Ankle ExoSkeleton

BY: DIEGO AVILA, EMMA DE KORTE, TRE GREEN

Project Description

-Partnered with Zachary Lerner

-Partnered with NAU Biomechatronics

-Develop Ankle Exoskeleton

-Focus on structure of system (not motor)

-Aid in walking motion

-Commonly going to be used for Cerebral Palsy

Background and Benchmarking

- There are currently multiple ankle exoskeleton products being developed
- These Three Below are products that we believe solve the current problem of a faulty transmission system between the ankle and the actuating system.

Technaid Robotic Ankle H3

- This system use a wave gear system to actuate the ankle movement and uses a 22 V battery

Figure 1: Diagram of the Technaid Robotic Ankle H3

The Rewalk Restore Soft Robotic Exosuit

- Uses a Bowden cable system with a gear driven actuating system

Figure 2: Diagram of the Rewalk Restore Soft Robotic Exosuit

Untethered Robotic Ankle Exoskeleton

- Also use a Bowden cable actuating system

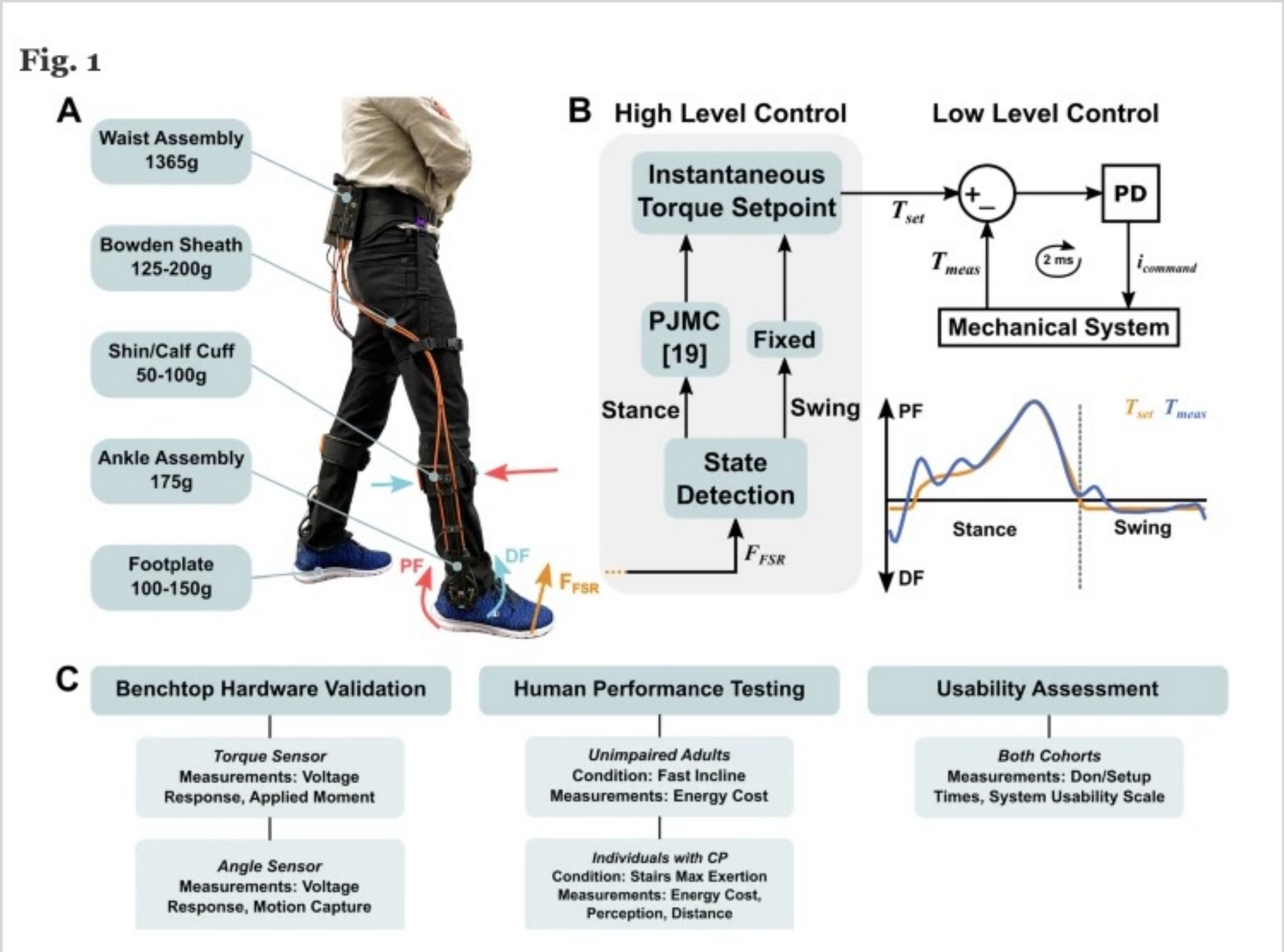


Figure 3: Diagram of the Untethered Robotic Ankle Exoskeleton

Customer Requirements

- Lightweight
- Easly put on and taken off
- Durable
- Economical
- Low profile

Engineering Requirements

- Given budget is $4000.00
- Range of motion for foot should be at least 45° in either direction~standard range of motion when walking
- Weigh <1kg (ankle piece)
- Cannot extrude from the body more than 10cm
- Lifetime of 100,000 steps

QFD

A	Technaid Eobotic Ankle H3
B	Rewalk Restore Soft robotic Exos
C	Untelthered Robotic Ankle Exosk

#	Technical Requirement	1	2	3	4
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	Descrease Timing	Decrease Cost of Each Leg	Decrease Protrusion from Body	Customer Opinion Survey: 1 Poor	2	3 Acceptable	4	5 Excellent
1	Lightweight	3	5	3	3	3	3	A				BC
2	Easy to take on and off	4	3	1	5	3	3		BC		A	
3	Durable	4	2	5	1	2	1			ABC		
4	Cost Effective	5	4	4	1	5	1					
5	Small in size, close to body	3	5	2	3	2	5	A	B		C	
	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 4: House of Quality for Robotic Exoskeleton

Literature Review of Biomechanics of the foot

- Dynamics HIBBELER, R. C. (2015). *Engineering mechanics: Dynamics*. PRENTICE HALL.
