DESIGN CENTER COLORADO

tensentric

Exo-Seat

Improving The Quality Of Life For Those With Multiple Sclerosis

ME Senior Design Team 31
Director: Dr. Derek Reamon

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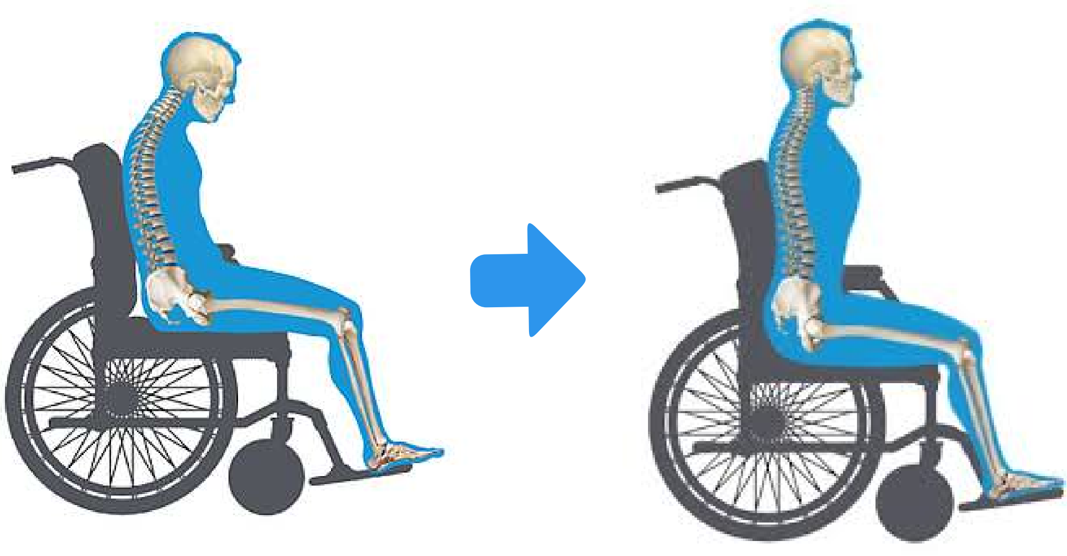
Overview

The Exo-Seat is a motorized seat belt system that attaches to a wheelchair. The initial prototype is being made specifically for our end user, Cindy, a patient with secondary progressive multiple sclerosis. Cindy spends the majority of her day in her wheelchair as she has lost all lower body function and has very limited upper-body function that worsens with heat and fatigue. Given her condition, she is often unable to hold her upper body upright in her wheelchair, forcing her into uncomfortable and painful fallen positions that severely compromise her respiratory function.

The goal of the Exo-Seat is to improve our client's independence and quality of life by empowering her to move freely and maintain a healthy posture without the need of constant assistance from caregivers. From collaborating with Tensentric, a local medical device and in-vitro diagnostics company, we implemented the unique factors that go into the design of a medical device including risk analysis, safety testing, design requirements, user needs documentation, and human factors engineering considerations. In doing so, we were able to develop a safe, easy to use and beneficial product that can not only improve Cindy's quality of life, but many others in similar conditions.



(1) Pictures retrieved from: Sharpe, Lindsey, and Dpt. "The Common Postural Abnormalities Seen in Wheelchair Seating and Positioning." Permobil Blog, hub.permobil.com/blog/common-postural-abnormalities-wheelchair-seating-positioning.

