Quality of Life Plus

Roboto Glove

Mohammed Alrashed, Evan Brown, Tim Farver, Saioa Lostra, Edgar Palma, Jenna Zwaanstra

Faculty Director: Alaa Ahmed

Contents

Background

This project focuses on designing and manufacturing a Roboto Glove (an instrumented exoskeleton glove) for Sgt. John Moore through Quality of Life Plus (QL+). QL+ partners with universities around the country to give engineering students hands-on experience by creating and delivering a device to wounded service members to help improve their quality of life. This device is specifically engineered for Sgt. Moore (*Figure 1, 2, and 3)* who lost almost all mobility and motor control in his right hand after being shot in his shoulder while serving in the United States Army.

Figure 3. Sgt. Moore recovering in the hospital after his injury

Figure 1. Sgt. Moore serving in the Marines

This injury left his hand stiff like a paddle making it difficult to easily open and close and his thumb is also set in a rigid position. He currently uses a simple mechanical strap (Figure 4) to grasp objects which results in him struggling with simple day-to-day tasks.

Figure 2. Sgt. John Moore

Figure 4. Current device

Project Goals

The main goal of this project is to engineer a device that allows for motor movement control and grip strength in Sgt. Moore's hand while ensuring it is durable and comfortable. The team formulated requirements for the device that served as measurable goals throughout the project (*Table 1)*. One key objective was ensuring that Sgt. Moore was able to grasp a variety of different objects from a steering wheel to a grocery bag, as defined by the adjustable forces requirement. In order to pick up everyday objects, the team set a force capability target of 15 lbf. To grab a wide variety of different-sized objects, a grasp capability of 3 inches was set; this is the diameter of a soda can. Since his current device is time-consuming to take on and off, the goal is to take on and off the new glove within 2 minutes. In case of an emergency and Sgt. Moore needs to quickly let go of an object, it should be fully released in less than 5 seconds. Lastly, to ensure the device is comfortable, the weight should not exceed 2 lbs and the total profile should be less than 2 inches.

Requirement	**Goal**
Adjustable Forces	Adjust grip force from 10 to 20 lbf.
Force Capability	Minimum grip force of 15 lbf.
Grasp Capability	Grasp width of 3 in.
Time for Putting on and Taking Off	Between 1 to 2 min.
Grip and Release	Fully release in less than 5 sec.
Weight	Under 2 lbs.
Profile	Total profile is 2 in. (top = 1 in. and bottom = 1 in.)

Table 1. Project requirements

Design Process

Preliminary Design

During the initial research of current designs, the team found that nearly all the exoskeleton glove devices are mainly used for stroke rehabilitation. These devices have similar functionality to what is needed, so aspects of these designs provided inspiration. However, these off-the-shelf devices did not meet the specific project requirements with Sgt. Moore's unique hand anatomy and desired goals. The team then decided between the use of an electronically or mechanically controlled device. The electronic design has the benefit of automatic control of finger movements, but it would not be as durable for outdoor activities that Sgt. Moore enjoys and would be harder for him to service in the future; the team wants to ensure the new glove can be used for years to come. Therefore, the team decided to move forward with a purely mechanical design where Sgt. Moore would manually adjust the amount of flexion in his fingers. This decision allows for the project goals to be met and requires less maintenance in the future.

First Prototype

After deciding on a passive mechanical device, the team created an initial prototype to determine if a BOA dial would be a feasible option as the method of actuation to allow for motor control movement of the hand. BOA dials are traditionally seen on snowboarding boots and cycling shoes; they provide a dial system that allows for sustained, adjustable tension when tightened.

With this passive mechanical device, the prototype would be on the right hand with the BOA dial resting on the inner forearm right below the elbow. Sgt. Moore would use his left hand to manually turn the dial to pull on the artificial tendons running along the palm side of his fingers to curl the fingers in to close the hand (*Figure 5*). By pulling up on the dial, the quick release function would be activated and the tension would immediately be released to allow Sgt. Moore to open his hand.

