Robotic Ankle Exoskeleton

Diego Avila, Emma De Korte, Tre Green

NAU NORTHERN ARIZONA UNIVERSITY

Project Description

- Partnered with Dr. Lerner and NAU's Biomechatronics Lab to design a lower extremity exoskeleton that aids the motion of walking.
- Budget $3800.00, team-fund $380
- Reduce metabolic power, increase ankle torque
- Designed for people with Cerebral Palsy and similar disabilities
- previous trial "did not observe a significant group level benefit relative to walking without the device. However, [they] did observe a marked benefit for [their] more impaired participants"[1]
- We have reiterated parts of their design (footplate, calf cuff, rod)
- Design A cover for the chain to pulley system
- Some differences (bracket, chain to cable, pulley)
- Focus was on the mechanical structure: how would the components interact (cable-rod, pulley-rod, bracket-rod cut outs)

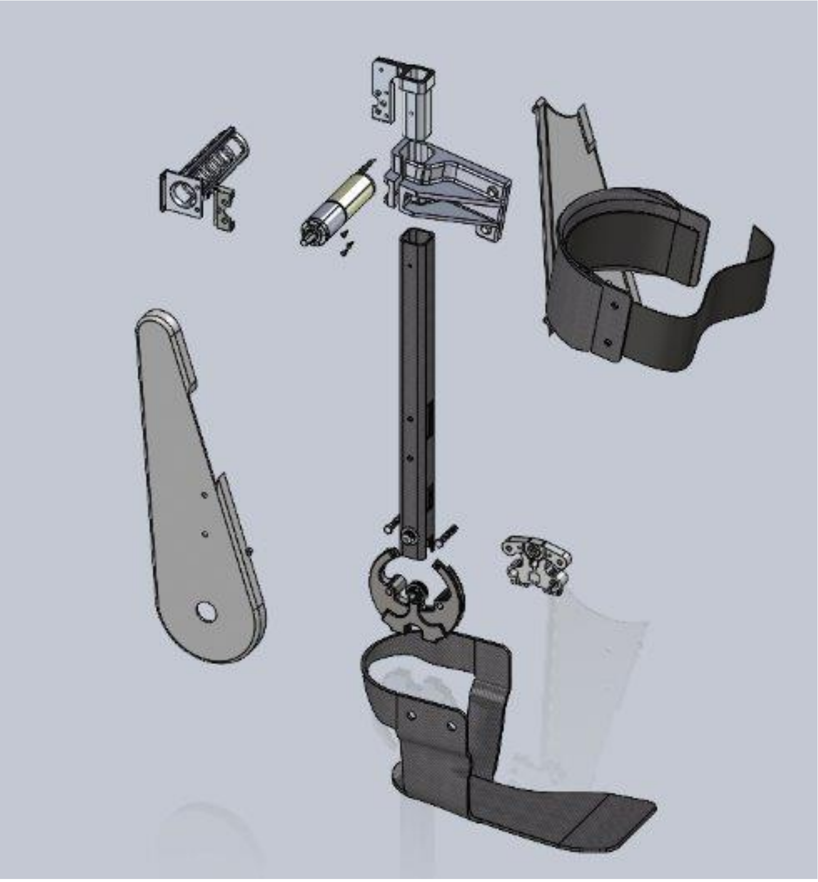


Figure 1: Exploded View of Design

Project Description

Deliverables

- Create design concepts
- Develop SOLIDWORKS CAD model
- Design mechanical components
- Fabricate/machine parts
- Assemble the ankle exoskeleton prototype
- Reiterate previous bracket design
- Design a chain/pulley cover

Success Metrics

- Budget
- Parts mesh without interference
- Lightweight
- Ease of use
- Complete exoskeleton
- Size is unobtrusive to daily life

Design Requirements

Customer Requirements

- **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

- **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)

QFD

		Decrease Weight	Increase Durability	Decrease Timing	Decrease Cost of Each Leg
1	Decrease Weight				
2	Increase Durability	-			
3	Decrease Timing	0	-		
4	Decrease Cost of Each Leg	+	-	+	
5	Decrease Protrusion From Body	++	0	0	0

	Customer Needs	Customer Weights	Technical Requirements: Decrease Weight	Increase Durability	Decrease Timing	Decrease Cost of Each Leg	Decrease Protrusion from Body
1	Lightweight	3	5	3	3	3	3
2	Easy to take on and off	4	3	1	5	3	3
3	Durable	4	2	5	1	2	1
4	Cost Effective	5	4	4	1	5	1
5	Small in size, close to body	3	5	2	3	2	5
	Technical Requirement Units		kg	steps	min	dollars	cm
	Technical Requirement Targets		<1	100,000	<1	<2000	<10
	Absolute Technical Importance		19	15	13	15	13
	Relative Technical Importance		1	2	3	2	3

Figure 2: House of quality for ankle exoskeleton

Benchmarking

Figure 3: Fully Active Chain and Sprocket Ankle Exoskeleton for Rehabilitation Assistance

