Hybrid- Exoskeleton Construction

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Neurological conditions (NC) affect millions of Americans and often reduce the quality of life for those afflicted by causing decreased muscular strength and limb control. These can then lead to secondary health conditions such as obesity, muscle atrophy, and other chronic conditions (Bellman et al., 2014). Although Common recreational activities could help them grow, they may lack the strength to repetitively perform the necessary actions for growth. However, performing these actions with neuromuscular electrical stimulation (NES) can provide sensory afferent feedback for those with NCs. This can then promote enhanced bone density, muscle development, and motor control; however, the individual's endurance limits the benefits. A limitation rehabilitation robots can and have overcome (Anaya et al., 2018).

Hybrid exoskeletons combine the advantages of NES with rehabilitation robots to effectively help those with NC. The project at hand is to design and construct a hybrid exoskeleton device that will act as a test bed for future studies. The design has two degrees of freedom which allows movement about the patient's elbow and shoulder joints. The NES of the device will eventually be controlled using simple control principles (Anaya et al., 2018). Participants can utilize the constructed device to perform various actions such as arm flexion and extension.

Once the project was defined to be a device that allows motion parallel to the transvers plane and rotation about the elbow and shoulder joints, a prototype was made. The first prototype is shown in Fig. 1, and it was meant to help get a simple idea of the device.

Once the basic design was modeled, we focused on improving the elbow joint and adding a sensor and motor. The sensor was to measure the torque experienced at the joint, and the motor helps with movement. Moreover, the design was changed such that aluminum extrusions will provide support instead of aluminum rods. This is because the aluminum extrusions will experience less bending and twisting than the rods. Lastly, a capstan was added to the design to offset the motor, and it is considered to have negligible torque loss due to friction. This is due to a wire tightly wrapped around the driving motor. With both wire ends connected to a wheel. The tension in the wheels causes a torque which will spin the wheel and the part connected to the wheel. This design is shown in Fig. 2.

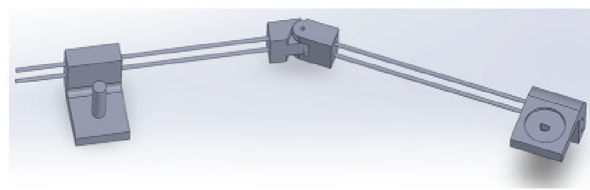

Fig. 1. Basic Design

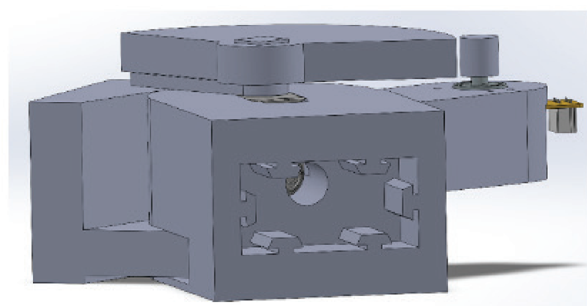

Fig. 2. Joint with Added Sensor and Motor

The elbow design with the torque sensor was then determined to be bulky and complex due to the sensors design and the way it measures torque. As a result, the next design was constructed without the sensor, and this design required less material. Moreover, the capstan was moved to be under the joint, so the joint would be more comfortable for the user. Lastly, grooves were added to the capstan and motor cap so the wire would not slip off the parts. Fig. 3 shows the updated design.

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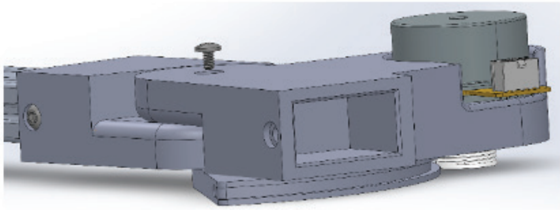

Fig. 3. Capstan Design

Once a design for the capstan was decided, we split up to work on other aspects of the design. One of us made a shoulder design with two spur gears to explore another option, and the other worked on a design for the shoulder. Fig. 4 shows the gear design, and Fig. 5 shows the shoulder design.

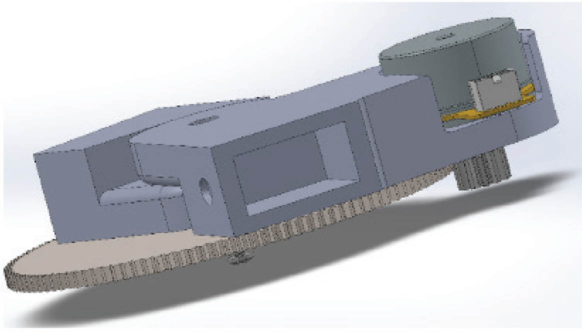

Fig. 4. Considered Gear Design

Once the gear design was modeled, it was realized that the custom gears with the desired setup would be hard to make. Moreover, the gears could wear out overtime, or something could get stuck in the teeth. This means the capstan is the preferred design.