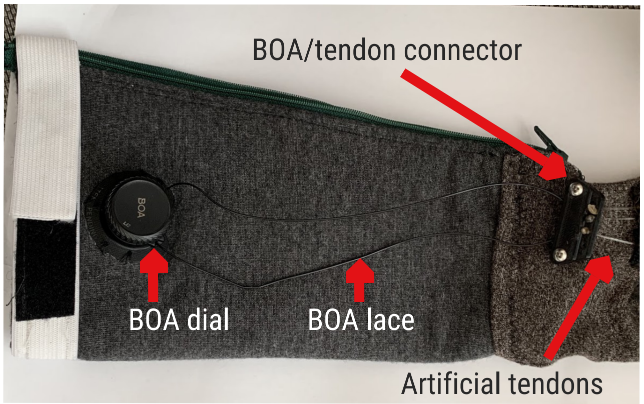


Figure 5. BOA dial set up

Monofilament was used for the artificial tendons. The other components were 3D printed which worked well, however, the wool glove material was difficult to attach components to and was not comfortable or breathable (*Figure 6*).

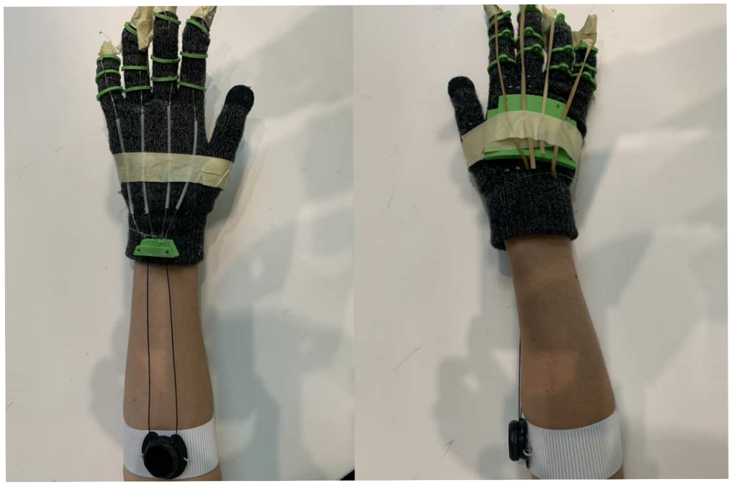


Figure 6. Initial prototype

Design Process

Second Prototype

After determining that the actuation was successful to allow for hand motor control, the goal of the second prototype was to create a more refined device to be tested by Sgt. Moore (*Figures 7 and 8*). This prototype focused on ensuring that Sgt. Moore's hand was returned to an open and resting position by the elastic shock cords after pulling up on the BOA dial to activate the quick release. The shock cords were held in place and adjusted with the back of the hand plate. In order for the fingers to move functionally, three finger rings were placed on the fingers. The rings were a key component, as they ran the shock cord along the back of the fingers and the monofilament along the palm side. A thumb wrap was also added to allow for Sgt. Moore to adjust his thumb position for various tasks.

This was the first prototype that was tested with Sgt. Moore. He found the cotton spandex glove and neoprene sleeve, where the BOA dial rests on the forearm, to be comfortable. However, adjusting the shock cord was difficult and time-consuming using the screw tightening system (*Figure 9*). From this prototype, the team learned that more friction was needed on the palm, fingers, and thumb for Sgt. Moore to easily pick up and hold onto objects. Additionally, a new back of the hand design would need to be implemented to reduce the time needed to put on and set up the glove.