Figure 4: Robotic ankle exoskeleton by H3

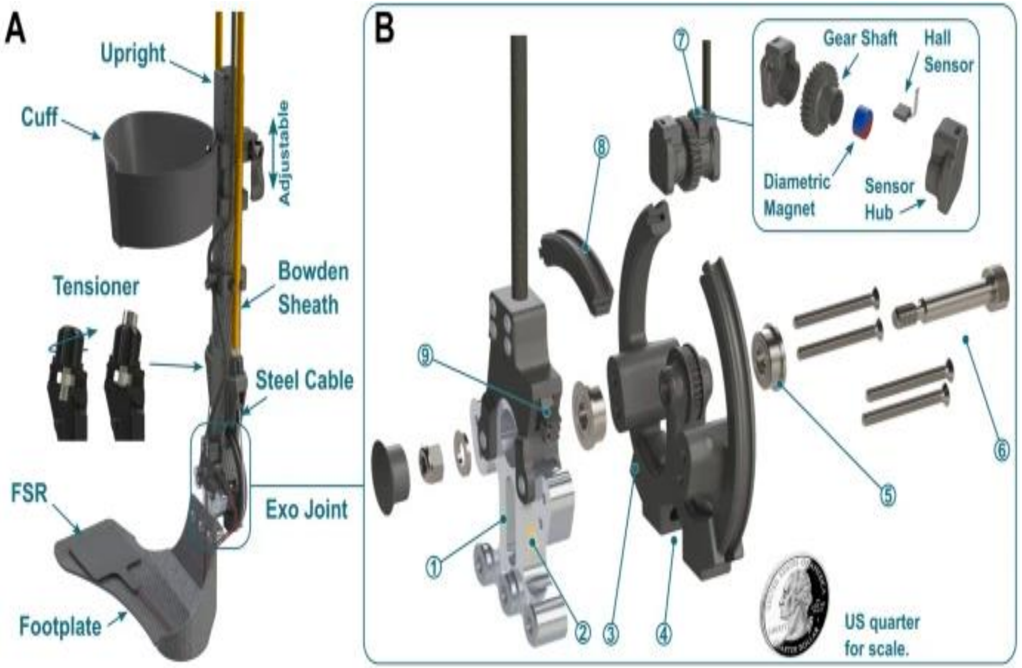


Figure 5: Ultra-lightweight and versatile untethered robotic ankle exoskeleton

Literature Review

Literature Review: Avila	Literature Review: De Korte	Literature Review: Green
• SHIGLEY'S MECHANICAL ENGINEERING DESIGN [2] • Gear Train: Gear Ratios, Torque, and Speed Calculations [3] • Fundamentals of modern manufacturing: materials, processes, and systems [4] • Usability and performance validation of an ultra-lightweight and versatile untethered robotic ankle exoskeleton [5] • Functioning 'mechanical gears' seen in nature for the first time [6]	• Mechanics of Materials [17] • Materials Science and Engineering: An Introduction [18] • Design Optimization [14] • Design of a Passive Gait-Based Ankle-Foot Exoskeleton [15] • Untethered Robotic Ankle Exoskeleton [16] • Material Selections [19]-[30]	• Engineering mechanics: Dynamics. [7] • Biomechanics of Movement: The Science of Sports, Robotics, and Rehabilitation. [8] • Biomechanics of the ankle [9] • Foot Biomechanics During Walking and Running[10] • A REVIEW OF GAIT CYCLE AND ITS PARAMETERS [11] • "What Is Cerebral Palsy?" [12] • "Biomechanical and Perceived Differences between Overground and Treadmill Walking in Children with Cerebral Palsy [13]

Mathematical Modeling

Cross Section Choice

$$T = F * r$$

Torque is produced from a force acting perpendicular to a body at a specified length

$$I = \frac{1}{2} M * r^2$$

Moment of inertia for a solid rod

$$I = \frac{1}{2} M(r_1^2 + r_2^2)$$

Moment of inertia for a hollow rod

Comparison of inertias revealed that a hollow tube has a higher strength: weight ratio than a solid rod, and would be able to handle torque better

Stress Experienced in the Bracket

- Max Torque Generated during walking test 36 NM
- Diameter of the pulley (.08m) sprocket (.01m)
- Found the Gear Ratio D_{out}/D_{in}
- Found the torque at the Sprocket
- Force acting on the Bracket (880 N)

$$\frac{\tau_{out}}{\tau_{in}} = Gear\ Ratio$$

$$F = \frac{\tau}{R}$$

Bolt/Rivet or Epoxy

- $F_y = 880Nsin(45º) = 748.8N$
- Factory of Safety (FoS) = 2
- Using trial and error
- Bolt $d = 9mm$
- Shearing force of bolt = $11.75 \frac{N}{mm^2}$
- Ultimate allowable stress of aluminum is $155\ N/mm^2$
- Epoxy Shear strength = 6.89-137 MPa

Mathematical Modeling – Material Selection

Sprocket

Gear teeth bending stress (Lewis Equation):

$$\sigma_t = \frac{W_t P_d}{FY}$$

Diametral Pitch:

$$Dp = \frac{Teeth}{Pitch}$$

Tangential Load:

$$W_t = \frac{2T}{Dp}$$

Variables:

- Pd = Diametral Pitch= 3.75mm
- T = Torque= 36 NM
- Teeth = 30
- F = Face Width = 11mm from chain width
- Y = Lewis Factor

