower-limb functionality are made in two main forms: rigid design exoskeletons and soft design exoskeletons. Cornwall (2021) gives us deeper insight into the differences between these designs. Rigid exoskeletons are great at taking weight off the human user due to their design, but they are heavy, utilize a lot of power, and are physically demanding on the human body to wear. Soft exoskeletons on the other hand are lightweight, energy efficient, and easy to wear, but the load of the device is put onto the human user and extra loads are not typically supported well by the system. Although there is not exactly a mechanical solution to these issues, we have designed a structure that utilizes the advantages of both designs while minimizing the disadvantages of both simultaneously. With the implementation of a previously designed mechanical structure, an invisible chair (Amazon), the design will reduce weight to this device under 20 kg while still reducing cost drastically without losing the ability to handle the force of the human user in the exoskeleton.

Fig. 1. Invisible Chair (Amazon, 2023)

The incorporation of this structure will allow the design to take a major difference from previously designed exoskeletons drastically. Specifically, this design will take a major turn away from the use of pneumatic and hydraulic actuators and their numerous disadvantages (Li) as electric actuation will work in conjunction in the new design of this exoskeleton utilizing stepper motors. Pneumatic actuation requires a pump, which would be very loud, and the placement would be invasive and likely induce discomfort. Hydraulics would also require a pump and a storage system for the fluid, which is counterintuitive to making this design both lightweight and portable. The storage system would need to be attached to the body to make the design portable and the dense nature of hydraulic fluid would make it difficult to store and heavyweight.

The usage of electric actuation will allow for high loads to be managed in the knee and hip joints as stepper motors produce high torque at a much lower cost than that of actuators that act at similar capacities. Additionally, the usage of electric actuation will produce noise less than 40 Db and reduce the annoyance of this device as well. The tradeoff here is a slight loss in the precision of the desired angles; however, this is not a concern as the exact angle of the seated and standing position of humans differ between each user. Borrowed from a previously published paper, the predicted necessary degrees of bending at both the knees and the hip are provided. For the knee, the seated angle is 60° and the standing angle is 120°. For the hip, the seating angle is 50° and the standing angle is 100° (Liu). For convenience, I provided these values in Table 1 below.

Table I. Degrees of Freedom and Specifications

	Sitting angle	Standing angle
Knee	60°	120°
Hip	50°	100°

The technical structure of the device in Figure 2 illustrates how the design will be both lightweight and minimally invasive. The backpack will store most of the electronics and wiring necessary for the system to operate smoothly. The invisible chair will attach to the user's lower limbs via Velcro and necessary straps. The belt will not only support the user's torso, but act as a support for the rigid design of both the motors and rods to be attached to. The design of the rods on the femur and shin were built in SolidWorks to be 3D printed for the prototype (shown in Figure 3), however, the final design will incorporate the same structure built out of metal.

Though we are still in the beginning stages of the design, we plan to utilize aluminum alloys to maximize strength and still allow the structure to be lightweight.