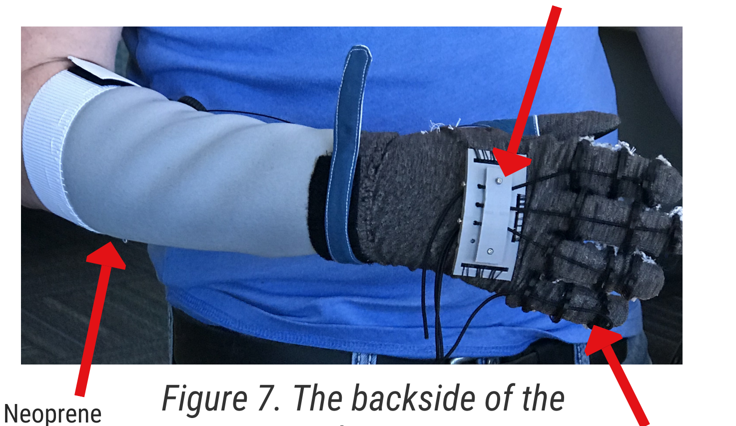


Figure 7. The backside of the second prototype

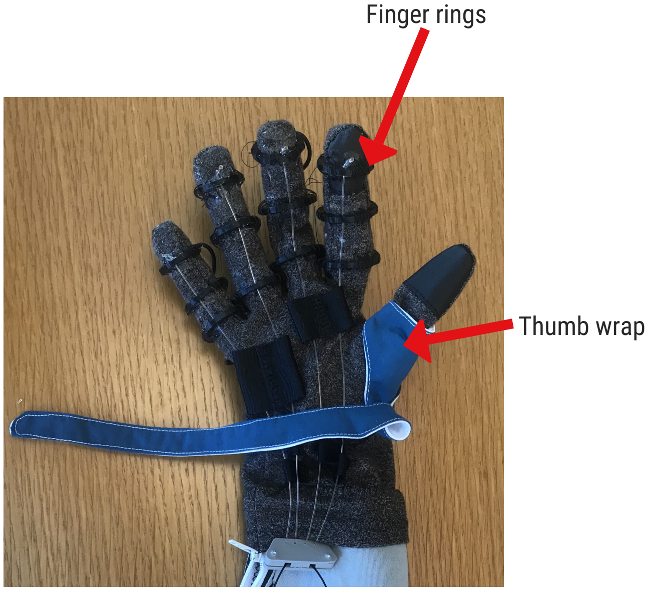


Figure 8. Palm side of the second prototype

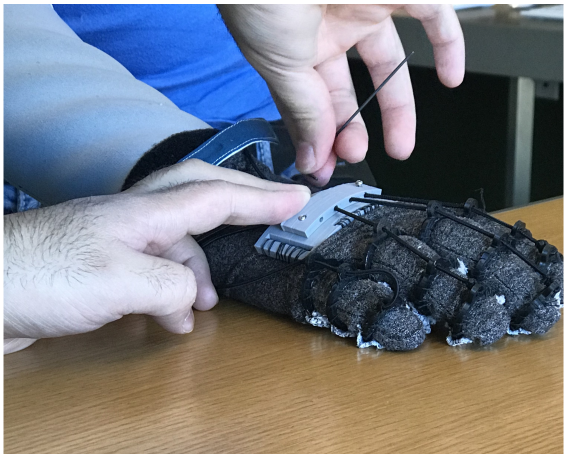


Figure 9. Adjusting shock cords with screw tightening system

Design Process

Third Prototype

After completing and testing the second prototype, the team determined that more friction needed to be added to the palm side of the glove to ensure objects did not slip out of Sgt. Moore's hand. The next prototype included non-slip material to the palm and thumb and modifications to the back of the hand plate (*Figure 10, 11, and 12).* Along with the addition of the non-slip material, the team made the decision to redesign the back of the hand component. The new back of the hand plate was slightly smaller but the major design difference was that it included hooks instead of individual screws for adjusting the tension of each shock cord. The new hook design allows for easier adjustability of the shock cord.