Gear

- Using the Lewis equation, the tooth bending stress = 828 Mpa
- The allowable stress for various materials
  - Steel=840 MPA
  - PLA= 37 MPA
  - Aluminum= 290 MPA
- Steel can be used for the sprocket material

Bracket

Aluminum 6061-T6 is the best material to use in this application

Table 1: Table of the various materials

Material	Hardness, Vickers	Ultimate Tensile	Yield Tensile	Density	Cost
Aluminum 6061-T6	107	310 MPa	276 MPa	2700 kg/m^3	$4.67-$252.94 (depends on thickness)
Low Carbon Steel	131	440 MPa	370 MPa	7850 kg/m^3	$0.55 per kg
Steel 4140	207	655 MPa	415 MPa	7833 kg/m^3	$0.55 per kg
Titanium Grade 5	349	950 MPa	880 MPa	4540 kg/m^3	$50 per kg

Footplate Thickness

- Dr. Lerner will provide a carbon fiber footplate
- Calculate the needed thickness of the footplate

- $\sigma = \frac{F}{A}$
  - $F = force\ exerted\ by\ user$
  - $A = to\ the\ surface\ area\ of\ the\ foot$
  - $\sigma = normal\ stress$
- $t = \sigma\ \frac{L}{S}$
  - $L = length\ of\ footplate$
  - $S = allowable\ stress\ of\ material$

Assuming the user is an average 14-year-old male

Mass: 60 kg

Foot length: 24.45 cm

Foot width: 9.65 cm

S = 3.5 GPA or 3.5*10^9 Pa

$$F = mg\mu \rightarrow \mathrm{F} = (60\mathrm{kg})(0.5)\left(9.81\ \frac{m}{s^2}\right) \rightarrow$$