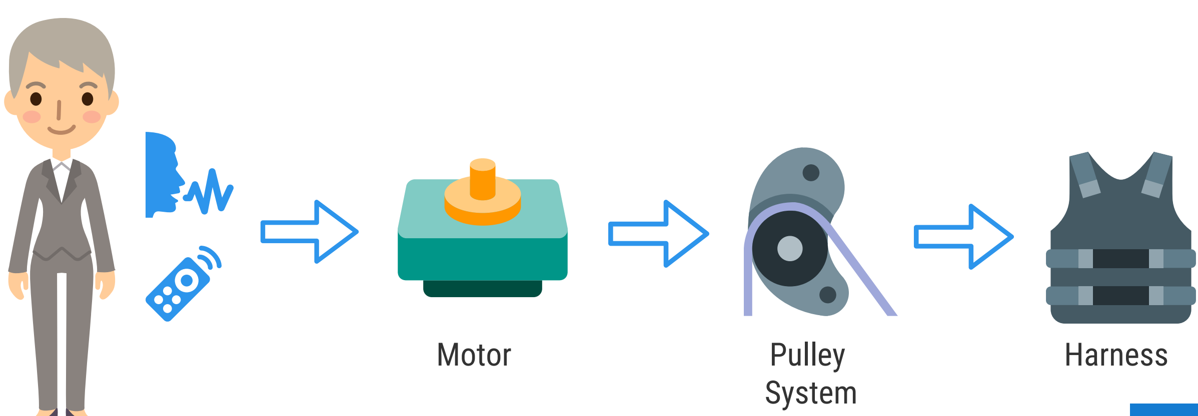
An Unmet Need Beyond One Patient

Common solutions in the market today that provide postural support for patients in wheelchairs include straps that bind the user in a static upright position or wheelchairs that tilt backwards, allowing for changes in weight distribution and relieving fatigue. The static straps restrict forward movement of the user's arms and torso, accelerating muscle degeneration and hindering the user's independence. While the tilting wheelchairs allow for increased backwards motion, there is still no solution for forward movement and postural support.

Through direct interaction and feedback with our customer, we have designed a device that surpasses the limitations of the current solutions and meets each of her primary needs. The defining qualities of the Exo-Seat that meet these terms are that it **encourages continued muscle use** in order to slow the progression of muscle degeneration, it **does not lose its effectiveness** even if the user's muscle degeneration progresses, it **promotes correct postural position** controlled by the user, and it is **adaptable the the user's current routines** without interfering with caregiver workflows or hindering any of the existing features on the user's wheelchair.

A number of people have come to us with inquiries about this device, as they feel they or someone they know could benefit from it as well. This has included individuals with varying levels of paralysis, spina bifida, and more. While this project started as a one-off product for an individual with MS, we have since seen an untapped market unfold for "smart" posture-promoting devices such as the Exo-Seat that address some of the most common pain points for wheelchair users. The Exo-Seat meets a vital niche of supporting forward upper-body movement and provides a long-lasting solution for all wheelchair users with concerns in maintaining their mobility, strength, comfort, health, and independence.

How the system works



A Human-Centered Approach

Our design is centered around direct feedback from our end user, Cindy, in order to develop the most effective product for her needs.

1 Brings user to correct postural position

The main function of the Exo-Seat is to pull Cindy's torso into an upright position while maintaining optimal comfort and safety. This is made possible by using a harness and motorized pulley system that attaches to Cindy's wheelchair. The harness wraps around the user's waist for security and has adjustable straps that secure to the waist in order to avoid discomfort from wrapping directly under the armpits. To provide postural support, the body of the harness includes aluminum plates along the spine to straighten the user's back. A cooling pillow was also added for increased comfort, lower lumbar support and temperature control. The belts that feed through the pulley system are then attached to the two harness straps to pull the shoulders back when the system is activated.

The pulley system operates using a brushless DC (BLDC) motor, a timing belt gear reduction, a pulley shaft, and pulley belts that attach to the harness. The pulley belts are routed through two sets of pulley rollers attached to the back of the wheelchair. To move Cindy up, the motor winds clockwise which wraps the pulley belts around the driven shaft. The torque that's created from this movement creates tension in the pulley belts. This tension is large enough to start moving Cindy's harness laterally at a comfortable speed. The system automatically stops winding up when Cindy is at the maximum position, with her shoulders pulled back to support her posture.