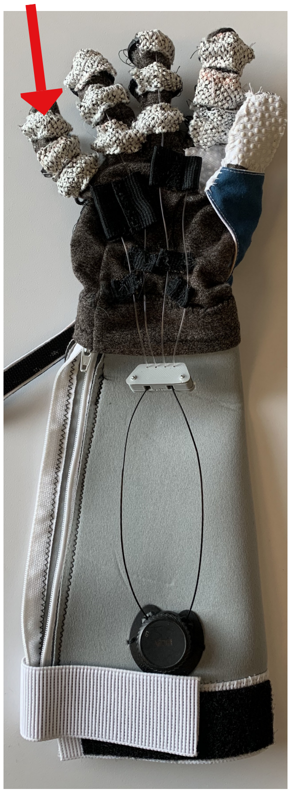


Figure 11. Palm side of the third prototype

Figure 12. The backside of the third prototype

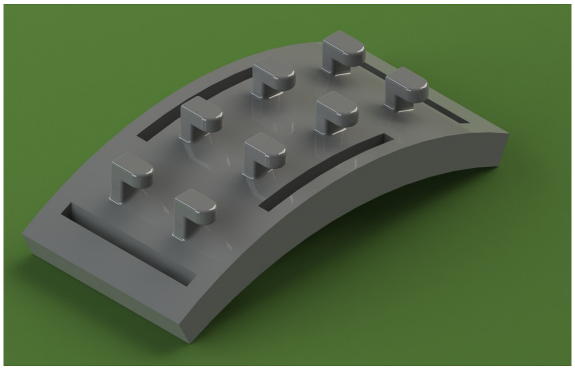


Figure 10. Rendering of the updated back of the hand plate

For this prototype, the team received beneficial feedback from Sgt. Moore. The new design for the back of the hand component was approved by Sgt. Moore since it allowed for easier adjustability and an overall better fit. Sgt. Moore also expressed that the rings were interfering with grasping objects due to geometry and lack of friction. This feedback was used and taken into consideration for the next iteration of the Roboto Glove in the fourth prototype.

Design Process

Fourth Prototype

While the third prototype was an improvement, it did not allow for the grip needed to pick up large and slick surfaced items. The team decided to remove the finger rings from the design, as they were bulky and prevented Sgt. Moore from picking up larger and smooth-surfaced objects. The rings were replaced with fabric monofilament guides on the palm of the hand and rubber band links on the back of the hand (*Figures 13 and 14*). In order to improve the grip capability, the team decided to get rid of the non-slip material and replace it with a Plasti Dip coating, a flexible, non-slip rubber coating. Two layers of Plasti Dip coating were applied onto the palm of the glove to add the extra friction that Sgt. Moore needed.

Figure 13. Palm side of the fourth prototype

Figure 14. The backside of the fourth prototype

After trying on the glove and testing it, Sgt. Moore gave the team his initial thoughts and suggestions. The removal of the finger rings and sleeker design was something that he appreciated since it made the glove more comfortable to wear and easier to pick up objects. The use of Plasti Dip worked significantly better for gripping objects when comparing that to the non-slip material. Something that Sgt. Moore did not approve of was the use of rubber bands instead of shock cords. The reason for this was that placing each individual rubber band was too time-consuming. Another issue that the team observed was that the sleeve was bunching up when actuating the BOA. All the input from Sgt. Moore and the observations from the team were taken into consideration for the design and construction of the final prototype.