$$\mathrm{F} = 294\ \mathrm{N}$$

$$\mu = \ 0.5$$

$$(friction\ coefficient\ of\ shoe\ against\ ground)$$

$t = 8.7 * 10^{-4}$ mm

Functional Decomposition

Black Box Model

Figure 6: Black Box model

Functional Decomposition

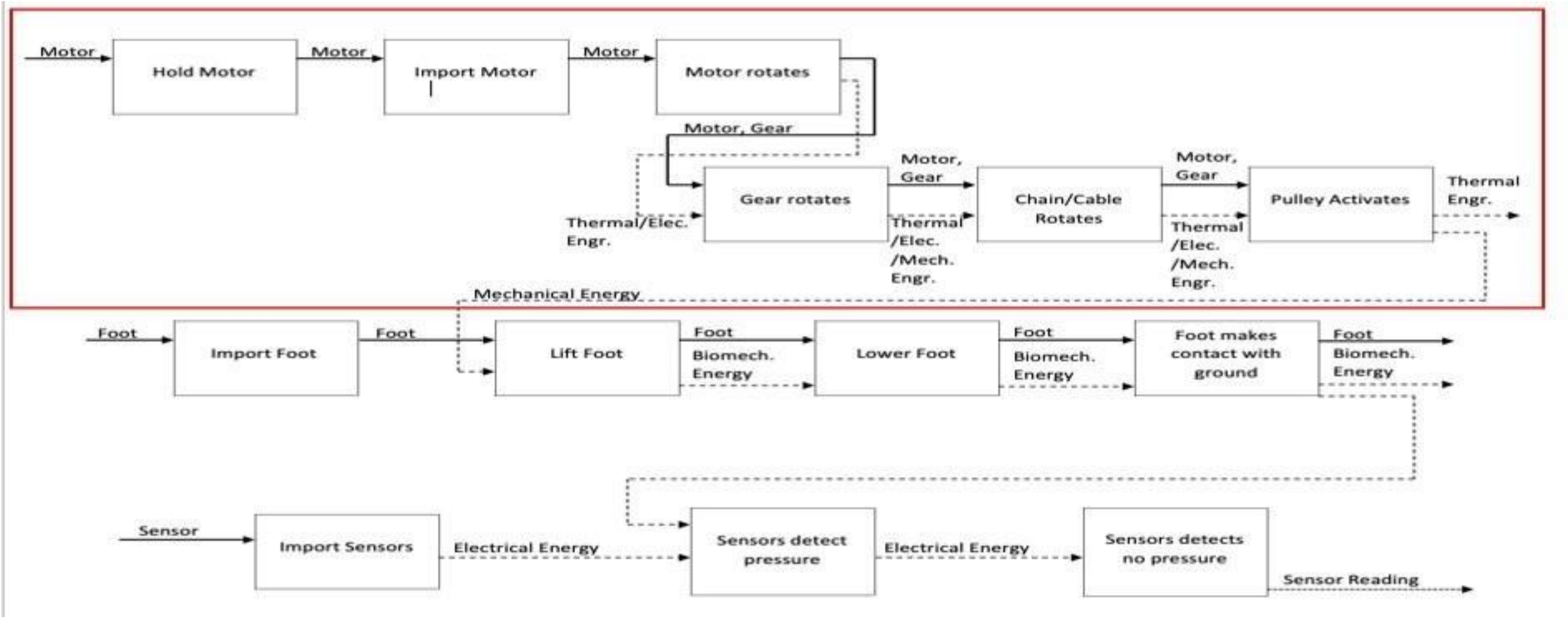


Figure 7: Functional Decomposition

Concept Generation

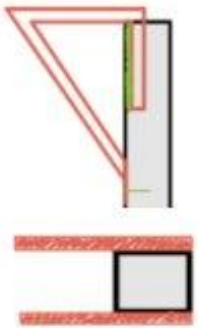
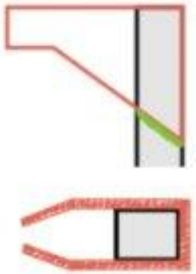
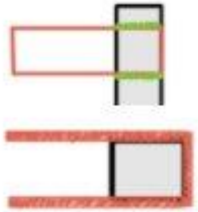
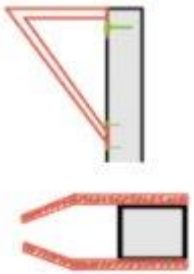
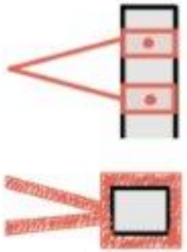
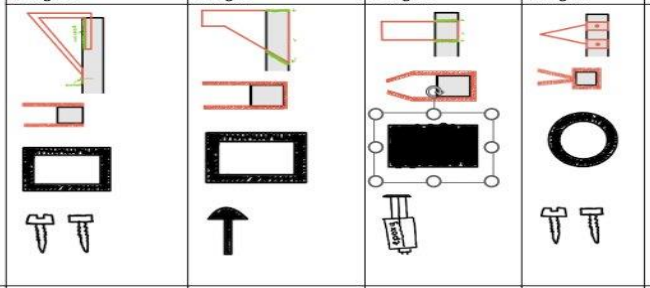
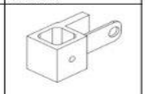
Subsections	1	2	3	4	5
Bracket Shape, A					
Cross Section, B					
How bracket is mounted, C	 Riveting	 Bolt/screw	 Epoxy		

Figure 8: Morphological design matrix

Concept Selection





Pugh Chart	Design 1	Design 2	Design 3	Design 4	Datum
Lightweight	+	+	S	+	datum
Easy to take on and off	N/A	N/A	N/A	N/A	Datum
Durable	+	+	S	S	Datum
Cost Effective	+	-	S	+	Datum
Small in Size, close to body	S	S	S	S	Datum
$\Sigma+$	#	2	0	2	Datum
$\Sigma-$	1	2	0	0	datum
Σs	1	1	3	2	datum

Figure 9: Pugh Chart

Table 2: Decision Matrix

		Design (1)		Design (4)	
Criteria	Weight	Score (1-10)	Weighted Scor	Score (1-10)	Weighted Score
Light Weight	0.4	9	3.6	8	3.2
Easily taken on and off	0.05	10	0.5	10	0.5
Durable	0.3	8	2.4	9	2.7
Cost effective	0.15	9	1.35	8	1.2
Small in size	0.1	7	0.7	9	0.9
Total	1		8.55		8.5

- Design 1 was rated the highest

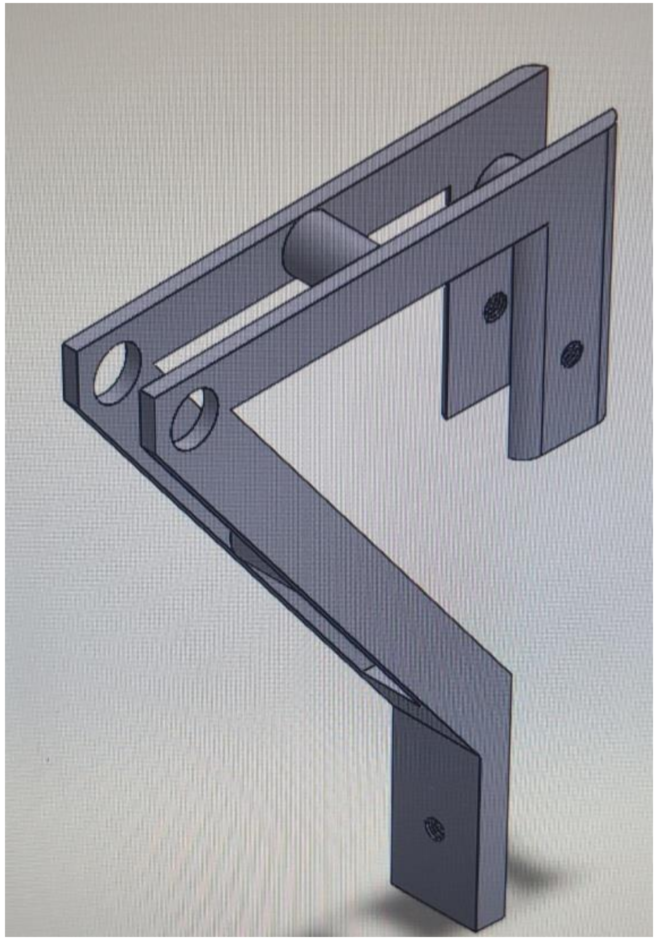


Figure 10: CAD of finalized bracket design

Gantt Chart

ME 476C: Robotic Ankle Exoskeleton

Group Members
Avila, D.; De Korte, E.; Green, T.