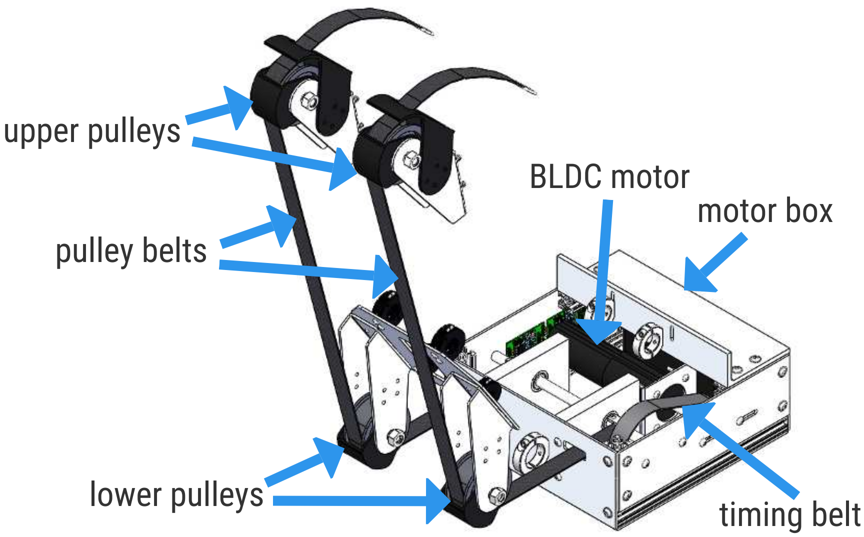


Fig. 1: The complete Exo-Seat system attachable to wheelchair (excluding the harness)

Fig. 2: Harness that attaches to the pulley belts

A Human-Centered Approach

2 Encourages continued muscle use

The Exo-Seat assists in the full range of upper-body forward movement for Cindy. As the system is pulling Cindy up or bringing her down, the system allows for Cindy to stop at any moment with a simple voice command, giving her the opportunity to perform tasks that she could not do otherwise such as leaning forward and reaching for an item. The high inertia from the gear ratio in the motor locks Cindy in place until she commands the system to pull her further up or release her back down.

The Exo-Seat motor utilizes a speed control system that pulls Cindy up at a slow and constant speed. Thus, the torque that the motor supplies is determined by how much weight she applies to the system. If Cindy uses her own muscles to help pull her up, and thus puts less weight on the system, the control system will automatically adjust its torque output to match this. In doing so, the system enables Cindy to activate her own muscles as much as possible, even when the system is running. The Exo-Seat encourages Cindy to continue to use her own strength to move when possible, while providing her with the confidence that if she gets stuck in an uncomfortable fallen position, she can recover from it with the assistance of the Exo-Seat.