Design Process

Final Prototype

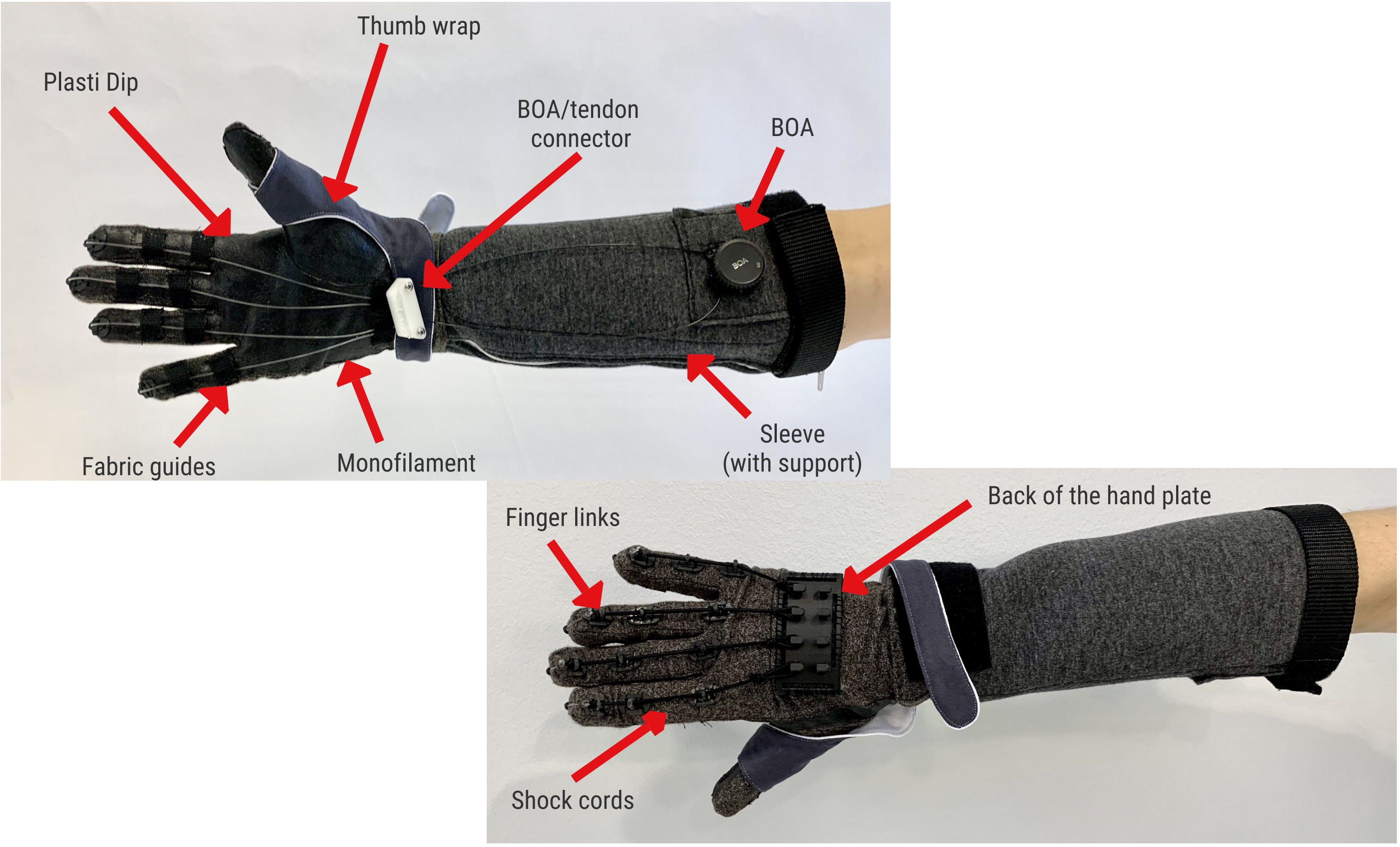


Figure 15. Final prototype

The final prototype (*Figure 15)* consists of monofilament fish lines that act as artificial tendons on the palm side of the hand pulled by a BOA dial via a connection device to cause finger flexion. Fabric guides along the palm keep the monofilament in place and prevent tangling. The rubber coating is also applied to the palm of the glove and the components that interface with the palm, in order to increase friction and provide a better grip in a variety of applications. Elastic shock cords run along the top of the fingers and are secured with hooks on the back of the hand plate to return the hand to an open resting position after the BOA is released. Finger links are located between each finger joint which guides the shock cord along the back of each finger and attaches the monofilament tendons to the tips of each finger. A custom-made thumb wrap allows Sgt. Moore to adjust his thumb position for various tasks. Finally, a neoprene forearm sleeve is sewn to the glove and the BOA dial sits near the elbow on the sleeve. To prevent the sleeve from bunching when the dial is engaged to close the hand, the team implemented a foam-covered aluminum support that is commonly used in splints and braces. This support is placed in a pocket on the inside of the forearm sleeve and the BOA dial is secured directly to the brace material. The sleeve also has a zipper which allows Sgt. Moore to take the glove on and off efficiently.

User Testing

To measure the overall success of the project, user testing data was taken with Sgt. Moore (*Table 2*). The team did not collect testing data for the first prototype, as it was a proof of concept to ensure the BOA dial provided an actuation to open and close the hand.

The adjustable force was measured by having Sgt. Moore grasp or pick up different-sized objects, such as a water bottle, grocery bag, and steering wheel. This test was given as a pass or fail, as the specific grip force was measured in the following force capability test.

Force capability was measured with a hand dynamometer to determine the maximum grip force that could be achieved. With the fourth prototype, this requirement was met and allows for Sgt. Moore to complete everyday tasks.

The grasp capability requirement was not met by the prototypes. The team determined that this goal will not be met, as Sgt. Moore's thumb is rigid and unable to move due to the nature of his injury.

The take-off and put on time fluctuated based on the prototype. The team found that the updated back of the hand plate with hooks and using shock cord instead of rubber bands will allow for these times to meet the project requirement.

The grip and release specification was met for all prototypes. After pulling up on the BOA dial, it took only about 1 second for the hand to be returned to an open and resting position.

Weight and profile requirements for all prototypes met the project requirements. Both weight and profile were well below the limits to ensure lasting comfort for Sgt. Moore.