Project Lead - Emma De Korte

Project Start: Tue, 1/16/2024

Display Week: 1

TASK	ASSIGNED TO	PROGRESS	START	END	DAYS
Project Management					
Go through and update Gantt Chart	E. De Korte	100%	1/16/24	1/19/24	4
Update BOM	T. Green	100%	1/16/24	1/19/24	4
Revise and Update all sections	D. Avila, E. De Korte, T. Green	100%	1/16/24	1/19/24	4
Engineering Calculations Summary					
Purchase Rod and Get machined	T. Green	100%	1/18/24	1/26/24	9
Task 1: Top Level Design Summary	D. Avila	100%	1/20/24	1/26/24	7
Task 2: Summary of Standards, Codes, and Regulations	D. Avila, E. De Korte, T. Green	100%	1/16/24	1/26/24	11
Task 3: Summarize the Conditions	D. Avila, E. De Korte, T. Green	100%	1/24/24	1/26/24	3
Task 3: State all Equations	D. Avila, E. De Korte, T. Green	100%	1/16/24	1/26/24	11
Task 3: Summarize the Minimum FoS	D. Avila, E. De Korte, T. Green	100%	1/20/24	1/23/24	4
Task 3: State What Changed	D. Avila, E. De Korte, T. Green	100%	1/23/24	1/26/24	4

Figure 11: Snapshot of the Gantt chart used for the entire project

- The team utilized a Gantt chart to stay on track for the entire project

Budget

- Our Budget was $3800, $3785.53 was spent

Table 3: Budget

Item #	Name	Manufacturer	Code	Quantity	Cost	Cost +Ship& Tax
1	800cc Onyx Filament Spool	Markforged	F-MF-0001	1	190	
2	50cc Carbon Fiber CFF Spool	Markforged	CF-BA-50	1	150	409.11
3	LL-Spark Plug Motor Mount Mod1	Protolabs	1471-8919-003	1	500.14	
4	Spark Plug Motor Mount Mod1	Protolabs	1125-8486-002	2	845.44	1483.77
5	Arduino Nano 33 BLE Sense Rev2 with headers	Arduino	ABX00070	1	34.8	
6	Teensy No Ethernet(TEENSY41_NE_PINS)	PJRC	TEENSY41_NE_PINS	1	41.68	
7	TMotor_Rev0_6_Maxon_2024-02-17_Second_REVISION_Y4	JLCPCB	Y4-5457140A	5	9.53	
8	TMotor_Rev0_6_Maxon_2024-02-17_Second_REVISION_Y4	JLCPCB	SMT02402171606419-5457140A	5	47.19	169.63
9	Tube - Square - Fabric - 0.75 X 0.88 X 66 Inch	Rockwest Composites	25484	1	258.2	258.2
10	LL-Spark Plug Motor Mount Mod1	ProtoLabs	1378-3378-002	1	479.11	
11	Spark Plug Motor Mount Mod1	ProtoLabs	1470-5930-002	1	478.13	1064.82
12	Manufacturing of Rod	Hawley Design Works		1	400	400
	Total					3785.53

Self-Funding Budget

Table 4: Self-funded Budget

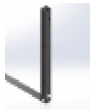
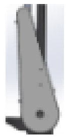
Self-Funding					
Item	Description	Units	Item Number	Vendor	Total Cost $
1	M4-.7 30mm Bolt	2		Home Depot	1.25
2	M4-.7 Hex Nut	4		Home Depot	1.25
3	M4.7 Washer	4		Home Depot	1.25
4	Roller Chain	1 ft X2	6027k91	Mcmaster	18
5	Stainless Steel Ball bearing	2	57155k585	Mcmaster	26.34
6	Stainless Steel Ball bearing 5mm	4	7804k138	Mcmaster	36.8
7	Stainless Steel Shoulder Screw	2	91273A392	Mcmaster	12.62
8	Steel Hex Nuts	100	90592A095	Mcmaster	4.76
9	Phillip Screws	1	92000A015	Mcmaster	7.96
10	Steel Cable 2mm diameter + Clamps	1		Amazon	12
11	PLA Filament	1		Amazon	18
12	Wire Cutters	1		Home Depot	34.98
13	Carbon Fiber Tubing	2		Rockwest composites	142.38
14	M5 x 0.80 mm Thread, 35mm Long	10		Mcmaster carr	10.36
15	M4 x 0.70 mm Thread, 30mm Long	50		Mcmaster carr	16.24
16	M3X30 Screws	2		Home Depot	0.75
17	M3 X 25 mm Screws+ Hex Nuts	50		Amazon	7
18	M2 Screws Assortment Pack	562		Amazon	10
	Shipping+Tax Total			MCMaster	30.46
Total Cost+ Shipping					392.4

- We need to fundraise 10% of our client Budget (380)
- Which was done by self-funding both of our initial prototypes and purchasing some final parts
- We fundraised $392.29

Manufacturing

- For this device we only needed to Manufacture 4 Parts

Table 5: Bill of Materials (Manufactured)

