Finalized Testing Plan

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P11 Robotic Arm Exoskeleton

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Design Requirements Summary:

The Robotic Arm Exoskeleton project has been tasked by Dr. Zachary Lerner to design and test a robotic arm exoskeleton that is able to assist the user with pull-ups. The overall goal of the project is for the team to engineer an exoskeleton that increases the number of pull-ups an individual can perform by 15%. The design specifications as outlined by the client are very minimal. Since this project is a new branch of study in Dr. Lerner's Biomechatronic's lab he is not as worried about engineering a sleek, highly efficient device rather he has instructed the team to focus on engineering a functional exoskeleton that can accomplish the project goal. The customer requirements are that the design must:

- CR 1: Be cable actuated
- CR 2: Use a pulley to create torque
- CR 3: Be low profile
- CR 4: Be lightweight
- CR 5: Operate independently of stationary machinery
- CR 6: Assist the user in a pull-up motion

As the team discussed these design requirements with the client the following engineering requirements were then created to establish qualitative and quantitative goals:

- ER 1: The design will use Bowden cable actuation
- ER 2: Will utilize Dr. Lerner's previous pulley design
- ER 3: Will protrude less than 10cm (about 3.94 in) from the user's body
- ER 4: Will weigh less than 6 pounds total
- ER 5: Will operate only from the user's body
- ER 6: Will increase the number of pull-ups a user can perform by 15%-20%

Testing Summary:

Table 1: Testing Summary Table

Test Name	Relevant DRs
Cable Actuation	ER1
Pulley Utilization	CR1, ER2
Protrusion Limit	CR3, ER3
Weight Limit	CR4, ER4
User Operation	CR5
Pull-up Test	CR3, CR4, ER6

Detailed Testing Plans:

Cable Actuation –

Summary:

This simple test is a physical demonstration that the engineered device incorporates cables into the design to actuate the pulley. No test subject is required but the fully constructed device is required to be present. This test will be answered with a simple yes or no as to whether the device uses Bowden cables and whether the device is functional based on the actuation of the Bowden cables.

Procedure:

1) Present the fully constructed exoskeleton device
2) Decide, as a team, whether Bowden cables were used in the design
3) Power on the device and evaluate, as a team, if the pulley rotates due to the tension and compression of the cable system
4) Conclude test

Results:

The team knows this test will be fulfilled because Bowden cables have been the only cable system considered while designing this project. The custom motor sprocket and chain system will connect to the cable at one end and will be looped through the pulley and back to the other ender of the chain creating a connection between the pulley and motor through Bowden cables. When the motor is powered the device will definitely create tension and compression in the cables enacting a moment about the pulley and making the device functional.

Pulley Utilization –

Summary:

This test is nearly identical to the Cable Actuation test. This test will require the same, fully constructed robotic exoskeleton and will be evaluated by the team whether or not the device used a pulley in its design. There are no variables being tested besides the yes or no evaluation of the device including Dr. Lerner's pulley.

Procedure:

1) Present the fully constructed exoskeleton device
2) Decide, as a team, whether Dr. Lerner's pulley design was incorporated into the device
3) Conclude test

Results:

The team expects this test to be successful since the final design being tested does already have a pulley on it. Dr. Lerner's pulley design was altered to fit the specifications of the design so it is not the original pulley design that could have been used but this does not necessarily trump the main purpose of this test which is to evaluate if the device uses a pulley or doesn't.

Protrusion Limit –

Summary:

The protrusion test is a quantitative test where the team will be measuring the protrusion of the biggest components of the device. This evaluates customer requirement 3 which is that the device needs to be low profile. The team will be testing against engineering requirement 3 which specifies that the device must protrude less than 10 cm from the user's body. This test requires a test subject, the fully constructed device, and a tape measurer. The team will only measure protrusion in the X or Y plane and will not be measuring at an angle from the test subject's body.

Procedure:

1) Make sure all components of the device are attached and secure
2) Place the device onto a test subject
3) Use a tape measurer to document how many centimeters extruding parts of the device protrude off the user
4) Compile all data into a table and evaluate if it meets or exceeds the engineering requirement

Results:

The team expects all components of the design to meet engineering requirement 4. The design process always included minimally sized components to ensure that the ability to protrude over 10 cm would never be met. If the design protrudes less than 10 centimeters from the test subject's body, then the design requirement and client acceptance will be marked as "Met". In the final presentation, the devices low-profile characteristics will be highlighted as a major achievement for this exoskeleton project.

weighs 6 pounds or less lightweight and

Weight Limit –

Summary:

The weight limit test requires only the fully constructed device and a scale to measure the total weight of the device. This determines if engineering requirement 4 is met which is one of the more important aspects to the project. A tolerance of 0 is set for this test since the team's design incorporates only a 1-arm exoskeleton and does not utilize both arms.

Procedure:

1) Make sure all components of the device are attached and secure
2) Place the device onto the scale
3) Record the number displayed by the scale in pounds
4) Reset the scale and conduct 2 more times
5) Conclude test

Results:

The team is unsure of the expected results from this test however the device does feel close to the 6-pound limit set by the client. Each member of the team has held, and some members have worn the device, and although it does not feel uncomfortably heavy the weight of the device is noticeable. If this engineering requirement is met (<6lbs.) then the team will highlight its lightweight characteristics during the final presentation as a major accomplishment of the project.