Prototype	Adjustable Force	Force Capability	Grasp Capability	Time for Put On and Take Off	Grip and Release	Weight	Profile
Second	Pass	13 lbf	38 mm	3 min./ 30 sec.	1.1 sec.	0.3 lb	1 in.
Third	Pass	13 lbf	38 mm	45 sec./20 sec.	1.1. sec	0.3 lb	1 in.
Fourth	Pass	18 lbf	38 mm	2.5 min./30 sec.	1.1 sec	0.2 lb	0.9 in.

Table 2. Summary of user testing based on project requirements. Red highlight indicates that the measurement did not meet the project requirement while green highlight signifies the measurement met or exceeded the requirement

The team is currently working on finalizing the final prototype to test with Sgt. Moore during the delivery meeting in a couple of weeks. Based on the results from the previous prototypes, the team has concluded that the final glove iteration would meet the desired goals for adjustable forces, force capability, the time it takes to put on and take off, grip and release, weight, and profile. The only goal that will not be met will be the desired grasp capability based on Sgt. Moore's hand anatomy from the injury.

Manufacturing Process

The final glove is both low cost and easily maintainable by Sgt. Moore, as common stock parts are incorporated throughout the design with sturdy yet non-permanent fixturing methods. The cotton spandex glove, elastic cord, and monofilament fish line are materials that are easily sourced and replaced from retail outlets like Amazon and local hardware stores. The BOA/tendon connector, finger links, and back of the hand plate are custom manufactured components and can be manufactured using FDM additive manufacturing (3D printing) as a replacement. Sgt. Moore has access to a 3D printer, so he will be able to replace parts over time as needed. Due to the nature of the project, the main process for assembling the glove involved sewing the various components with reinforcements of adhesive when required. Pictures of the team manufacturing can be seen in *Figures 16, 17, and 18*.

While a cost-effective design was not an original requirement, the use of widely available materials and components allowed for the device to be manufactured at a low price. The total cost to manufacture the glove design is $336.10, which makes the design an affordable and accessible device.

Figure 16. Assembling the back of the hand plate

Figure 17. Sewing the neoprene sleeve

Figure 18. Sewing components to the first prototype

Challenges

Throughout the project, the team faced many different challenges. As they began assembling the prototypes, new and sometimes unforeseen problems would arise. At the beginning of the project, the team struggled to find a solution on how to move Sgt. Moore's thumb, as it moves in a very different way than the other fingers. In the final design, the team formulated a thumb wrap design that would allow for Sgt. Moore to move his thumb to the desired position manually.

Another challenge that the team faced was the guidance of the artificial tendons along the fingers. The original idea consisted of finger rings (*Figure 19*), but these proved to be bulky and interfered with the grasping of different objects. Based on previous research and design ideas, the team created new finger links (*Figure 20)* to hold the shock cord. Fabric guides were also added on the palm side of the fingers to eliminate the finger rings completely. This allowed the device to be more compact and allowed for Sgt. Moore to easily grasp and hold onto objects. This was implemented into the final design (*Figure 21)*. Overall, the team was able to find a solution to all the challenges and created a functional prototype for Sgt. Moore.

Figure 19. Rendering of original finger ring design

Figure 20. Rendering of updated finger link design

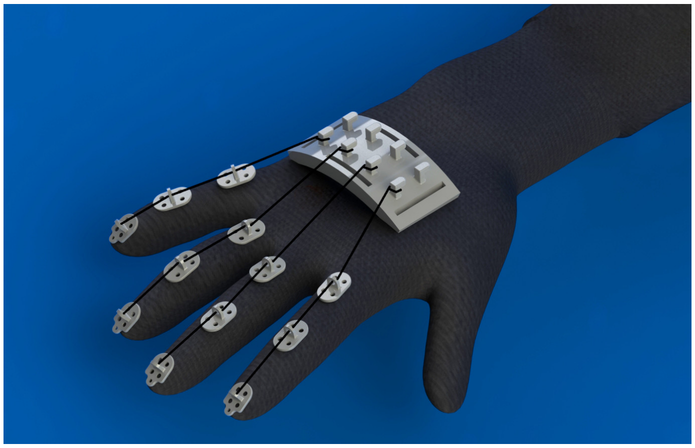


Figure 21. Rendering of the final successful design

Next Steps & Conclusion

In order to maintain the device for years to come, the team will include cleaning and maintenance instructions when delivering the final product to Sgt. Moore. To improve this project, a primary next step would be to implement some body movement to control the BOA dial. This could be done by using some electromyography (EMG) sensors that interact with either the brain or body muscle signals to adjust the BOA dial tension autonomously. These design improvements would make it easier and less time-consuming to adjust the BOA dial tension, as Sgt. Moore would not be required to use his left hand to turn the dial.