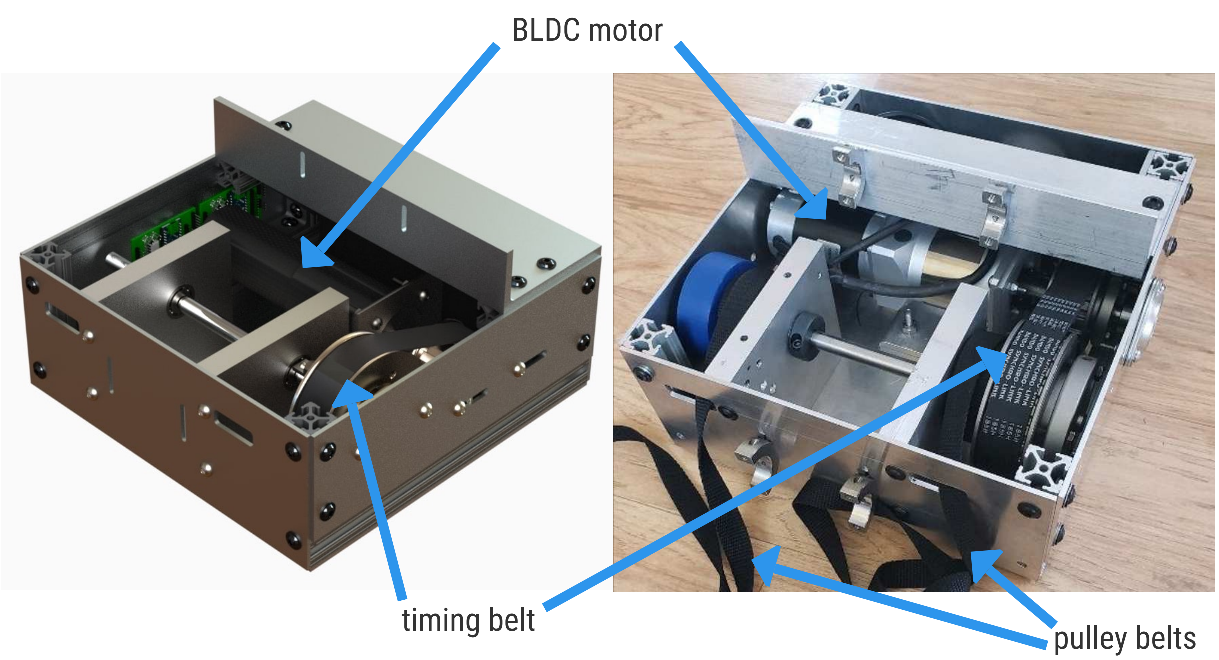


Fig. 3: Motor box CAD rendering (left) and manufactured motor box (right)

A Human-Centered Approach

3 Does not lose effectiveness

A key requirement in our design is its long-term utility for Cindy. The Exo-Seat is made with high-end materials and parts that can withstand long term use and wear. A brush-less DC motor was chosen for this application due to the reliability and low maintenance of such motors. The motor box and pulley system are designed to sustain through long-term wear and the harness is made to be easily washable for continual use.

The user control and internal speed control system of the Exo-Seat are designed such that changes to the user's physical conditions such as the user's weight, size, or physical strength and ability will not change the effectiveness of the device. This requirement is essential particularly for patients with muscular degenerative disorders such as MS, as the system must adapt to the user as further muscle degeneration occurs.

The Exo-Seat system can be controlled by Cindy using voice commands, enabling her to control the system without any need for movement of her arms or fingers. Additionally, the speed control system employed by the Exo-Seat enables a wide range of torque potential that will automatically and immediately adjust according to the patient's strength and ability to assist at any given time. The maximum torque applied meets a large safety factor above the estimated maximum torque that will be applied given the user's current physical conditions.

The system will be delivered to Cindy with a user manual, spare parts, and maintenance instructions. The initial implementation will be done by members of the senior design team and the project manager will provide initial in-person training for all of the caregivers who will be interacting with the device.

Voice Control Commands List

Initiation Command (i.e. "Hey, Felix")

- Pull me up
- Bring me down
- Stop

Fig. 4: View of upper and lower pulleys attached to wheelchair (top), view of lower pulleys and motor box attached to wheelchair (bottom)

A Human-Centered Approach

4 Adaptable to user's current routines

The mechanical components of the Exo-Seat are designed to be easily attachable and detachable to Cindy's wheelchair. This way, the caregivers could remove certain components when they need to access various parts of the wheelchair. Most of the components are encased in protective covering to isolate the moving parts. The motor box conceals the majority of the moving mechanical components and electronics. The pulley rollers located on the back of her chair have covers to prevent the belt from getting loose and fingers/hair from getting stuck.

All elements added to the wheelchair have been designed to not extend past the current shape of the wheelchair, ensuring that the device adds no greater difficulty in fitting the wheelchair through tight spaces. The motor box and pulley system attach to the wheelchair without damaging or modifying the wheelchair in any way.

In addition to voice control, the Exo-Seat also has a wired remote control that issues the same commands as the voice control. This is meant to be used primarily by the caregivers as an additional way to easily interact with the system when working with Cindy in it.

Why Our Customer Needs Matter

Promoting correct postural position:

- Relieves stress on internal functions such as respiratory functions
- Reduces pain and discomfort
- Encourages proper muscle movement
- Prevents fatigue

Encouraging continued muscle use:

- Slows muscle degeneration
- Enables greater independence from caregivers
- Promotes physical well-being

Maintaining effectiveness as muscle degeneration progresses:

- Provides a valuable and life-long investment
- Preserves sense of security for the future
- Enhances physical therapy exercises and goals

Adaptability to user's current routines:

- Does not disrupt caregivers' current workflows
- Is easy for both user and caregivers to operate
- Seamlessly integrates into user's life
- Does not compromise the existing functionality of wheelchair

Safety As a Top Priority

Electro-mechanical redundancy and safety measures are essential to mitigate major risks and provide safe user operation. The test engineer has created a systems risk analysis document that is intended to address the potential safety hazards to the patient and the clinician while using the Exo-Seat with a probability of occurrence versus severity FMEA analysis utilizing some medical device standards.