	Current Bill of Materials (Manufactured)											Lead Times	
	Part	Number in Category	Manufactor/Source	Quantity Needed	Cost Per Unit	Quantity Purchased	Item Number	Link	How it will be aquired	Part Status	Who will Manufacture	Start Date	End Date
	Spark Plug Motor Mount Mod1	1	ProtoLabs	1	$479.11	2.00	1125-8486-002	Link	Manufactured	Manufactured	ProtoLabs	5-Feb	9-Feb
	3" Pulley (Most likely 3D printed)	2	Lerners Lab	1					Manufactured	Manufactured	Lerners Lab	Unknown	Unkown
	Carbon Fiber Tubing	3	Rockwests-composites	1	$215.00	1	25484	Link	Manufactured	Manufactured	Hawley Design Works	Unknown	27-Mar
	Cable Cover	4	Personally	1		1			Manufactured	Manufactured	Self Manufactured	26-Mar	27-Mar

Purchasing

Table 5: Bill of Materials (Purchased)

Current Bill of Materials											
Part	Number in Category	Manufactor/Source	Quantity	Cost Per Unit	Quantity Needed	Cost per Unit needed	Quantity of Unit purchased	Item Number	Link	How it will be aquired	Part Status
Footplate	1	Provided by Lerner	1	-	1		Provided			Provided	Aquired
Torque Sensors	2	Provided by Lerner	1	-	1		Provided			Provided	Aquired
M2 X 6 Screws	3	Amazon	120	$9.98	3	0.1	1		Link	Purchased	Aquired
Chain (1ft, 05B, 8mm Pitch)	4	McMaster-Carr	1	$9.00	1.00	9.00	2.00	6027k91	Link	Purchased	Aquired
M3 X 30 Screws	5	Home Depot		$0.75	2.00	0.75	1.00	1008004730	Link	Purchased	Aquired
M3 Nuts		Amazon	40	$6.38	3.00		1.00		Link	Purchased	Aquired
Stainless Steel Ball bearing 5mm	6	Mcmaster-Carr	1	$9.20	4	36.8	4	7804k138	Link	Purchased	Aquired
Stainless Steel Shoulder Screw	7	Mcmaster-Carr	1	$6.31	1	6.31	2	91273A392	Link	Purchased	Aquired
Steel Hex Nuts	8	Mcmaster-Carr	100	$4.76	2	0.1	1	90592A095	Link	Purchased	Aquired
Steel Cable 2mm diameter + Clamps	9	Amazon	1	$12	1	12	1		Link	Purchased	Aquired
PLA Material	10	Amazon	1000 Grams	$18	107.8 Grams	1.94	1			Purchased	Aquired
800cc Onyx Filament Spool	11	MarkForged	800 cm^3	$190	Volume-25 Cm^3	5.93	1	F-MF-0001	Link	Purchased	Aquired
50cc Carbon Fiber CFF Spool	12	MarkForged	1	$150			1	CF-BA-50	Link	Purchased	Aquired
M5 x 0.80 mm Thread, 35mm Long	13	McMaster-Carr	10	$10.36	2	2	1	90116A267	Link	Purchased	Aquired
Motor	14	Maxon	1	$715.13	1	715.13	Provided		Link	Provided	Aquired
Gearbox	15	Maxon	1	$294.65	1.00	294.65	Provided	370782	Link	Provided	Aquired

FMEA

Part # and Functions	Potential Failure Mode	Potential Effect(s) of Failure	Potential Causes and Mechanisms of Failure	RPN	Recommended Action
1 Bracket to hold Motor	Stress Rupture & low Cyle Fatigue	Total loss of function ability	Incorrect bolt tolerances, incorrect design, and material selection	180	Make sure Bracket design can withstand the forces applied
2 Bolts & Screws	Impact Fatigue	Damage to the Rod and total loss of function ability	Loose tolerances and wrong size selection	140	Design Bracket and rod for tight tolerances
3 Rod	Surface Fatigue & Stress Rupture	Shearing of the rod and deformation of the Rod	Have a sustained load at 1 point of the bracket and bracket not being fully tighten to the rod	288	Make sure Bracket Design and tolerances are Correct
4 Sprocket	Cycle Fatigue	Deformation or shearing of Sprocket teeth	Stress on sprocket may cause deformation overtime	84	Make sure sprocket material Selection is correct
5 Chain	Impact Deformation	chain having deformation in the links or pins causing it to break	The tension force acting on the the chain	84	Make sure the current chain material is selected
6 Pulley	Surface Fatigue Wear	Surface damage of pulley and a decrease of effectiveness	Friction of the wire rubbing on the pulley	32	Make sure that the material selected won't erode
7 Pulley Wire	Deformation Wear	Wire deforming over time	Tension Stress on wire causing the wire to deform overtime	16	Make sure the material selected can withstand the force
8 Foot Plate	Impact Fracture	Fracturing of footplate at attachment point to the pully	Force acting on footplate are greater than what it can handle	80	Do force analysis on footplate
9 Bearing	Cycle Fatigue	Increase in friction in the bearings and a loss of power	Deterioration of bearings and lubrication in the bearing getting dirty	54	Make sure to keep the bearing as clean as possible
10 Motor	Cycle Fatigue	Loss of torque or the motor becoming nonfunctional	Deterioration of motor part over multiple cycles	42	Make sure the motor selected can handle the number of cycles required
11 Calf Cuff	Impact Fracture	Calf cuff breaking	Impact force of the user breaking the calf cuff	8	Make sure the calf cuff is accessible for all users
12 Wire Clamps	Cycle Fatigue	Pulley cable disconnecting	Pulling forces causing the clamps to loosen and fail.	70	Make sure that clamps are installed correctly before running tests.
13 Cable cover	Impact Fatigue	Cover cracking of falling off the device	An impact causing the cover to fracture and break	5	Make sure that the cover is attached properly to the device