This project allowed the team to learn various aspects of engineering and see how engineers can make a lasting impact on someone's life. Through many different iterations and hours, the team engineered a Roboto Glove that they are proud to give to Sgt. Moore to be used in his daily activities.

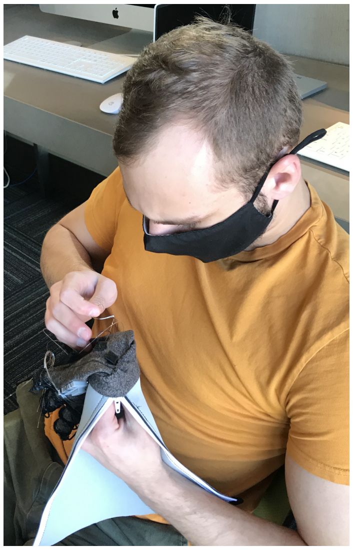


Figure 22. Hand sewing components to the second prototype

Acknowledgements

The team would like to express gratitude to Scott Huyvaert and Sgt. Moore from QL+ for their unlimited support and guidance throughout the project. They would also like to extend their thanks to Daniel Feeney and Brett Valdika from BOA for sponsoring our project and providing guidance throughout the process. The team appreciates the support and feedback from their director Dr. Alaa Ahmed. The team would also like to thank Jayne Schembri from Exclusively Handmade for designing a custom thumb wrap and shipping it internationally to the team. Finally, the team would like to thank Design Center Colorado for their support and resources throughout the academic year.

About the Team

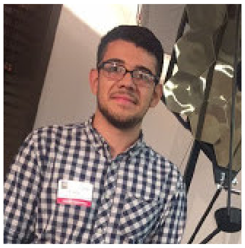
Jenna Zwaanstra (Project Manager): I was born and raised in Colorado. I will graduate this May with a Bachelor's Degree in Mechanical Engineering, a minor in Engineering Management, and a certificate in Engineering Leadership. I am interested in the manufacturing and quality side of engineering and want to learn more about the biomedical application of engineering. Outside of school, I enjoy being outside, hiking, working out, and camping. My goal is to climb all 58 14ers (mountain peaks exceeding 14,000 feet) in Colorado.

Mohammed Alrashed (Logistics Manager): I was born in Saudi Arabia. I will graduate this May with a Bachelor's Degree in Mechanical Engineering. I am interested in the engineering project management and leadership side of engineering and want to learn more about managing and leading big oil and gas engineering projects. Outside of school, I enjoy being outside, playing soccer, mountain biking, and hiking.

Evan Brown (Finance Manager): I was born in Seattle, Washington, and I moved to Colorado to attend the University of Colorado Boulder. In May I will graduate with a Bachelor's Degree in Mechanical engineering and a minor in Business Analytics. I am interested in the sales side of engineering and want to learn how to sell an engineering product. Outside of school, I enjoy being outside, more specifically, skiing, golfing, and working out.

Saioa Lostra (CAD Engineer): I am from Portland, Oregon, and I moved to Colorado to attend CU Boulder in 2017. I will be graduating this Spring with a Bachelor's Degree in Mechanical Engineering. I am interested in both the aircraft industry and the biomedical industry within mechanical engineering and hope to pursue either of those industries after graduation. Outside of school, my hobbies include hiking, skiing, camping, and playing ultimate frisbee.

Tim Farver (Manufacturing Engineer): I was born in Flint, Michigan, and raised in beautiful Colorado, where I have been attending CU Boulder since 2018. This year, I will be graduating with a Bachelor's Degree in Mechanical Engineering and a minor in Engineering Management. I'm interested in the R&D side of engineering, with a special interest in the biomedical field. My passions include climbing, hiking, backpacking, and DIY projects.



Edgar Palma (Systems and Test Engineer): I was born in California but I was raised in Colorado. I will be graduating with a Bachelor's Degree in Mechanical Engineering this upcoming May. I am interested in the Aerospace, more specifically spacecraft, side of engineering and I would love to work in the industry after graduation. Some of my hobbies and interests include soccer, hiking, and watching all different genres of movies.