The largest safety risk was pulling Cindy too far into her wheelchair. To prevent this, there are four lines of defense.

Lines of defense

Motor encoders

- Continually keep track of the position of Cindy as the rope is wrapped or unwrapped

Hall effects sensors

- Continually keep track of the position of Cindy as the rope is wrapped or unwrapped

Breakaway buckles

- Located in the pulley belt
- Break at a determined force and separate Cindy's harness from the motorized system

Mechanical hard stops

- Interfere with the motor box that would stall the motor

In the case that the motor is stalled, current sensors in the motor driver will shut off the system entirely. All four of these mechanisms working together drastically decrease the risk involved while operating the Exo-Seat.

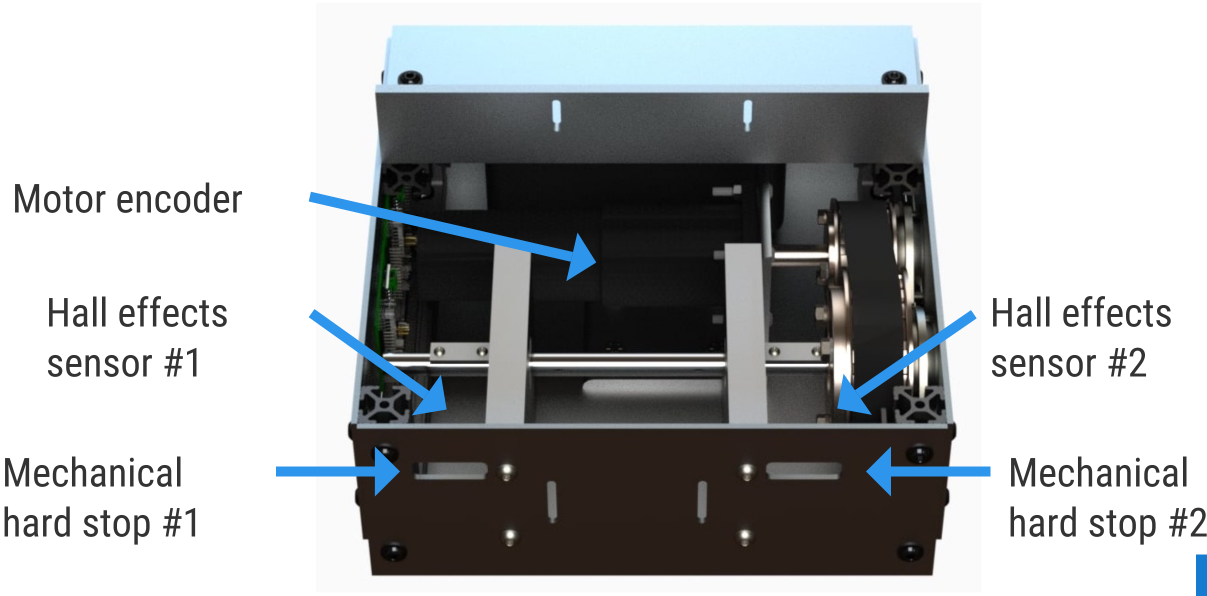


Fig. 5: Redundant safety features of the Exo-Seat

Testing and Results

As the final prototype was being designed to be delivered to Cindy, it had to go through several design iterations, extensive testing and include several safety measures.

Testing Types

- Safety Testing
- Engineering Testing
- Verification Testing
- User Needs Testing

One of the most important tests done on the Exo-Seat was the **Speed Control Disturbance Rejection Test,** because it provided evidence for the effectiveness of our control system. In this test, the ability of the controller to reject disturbances to the system without causing discomfort or harm to the user was tested and analyzed. The results showed that although there is some steady-state error in the system, the system performance is satisfactory showing maximum deviance of 4.5 RPM when subjected to a load of 21.7 lbs. This corresponds to a 0.452 (lb*ft) torque and is close to the maximum disturbance that we expect the system to be under.

We concluded confidently that even with a 4.5 rpm deviance from the set speed that the system will still reach the final position in a reasonable time. We have also concluded that the maximum rate at which the system changes speed is less than 1 RPM per second, with a shaft radius of 0.25 inches this corresponds to an acceleration of 0.0022 ft/s2 which is smooth enough to not cause any issues with discomfort from quick changes in velocity.