User Operation –

Summary:

This test is a simple visual test demonstrating whether the device can be operated entirely from the test subject, or if the device needs the assistance of stationary machinery to operate it. This would include a large stationary battery to supply power to the motor, or a specific test area in which the loose cables or components will be held up by some other device. This test will evaluate customer requirement 5 and will only require a test subject and the fully constructed device.

Procedure:

1) Place the device onto the test subject
2) Visually evaluate, as a team, whether the test subject is able to power the device by themselves and utilize its functionality
3) Document evaluation and conclude test

Results:

The customer requirement that this test evaluates is a prominent design requirement which is also affected by the devices lightweight and low-profile characteristics. The team knows that the device was constructed to hold all power systems and batteries on the user’s body which enables the device to be independently operated by the user. The team expects this test to pass with no chance of failure.

Pull-up Test –

Summary:

This is the most important test for this project. This test evaluates the amount of assistance supplied from the motor to the user’s shoulder complex while performing pull-ups. The test subject for this test will be measuring the amount of unassisted and assisted pull-ups that they are able to complete while wearing the device. It is difficult to exclude variables such as personal strength and body weight, but the team’s test subject will be an individual who meets most male geometry averages. This means the test subject will be about 170 pounds in weight, will be roughly 5’10’’ to 6’ tall, and will possess the ability to perform some pull-ups but no more than 10.

Procedure:

1) Place the exoskeleton device onto the test subject
2) Allow the test subject to perform as many pull-ups as possible (unassisted) and record the number
3) Allow 5 to 10 minutes of rest time so that the test subject can complete another set of pull-ups with rejuvenated endurance
4) Power on the device and allow the test subject to perform as many pull-ups as possible (assisted) and record the number
5) Conduct this test 3 times in total and collect all data into one spreadsheet
6) Analyze the results and calculate if there was a 15% increase in pull-ups performed between the assisted and unassisted repetitions.

Results:

The team is strictly measuring the number of pull-ups an individual can perform while assisted and unassisted. The expected result is that the test subject will be able to perform more pull-ups while assisted by the device than when they aren't assisted. This will be calculated by taking the percent difference between the two measured values. Equation 1 will be used for this calculation.

$$I = \frac{P_A - P_{UA}}{P_{UA}} \times 100$$

Equation 1

I: The total increase as a percentage

P_A: Number of completed assisted pull-ups

P_{UA}: Number of completed unassisted pull-ups

Conclusion:

If the device does increase the number of pull-ups that the test subject was able to complete then the project will be deemed a success, and the team will be able to discuss the results of why the torque actuated on the pulley is sufficient for assisting the user's shoulder complex.

Specification Sheet Preparation:

Table 2: CR Summary Table

Customer Requirement	CR Met? (Yes or No)	Client Acceptable (Yes or No)
ER1 – Cable Actuated System	Yes	TBD
ER2 – Uses Previous Pulley Design	Yes	TBD

ER3 – Low-Profile	TBD	TBD
ER4 – Lightweight	TBD	TBD
ER5 – Operate Independently	Yes	TBD
ER6 – Assist During Pull-up Motion	TBD	TBD

Table 3: ER Summary Table

Engineering Requirement	Target	Tolerance	Measured Value	ER Met? (Yes or No)	Client Acceptable (Yes or No)
ER1 – Bowden Cable Actuation	N/A	N/A	N/A	Yes	TBD
ER2 – Previous Pulley Design	N/A	N/A	N/A	Yes	TBD

ER3 – Operate from Users Body	N/A	N/A	N/A	Yes	TBD
ER4 – Protrude < 10cm	10 cm	+ 2.5 cm	TBD	TBD	TBD
ER5 – Weigh < 6 lbs.	6 lbs.	+ 2 lb.	TBD	TBD	TBD
ER6 – Increase	15% Increase	+ 5%	TBD	TBD	TBD

QFD:

The team has updated the customer and engineering requirements since the beginning of the project. The client was able to specify for the team that the design should use his pulley design, as well as that the design will measure the pull-up assistance by calculating the difference between assisted and unassisted pull-ups. The team has since dropped the “Safety” and “Stability” customer requirement and have further defined the “Portable” requirement to be CR5. Figure 1 is a copy of the team’s initial quality functional deployment. The weight of each customer requirement remains as well as the relationship between each customer and engineering requirement. As stated at the beginning of this report, the team is presenting to the client a robotic exoskeleton that is lightweight, low-profile, cable actuated, independently operable, utilizes a pulley, and ultimately offers assistance to a user when performing a pull-up.

		Technical Requirements						
Customer Needs	Customer Weights	Increase mobility	Decrease total load on arm and shoulder muscle	DC Motor actuation	Increase shoulder and back stability	Implement a failsafe mechanism	Increase everyday quality of life	Cable driven system
Lightweight	5	9	3	1			9	3
Portable	3	3					9	3
Low Profile	5	9		3	1	1	3	9
Comfort	3	1			1		9	
Safety	4			3		9	3	3
Stability	4		3	1	9		1	3

Figure 1: Initial QFD