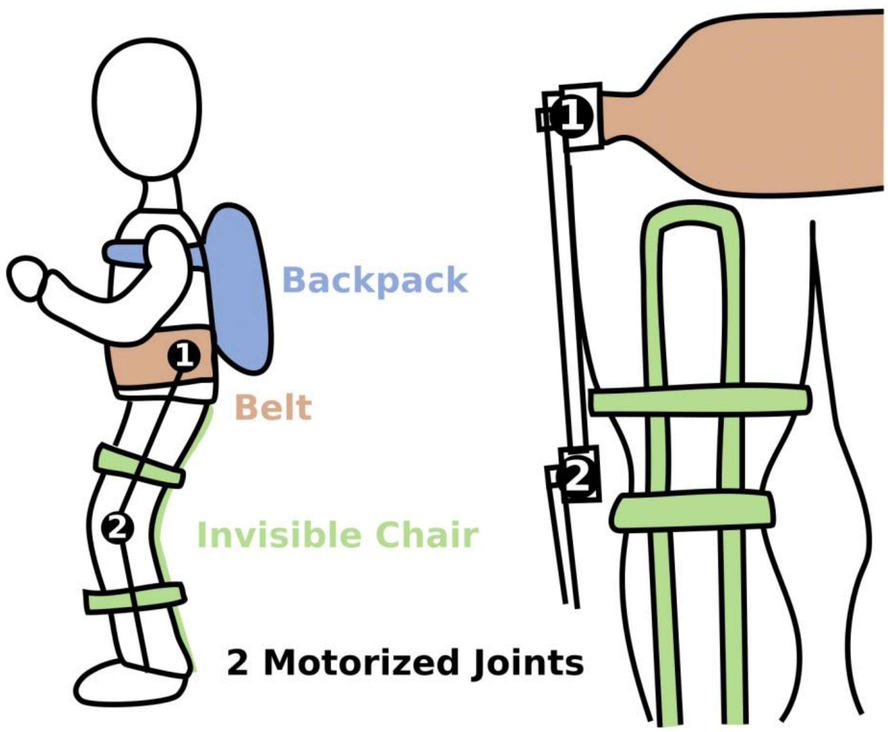

Fig. 2. Initial Design

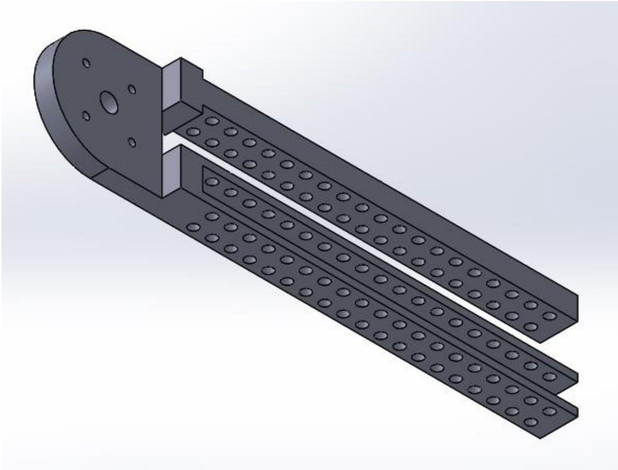

Fig. 3. Adjustable Brace Design for Femur and Shin

Despite DC motors being the cheapest option in motor selection, stepper motors will be able more ideal to manage higher holding torque. The weight of the person and the load they may obtain will be able to be managed with less worry of the device failing. The slower nature of the movement utilizing stepper motors will be more ideal for sitting and standing as this device is aimed to assist users with limited lower limb functionality, especially elderly people. Although stepper motors could potentially burn out, we are provided detailed documentation by manufacturers that allow us to predict how much torque and current the motors can handle prior to failure. With this information, we will calculate and augment our system to a factor of safety of 2 so our system will not fail due to mechanical loading.

The Intersections Between the User and the Structure

The important question at hand is how this device will interact with the user. Outside of the physical advantages this device will provide, several sociotechnical questions remain unanswered to this point as this device is one of the first of its kind. This device will allow users with lower limb incapabilities to live a better quality of life as they will be assisted in performing what most humans consider a basic human action. This device will advance the healthcare system in its entirety and change the way people receive lower limb care as we currently know it. The interactions between the user and the device will only aid in changing the world of rehabilitation for a variety of recovering patients and reduce the risk of injury for elderly people and those at risk of falling. There will no longer be a need to be physically present at a healthcare facility to receive care for a problem that can be fixed at home with the proper resource.

This low-cost design will allow a larger spectrum of people from a variety of socioeconomic statuses to take advantage of this new innovative technology. The current status of lower limb exoskeletons marginalizes several communities that will benefit from this new type of technology as it costs several thousands of dollars. Because lower limb exoskeletons to date are restricted to military usage, commercial usage, and wealthy individuals who can afford it, the majority of those in need are still in pursuit of a financially plausible solution. The answer to this dilemma will be the production and exposition of this device as it will help those who need it most: elderly people and people in need of lower limb care.

The lightweight design of this system will allow a larger scope of individuals at different stages in recovery and a large array of capability to reap the benefits of this minimally invasive technology. From stroke patients in recovery to elderly people whose bodies are not the same as they once were, this device will change the way their everyday lives are lived. The tasks they can perform will be multiplied as they will be able to sit and stand freely. For individuals of different heights, weights and capabilities, this device will be easily adjustable and comfortable for all body types. Due to the structure of this device and its lightweight structure, users do not have to worry about fatigue induced by the device. Now this may seem trivial but what good is an assistive device if you cannot rely on it to use whenever you want it or genuinely need it. The lightweight aspect of this device makes it extremely practical and gives it an extreme edge over its competitors. With the exception of changing its batteries, this device will work all day long, ready to assist in sitting and standing whilst not tiring the user or slowing them down. Though predicting the thoughts about the device from an outside perspective is not an easy task, it is assumed that this device will be mainly utilized in the comfort of one’s home behind closed doors. If used outdoors or simply observed from anyone other than the user, this device will appear futuristic and will appeal to their eyes as nothing less than an advancement in the current state of technology.

Conclusion

The minimally invasive, low-cost, and lightweight design of this device will be the only lower-limb exoskeleton available to healthcare patients and elderly people of its kind. The design will incorporate a compact hybrid design using both a rigid and soft exoskeleton design. With the usage of modern technology for both the device’s structure and support, this device has the capability to be implemented almost immediately. The machinery available at the university will allow for the structure of the device to be cut and implemented onto our final product swiftly and quickly, implying that real company’s will be able to mass produce this design at low costs and deploy it into the healthcare industry. In little time, this device will be able to positively effect the lives of several individuals seeking lower limb assistance and protection against the risk of falling when sitting and standing. With the relatively low amount of information regarding lower limb exoskeletons, this knowledge and insight can be utilized in several other fields of study including robotics and automation. In the near future, the hope is to see this device incorporated into the healthcare industry and reach the homes of those in need for low costs.

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