1st Initial Prototyping

- How will our bracket Interface with our rod and if there will need to be any adjustments to the current tolerances?
- Which bracket design will be the most stable and rigid?
- To answer these questions, we made two physical prototypes of both bracket designs which our team are considering using.

Figure 12: Bracket design 1

Figure 13: Bracket design 2

Answers and Things we Learned

- Both designs were stable enough to work as a design
- The tolerance on one of the brackets needs to be adjusted since the piece that goes into the rod is a little difficult to put inside the rod.
- One valuable thing that we learned was that we need to adjust our design to have the motor placed lower on the rod, so that we can make a smaller hole in the rod for the pulley.
- To achieve this, we plan on combining out two designs.

2nd Prototype

- How will our complete design mesh together and will there need to be any changes to tolerances?
- Will our chain to pulley system work as designed or will we need to make changes?

Figure 14: 2nd 3D printed Prototype

Main Things Learned

- Difficultly with attaching the motor to the motor bracket cause of the small clearance
- Need to remove links in our chain to help reduce unnecessary weight
- Tolerance adjustments for bearings holes, because some caused difficulty with the hole being too small or too large

Second Semester Changes

- Bracket design was changed with the guidance of our Client

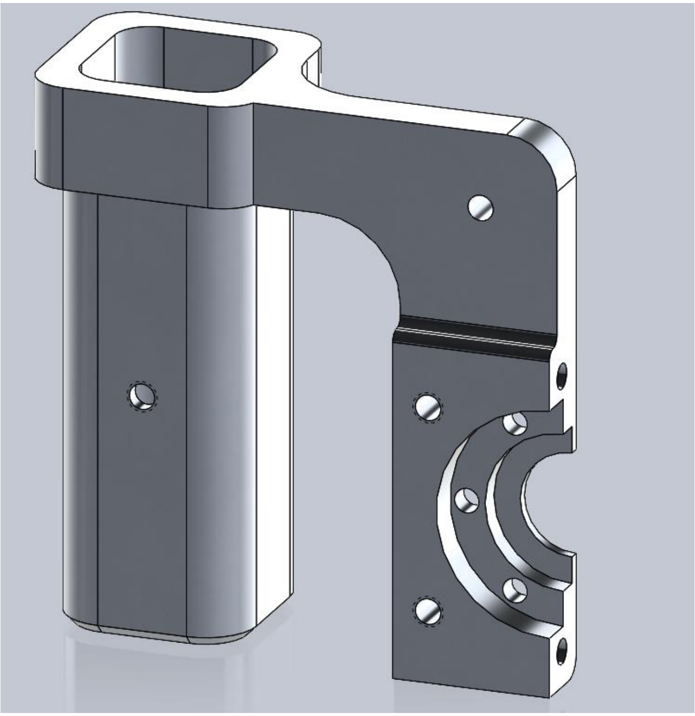


Figure 15: Updated spark-plug motor bracket

- A cover was designed to reduce possibility of injury due to pinch points

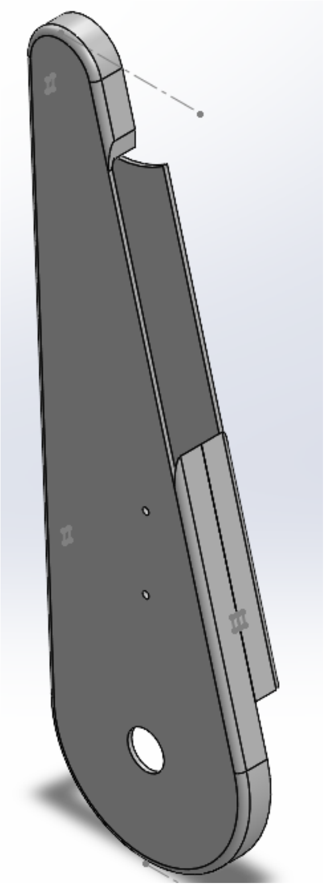


Figure 16: Cover design

Final Design

Figure 17: Final assembled exoskeleton

Video of a user walking in the completed exoskeleton

Testing

Table 6: Testing Summary

Experiment/Test	Relevant DRs	Testing Equipment Needed	Other Resources
Ex1 – Weight Test	CR1- Light Weight ER3- Weight<1kg	Scale Device to take photo	Space to place scale and weigh device
Ex2 – Range of Motion	CR2-Ergonomic ER2-Range of motion of 45 degreed in either direction	Level/Level App Device to take photo	Table to place device
Ex3 – Measurement Test	CR2-Ergonomic CR5-Low Profile ER4-Cannot Extrude > 10cm	Ruler/Measuring Tape Device to take photo	Flat ground to place device
Ex4-Cost Analysis	CR4-Economical/ Cost Effective ER1-Less then 1900 per leg	BOM	
Ex5- Durability Test	CR3- Durable CR6- Have a chain to pulley System ER5-Liftime of 100,000 Steps	SolidWorks & Torque Sensor	Treadmill
Ex6 – Time Test	CR2-Ergonomic ER6- Time to take on/off (<60s)	Stopwatch Device to make a video	Space to put on device