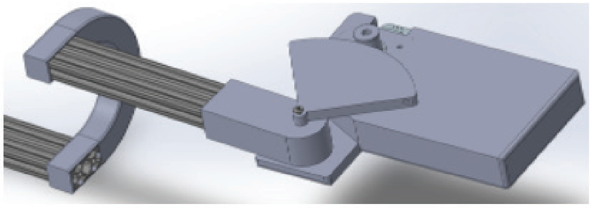

Fig. 5. Shoulder Design

As Fig. 5 shows, the shoulder was designed in a similar fashion to the elbow. Also, there is a U-shaped part in the design. This part is to allow for the elbow joint to rest below the elbow while the shoulder is above the shoulder. It also allows for the length to be adjusted to comfortably fit the user's upper arm. Lastly, a large block can be seen extruding out from the joint. This extrusion will allow for a mount to be constructed to support the device.

The design in SolidWorks was then finalized and the construction began. Figure 6 shows the SolidWorks assembly of the total system.

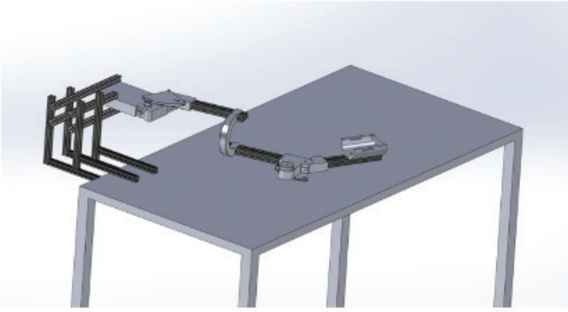

Fig. 6. Complete SolidWorks design with table

Each joint features a motor and a torque transition method called a capstan. This feature allows the motor to be offset from the axis of rotation so that the user does not have the motor directly above or below their joint. The forearm of the exoskeleton will slide on the surface of a table so that the structure is supported throughout the movement. The shoulder joint is suspended over the user's shoulder to allow easier control of the upper arm when in use. A frame made from aluminum extrusions that attach to the table supports the shoulder joint. Figure 7 shows the physical model of the exoskeleton in its current state.

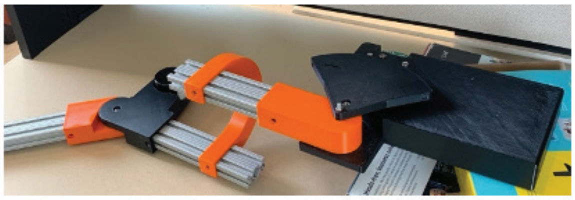

Fig. 7. Current state of physical model

The construction will require further attention in a few areas before testing can take place. For example, the wire needs to be added to the motor caps and capstans. Also, the frame that supports the shoulder needs to be built, and there are a few parts that still need to be 3D printed. Although the construction is not complete, the mobility and general functionality of the system has proven sufficient. The exoskeleton's current state allows manual rotation about each of the joints. This means when the motors are up and running, the assembly will run smoothly.

Once the build is complete, a PID controller will be implemented to control the motors and move the exoskeleton on its own. To make this a hybrid exoskeleton, functional electrical stimulation (FES) needs to be implemented into the system. This will stimulate muscle contraction in the participant wearing the exoskeleton causing it to move. Once this exoskeleton is paired with FES, it will act as a test bed to gather data on how effective hybrid exoskeletons can be in rehabilitating people who suffer from NCs (Anaya et al., 2018).

Statement of Research Advisor

The Controls, Autonomy, and rehabilitative Engineering (CARE) lab in the Auburn University Department of Mechanical Engineering is focused on the design of controllers for nonlinear dynamical systems. In this work, Joseph and Ellis led the design and construction of a hybrid exoskeleton to assist in the rehabilitation of individuals with movement disorders. The exoskeleton incorporates capstans to reduce friction in the joints and is capable of being adjusted to properly fit individuals with ranging arm sizes. The exoskeleton will be used during experiments in the CARE lab for years to come.

-Brendon Allen, Samuel Ginn College of Engineering

References

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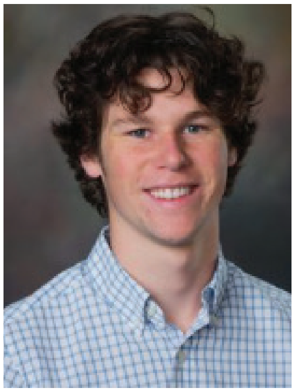
Authors Biography

Joseph Crapet is a junior-year student pursuing a B.S. degree in Mechanical Engineering at Auburn University. He has primarily worked on the elbow joint design for the hybrid-exoskeleton.



Ellis Spieler is a senior-year student pursuing a B.S. degree in Mechanical Engineering at Auburn University. He has designed the working mechanism for the shoulder joint of the hybrid-exoskeleton.

Brendon Allen received his Ph.D. in 2021 from the Department of Mechanical and Aerospace Engineering from the University of Florida. He joined the Department of Mechanical Engineering at Auburn University in 2021. His main research interests include the development of robust, adaptive, or learning Lyapunov-based control techniques for uncertain nonlinear systems such as: rehabilitation robotics, and autonomous systems.