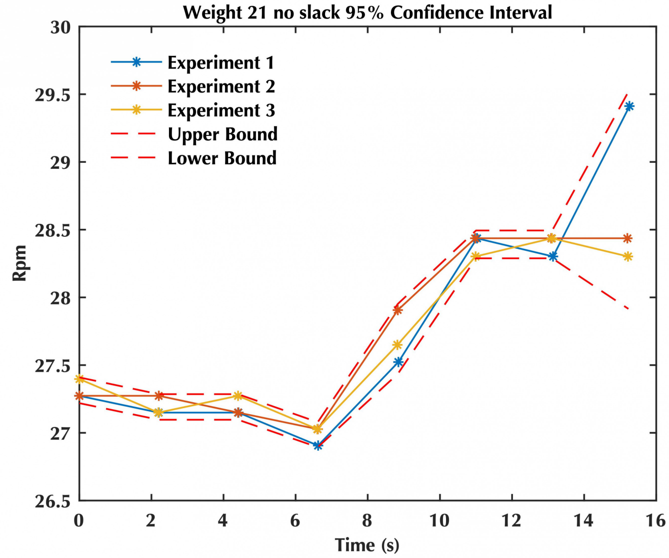


Fig. 6: Response to removing weight from the system

In Fig. 6, the weight is removed from the system causing a jump in speed that evens out. This simulates the real life situation of when the user is able to use more of her muscles to pull herself up, and less help is needed by the system.

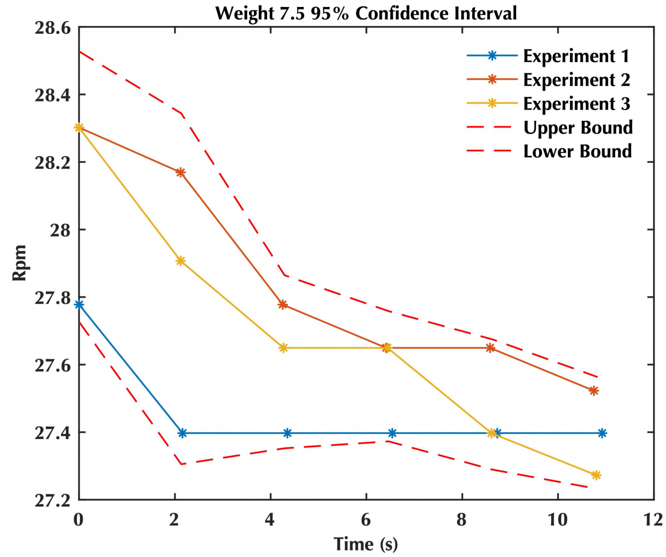


Fig. 7: Response to adding weight to the system

Fig. 7 shows an initially faster speed that drops down when the weight is added to the system and settles to a steady value. This simulates the real life situation of the user adding a sudden increase in weight to the system when it is pulling her up.

Looking Forward

Due to the pandemic, we were unable to finish all testing required and thus will not be delivering the device to Cindy at this time. However, we plan to deliver the product to Cindy once it is safe and final testing has been completed. The remaining essential tests that are still to be done before delivery are: 1) correct postural positioning test, which will verify that the system puts the user in a correct postural position from different starting locations and requires multiple iterations with the user, and 2) safety testing for all the safety mechanisms in the system which include the hall effects sensors, mechanical hard stops, current sensor, and breakaway buckles implemented in the harness.

Conclusion

Through this project, our team was able to see something that few teams do: the direct impact of our innovation. After demoing our working device, Cindy and her caregivers described the Exo-Seat as “life-changing” for her. Working with Cindy provided us with a new perspective on engineering, giving us the valuable human-centered design experience of working directly with our customer throughout the design process.

Our device solves a common yet unmet need among many wheelchair users, addressing the importance of forward upper-body movement in maintaining the user's mobility, strength, comfort, health, and independence. Through our human-centered design approach we have developed a device that will not only make a significant impact on Cindy's quality of life, but has uncovered a potential impact far beyond one person. This is an impact that members of our team plan to continue to explore moving forward with the Exo-Seat.