Testing

Ex1 – Weight Test

Purpose: Leg must weigh ≤1000 grams

Anticipated: SOLIDWORKS Analysis = 808.85 grams

Results: 793 grams

Figure 18: Image of weight test

Ex2 – Range of Motion Test

Purpose: Leg be able to move 45º in either direction

Anticipated: SOLIDWORKS Analysis = 128.54º in either direction

Results: 47º Forward, 49º Backward

Figures 19-20: Images of range of motion test

Ex3 – Measurement Test

Purpose: Leg should not extend more than 10 centimeters from the user

Anticipated: SOLIDWORKS Analysis = 4.95 centimeters

Results: 5 centimeters

Figure 21: Image of measurement test

Testing

Ex4 – Cost Analysis

Purpose: One leg must cost ≤ $1,900

Results: $1786.57

Table 7: Cost analysis test results

Part	Quantity Per Unit	Cost Per Unit	Quantity Needed	Cost per Unit needed
Footplate	1	-	1	-
Torque Sensors	1	-	1	-
M2 Assortment of Screws + Nuts	562	$9.98	6	0.1
Chain (1ft, 05B, 8mm Pitch)	1	$9.00	1	9
M3 X 35	2	$2.00	2	2
Stainless Steel Ball bearing 5mm	1	$9.20	4	36.8
Stainless Steel Shoulder Screw	1	$6.31	1	6.31
Steel Hex Nuts	100	$4.76	2	0.1
Steel Cable 2mm diameter + Clamps	1	$12	1	12
PLA Material	1000 Grams	$18	107.78 Grams	1.94
800cc Onyx Filament Spool	800 Cm^3	$190	Volume-25 Cm^3	5.93
50cc Carbon Fiber CFF Spool	1	$150	-	-
M5 x 0.80 mm Thread, 35mm Long	10	$10.36	2	2
Motor	1	$715.13	1	715.13
Gearbox	1	$294.65	1	294.65
Bracket	1	479.11	1	479.11
Rod + manufacturing	1	221.5	11 inch	221.5
Total	1786.57			

Ex5 – Durability Test

Purpose: Leg needs to withstand ≥ 100,000 steps

Results: 375,200 steps

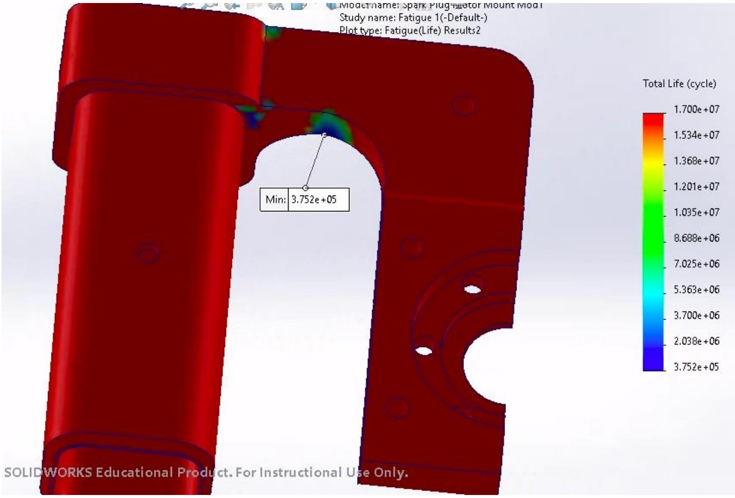


Figure 22: Fatigue Analysis

Ex6 – Time Test

Purpose: User should be able to put on leg in ≤ 60 seconds

Results: 3 Tests (22s, 18s, 20s); 20 second average

Testing Results

Table 8: Engineering Requirements summary

Engineering Requirement	Target	Tolerance	Measured/Calculated Value	CR met? (✓ or X)
ER1-Low cost	$1,900	+ $10	$1786.57	✓
ER2- Range of Motion	± 45°	≥±45°	-47° Forward 49° Backward	✓
ER3-Weight	<1kg	+ 5 g	793 g	✓
ER4-Dimensions	Extrude < 10 cm	± 5 mm	Max Protrusion 5cm	✓
ER5- Lifetime	100,000 Steps	- 100 steps	375,200 steps	✓
ER6- User Friendly	Time to take on/off < 60s	+ 5 s	20 s	✓

Table 9: Customer Requirements summary

Customer Requirements	CR met? (✓ 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	✓

Future Work

- Redesign Cover to remove excess material and help with weight reduction.
- Add Cable caps to help reduce fraying of the steel wire rope
- Do additional testing for material selection of our bracket
- Outdoor Walking test to see if dust and debris effect devise
- Long term test +30 min

Any Questions?

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