Robotic Ankle Exoskeleton

Finalized Testing Plan

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1 Design Requirement Summary

One of the customer requirements that we were given is that the ankle exoskeleton needs to be lightweight. Because the primary users of this product will be people between the ages of 8-16 with cerebral palsy. So having a heavy exoskeleton will be very advantageous for the user. The second requirement is that it needs to be ergonomically. Having a human-centered design will allow the user to easily put on and remove our product. The third requirement is it needs to be durable. Meaning that our design needs to be able to last for multiple uses. The fourth requirement is that our product needs to be economical. So, we need to keep our costs for the product as low as possible without compromising on the quality. The second to last requirement is that our design needs to be low profile. So that our product doesn't unnecessarily protrude from the ankle or cause a hinderance to the user during their daily life. The last customer requirement is that the actuating system for our exoskeleton must use a chain to pulley system.

There is a lot of creative room for the engineers on this project. Considering that biomechanics is a newer advancement, there are not many designs to reference. Because of this, we are working off of the previous team's progress and fixing aspects of that design. Through trial and error, Doctor Lerner has directed us to reposition the motor house onto the calf cuff and feed our pulley cables through the supporting bracket. This requirement doesn't necessarily have a quantitative result, but it is a requirement for our design.

Customer requirements

During our client meetings with Lerner, we discussed some of his requirements which he believes. our product should meet. These customer requirements are listed below.

CR1 - Lightweight
CR2 - Ergonomic- Human Centered Design
CR3 - Durable
CR4 - Economical or Cost Effective
CR5 - Low profile- nonobtrusive to daily life
CR6 - Have a chain to pulley system

Engineering requirements

The following deliverables are our constraints moving forward:

ER1 - $3,800.00 budget
ER2 - Range of motion should be 45 degrees in either direction (resting is 90)
ER3 - Weight < 1 kg per leg
ER4 - Cannot extrude from the body more than 10 cm
ER5 - Lifetime of 100,000 steps
ER6 - Time to take on/off (<60 s)

2 Top Level Testing Summary

Table 1 shows the different experiments and tests to be conducted to satisfy the respective customer and engineering requirements.

Table 1: Test Summary Table

Experiment/Test	Relevant Design Requirements
Ex1 – Weight	CR1, ER3
Ex2 – Range of Motion	CR2, ER2
Ex3 – Measurement Test	CR2, CR5, ER4
Ex4 – Cost Analysis	CR4, ER1
Ex5 – Walking/Durability Test	CR3, CR6, ER5
Ex6 – Time Test	CR2, ER6

3 Detailed Testing Plan

3.1 Weight Test

One exoskeleton leg must weigh less than 1,000 grams. The team will utilize a scale that can withstand at least 1,500 grams, level, and timer. To complete the test, one leg will be placed on the scale for at least 30 seconds and repeated a minimum of four times to ensure the reading is accurate. The mechanical portions of the design will be isolated as the electronic components are not within the team's overall project scope.

Specific Procedural Steps:

1. Using a level, place it on the surface where testing will occur, ensure the surface is level, if not level, adjust surface until level
2. Place the scale on the leveled surface
3. Turn on scale and tare to ensure it scale reading is zero
4. Place the constructed mechanical components on the scale
5. Set a timer for 30 seconds
6. Record the weight in grams
7. Repeat steps 3-6 a total of four times

Using the weight analysis function within SOLIDWORKS, it is anticipated that one singular leg will weigh about 808.85 grams.

3.2 Range of Motion Test

Since the exoskeleton is used to adjust the gait cycle, there needs to be at least 45 degrees in either direction on a flat walking surface. To measure the 45-degree angle, the team will use a protractor. A level will be used to ensure the ground is flat. The protractor will be placed in line with the shoulder screw parallel to the ground, then a team member will adjust the carbon fiber tubing accordingly. To ensure only the range of motion is tested, the footplate will be affixed to the ground and the carbon fiber tubing itself will be adjusted.

Specific Procedural Steps:

1. Using a level, place it on the surface where testing will occur, ensure the surface is level, if not level, adjust surface until level
2. Place the footplate on the leveled ground
3. Have one team member hold footplate to ensure the device does not leave the ground
4. Have another teammate adjust the rest of the exoskeleton until it will no longer move
5. Have the remaining teammate measure the angle using a protractor, protractor can be placed on level to ensure it is parallel to the ground
6. Record the measured angle
7. Adjust the upright in the other direction until it will no longer move
8. Repeat steps 5 and 6

Using the measuring tools within SOLIDWORKS, it is anticipated that the exoskeleton has at least a 128.54-degree range of motion.

3.3 Measurement Test

The exoskeleton needs to be close to the user's leg, it should not exceed 10 centimeters from the body. A measuring tape will be used. The measurement will be from a touch point on the calf to the outer most item on the exoskeleton. The team will measure multiple points across the leg to ensure all items do not exceed the requirement.

Specific Procedural Steps:

1. Have one teammate put on the exoskeleton
2. Using a measuring tape, measure the distance from where the exoskeleton touches the leg to the outer most protruding item
3. Record that measurement
4. Repeat steps 1 and 2 in various locations to ensure the first measurement was the largest

Using the measurement tools within SOLIDWORKS, the exoskeleton is anticipated to be 4.95 centimeters.

3.4 Cost Analysis

To ensure that one exoskeleton leg costs less than $1,900, the team will perform a cost analysis utilizing the bill of materials. Based on current purchases, the entire budget was used, therefore it is anticipated that the cost of one leg will be within the $1,900 cost.