We hope that this project inspires future engineering teams to seek out projects that will make an impact on individuals in their community. We also hope to be an example of the importance of working closely with the product’s end users to create a device that will effectively meet their needs.

Fig. 8: CAD rendering of complete Exo-Seat system attached to wheelchair

Meet the Team

Morgan Kauss is the Founder and Project Manager of the Exo-Seat. She worked as a caregiver for Cindy, the project's client, which led her to identify a problem and create a solution to improve Cindy's quality of life. She secured pro bono sponsorship with Tensentric and the team through senior design. She is a mechanical engineer who focused on user needs, human factors and bio-mechanics, as well as worked closely with Tensentric's systems engineer learning medical device documentation. Morgan is passionate about improving the lives of those who suffer from medical conditions and is currently searching for a job in the medical device field.

Sonya Schuppan is the Co-Founder, Electrical/Software Engineering Lead, and Logistics Manager of the Exo-Seat. She designed the control system for the Exo-Seat, developed much of the Exo-Seat firmware, oversaw all electrical and software design aspects and worked with Tensentric's software engineering mentor. Sonya enjoys building systems that have the power to improve people's lives. She will be graduating with a B.S. in Electrical and Computer Engineering and a minor in Computer Science and will be joining the Microsoft Silicon Design Team after graduation.

Adam Smrekar is the Financial Manager/Software Engineer of the Exo-Seat project. He planned and managed this project's finances. This includes planning, purchasing, documenting all necessary financial information, and effectively communicating between different companies and teams. He also developed the wired controller and voice control system to allow user feedback to the electrical system. Adam enjoys developing software for projects that improves people's lives. He will be graduating with a B.S. in Electrical and Computer Engineering and a minor in Computer Science.

Matthew Human is the CAD and Manufacturing Engineer of the Exo-Seat project. He led the design and manufacturing effort for the mechanical system. This included the design of the motor box, back pulley rollers, and the integration of all the mechanical subsystems. His main responsibility was to ensure that the design was functional, practical, and safe for the user. He worked closely with Tensentric's mechanical engineering mentor. Matthew will be graduating with a B.S. in Mechanical engineering this spring and has great interest in the biomedical engineering field. He will continue working at Terumo BCT, a medical device company, as a Mechanical Engineer after graduation.

Meet the Team

Mohammed Alsheikh is the Test Engineer of the Exo-Seat. He planned, designed, improved, and assessed the quality and safety of the product. Working hand to hand with the Systems Engineer at Tensentric, he ensured a full understanding of the client's view of the product and specifications. He also created very detailed testing plans, system risk analyses, and worked with both Mechanical and Electrical Engineers on the team. Mohammed will be graduating with a B.S in Mechanical Engineering, and a minor in Engineering Management. He will be joining the Saudi Aramco EXPEC Advanced Research Center Production team after graduation.

Edward Herrick-Reynolds is the Systems Engineer of the Exo-seat project. He worked with both the mechanical and electrical teams during the design process to ensure subsystems could be integrated and devised tests to verify that systems were working properly post integration. He worked on the feedback design of the controller and modeling the system in Simulink as well as performing data analysis on testing results to verify that the system was meeting performance goals and was safe to be used. He will be graduating with a B.S in Mechanical Engineering and a minor in Applied Mathematics.

Guanxiong Fu is the Firmware Engineer of the Exo-Seat project. He led the embedded software design and development for the project. His main responsibility for the project was to design and develop firmware for the main motor controller. He also led the research and decision-making process in choosing the battery, as well as the integration of the battery into the electrical system. Guanxiong enjoys designing embedded software for cool projects, especially when the problems presented are challenging and fun to solve. He will be starting his masters in Electrical and Computer Engineering with a focus in Power Electronics and Embedded Systems Engineering in Fall 2020.

Brandon Lewien is the Electrical Engineer of the Exo-Seat project. He designed all the printed circuit boards (PCB) for the system. This included the design of the motor driver, power distribution, wiring integration (for subsystems), mechanical mounting integration, power switch, and remote control PCBs. He also led the research and decision-making process in choosing the motor. Brandon enjoys designing electrical systems and firmware design for large scale projects that improve people's lives. He will be graduating with a B.S. in Electrical and Computer Engineering and a minor in Computer Science.