3.5 Walking/Durability Test

To test the durability of the exoskeleton, a treadmill will be used, and the user will put on the exoskeleton and walk on it for 10 minutes. The NAU Biomechatronics lab is preforming this test specifically and no other information was provided about the test to be preformed.

Specific Procedural Steps:

1. Prep the treadmill and make sure all settings are set to the correct values
2. Have the user put on the fully assembled exoskeleton leg with both mechanical and electrical components
3. Double check that exoskeleton turns on and functions
4. Have user step onto treadmill and prepare to begin testing
5. Set a timer for 10 minutes and have the user walk on the treadmill at comfortable walking speed for the user
6. After the test, record any changes or deformations to the device
7. Record any additional data that may be collected (specific data recorded will be determined by the NAU Biomechatronics Lab)

It is anticipated that the exoskeleton leg will withstand the 10 minute walk test with minor deformations.

With the walk test only being 10 minutes, this will not be a full test to determine if the leg can withstand the minimum of 100,000 steps. Therefore, in addition to the walk test, the team will preform a fatigue test on the device utilizing the fatigue analysis feature within SOILDWORKS. The software will be used to determine how many cycles the device can go through and to make an educated determination if it satisfies the customer requirement.

3.6 Time Test

The user of the exoskeleton should be able to remove and put on one exoskeleton leg in less than 60 seconds while sitting. To perform the test a stopwatch will be used, each team member will place on the exoskeleton and be timed three times. The average of each group will be averaged for an overall time.

Most users of this device will have varying limitations; therefore, the team will try their best to simulate these limitations such as; restricting use of the knee.

Specific Procedural Steps:

1. With one teammate holding the stopwatch, have another prep to put on exoskeleton
2. Once all members are ready, hit start on the stopwatch while the person puts on the leg
3. Stop the timer when all straps and additional items are put on and ready to be used

4. Record the time
5. Have the user repeat steps 2-4 an additional two times
6. Repeat steps 1-5 for all teammates to get a total of 12 times

Since the team has not had a completed assembly yet, there is no reference as to how long it will take.

3.7 Results

Based on the initial modelling of the system within Solidworks, the 2024 exoskeleton design is expected to meet all specified engineering and customer requirements. These specifications include a mobility range of 45 degrees up and down, total weight of 1kg or less, extrude no more than 10cm from the body, and can quickly be taken on and off (<60s). The system is also expected to withstand all applied loads based on the factors of safety produced from stress and strain simulations within Solidworks. The main components that are under the most stress are the bracket, screws, pulley and cable. After modelling the system, the following factors of safety were calculated, proving that the system will not fail under the applied loads:

Subsystem	Part	Load Case Scenario	Material	Minimum FOS
Subsystem 1				
	1 (Bracket)	Maximunm toque output being produced from the motor being applied to all the shaft attachment point	Al 7075	1.5
	2 (Screw)	All the forces in the Y-direction generated from the motor being placed on a single attachment screw	Zinc Coated Steel	19.26
	3 (Sprocket)	Motor is functioning at full capacity and the the sprocket is pulling the chain with maximum force	Steel	1.3
Subsystem 2				
	1 (Cable)	The torque being produced by the cable is greater than the minimum torque necessary to help the average person walk	stainless steel	1.03

4 Specification Sheet Preparation

Tables 2 and 3 are the specification sheet preparations.

Table 2: Customer Requirement Summary Table

Customer Requirements	CR met? (✓ or X)	Client Acceptable (✓ or X)
CR1-LightWeight		
CR2-Ergonomical-Human Centered Design		
CR3-Durable		
CR4-Economical or Cost		

Effective		
CR5-Low Profile-Nonobtrusive to daily life		
CR6- Have a Chain to Pulley system		

Table 3: Engineering Requirement Summary Table

Engineering Requirement	Target	Tolerance	Measured/Calculated Value	ER met? (✓ or X)	Client Acceptable (✓ or X)
ER1-Low cost	\$3,800	$\pm$ \$10			
ER2- Range of Motion	$\pm 45°$	$\geq \pm 45°$			
ER3-Weight	$< 1kg$	$\pm 5\ g$			
ER4- Dimesnions	Extrude $<$ $10cm$	$\pm 5\ mm$			
ER5- Lifetime	100,000 Steps	$\pm 100\ steps$			
ER6- User Friendly	Time to take on/off $< 60s$	$\pm$ 5 seconds			

5 QFD

The tests that will be conducted to answer our ERs are directly correlated with the CR's that were given to us at the beginning of the projects. The first test is to ensure that our design's weight is under 1 kg, it ensures it is lightweight, which meets CR1. Then our second tested ER which is range of motion is to ensure that it is a close to possible to the range of motion of the human foot which ensures our design is ergonomical meeting CR2. Our next tested ER is making sure that our bracket does not protrude from the leg greater than 10 cm. This test makes sure that our design is ergonomic (CR2) and not obtrusive to the user's daily life (CR5), since the longer the devices is the harder it is to wear and use. The next tested ER is making sure that our device costs less than \$1,900 per leg, which would meet the CR of the device being economical and cost effective. The second to last tested ER is that our device has a life of 100,000 steps. This will make sure that our device is durable enough for daily use (CR3) and ensure that the chain and pulley system that our customer requires works properly. Then our last test, which will test ER6, will make sure that the device that we create is ergonomical and not awkward or a hassle to put on. All these engineering requirements are directly connected to the customer requirements given by our clients, which ensures there is a purpose behind each test conducted.