- Uchida, Thomas K. *Biomechanics of Movement: The Science of Sports, Robotics, and Rehabilitation*. MIT Press, 2021.
- Brockett, Claire L, and Graham J Chapman. "Biomechanics of the ankle." *Orthopaedics and trauma* vol. 30,3 (2016): 232-238. doi:10.1016/j.mporth.2016.04.015 (Muscles involved with foot movement)
- Chan, Carl W, and Andrew Rudins. "Foot Biomechanics During Walking and Running." *Mayo Clinic Proceedings*, 5th ed., vol. 69, 1994, pp. 448–461. (Foot mechanics when walking)
- Kharb, Ashutosh, et al. *A REVIEW OF GAIT CYCLE AND ITS PARAMETERS* , vol. 13, July 2011,
- "What Is Cerebral Palsy?" *Centers for Disease Control and Prevention*, Centers for Disease Control and Prevention, 2 May 2022, www.cdc.gov/ncbddd/cp/facts.html.
- Jung, Taeyou, et al. "Biomechanical and Perceived Differences between Overground and Treadmill Walking in Children with Cerebral Palsy." *Gait & Posture*, 2016, pp. 1–6.

Literature Review of Gear System

- BDYNAS. (2020). *SHIGLEY'S MECHANICAL ENGINEERING DESIGN, 11TH EDITION, SI UNITS* (11th ed.). MCGRAW-HILL EDUCATION (AS.
- Cammit, Joel (2013). *Exploring Robotics, https://www.google.com/url?sa=t&source=web&rct=j&opi=89978449&url=http://www.sci.brooklyn.cuny.edu/~kammet/syllabus-spr13.pdf&ved=2ahUKEwjb3pe3x7WBAx*
- "Gear Train: Gear Ratios, Torque, and Speed Calculations". https://www.smlease.com/entries/mechanism/gear-train-gear-ratio-torque-and-speed-calculation/
- Groover, M. P. (2021). *Fundamentals of modern manufacturing: materials, processes, and systems*. Wiley.
- *Lerner, Zachary (2022).* Usability and performance validation of an ultra-lightweight and versatile untethered robotic ankle exoskeleton. Northern Arizona University. *https://doi.org/10.1186/s12984-021-00954-9.*
- *Lewsley, Fred (2013). Functioning 'mechanical gears' seen in nature for the first time.* University of Cambridge. https://www.cam.ac.uk/research/news/functioning-mechanical-gears-seen-in-nature-for-the-first-time

Literature for Materials of Exoskeleton

- [1] A. I. Alateyah et al., "Design optimization of a 4-bar exoskeleton with natural trajectories using unique gait-based synthesis approach," De Gruyter, https://www.degruyter.com/document/doi/10.1515/eng-2022-0405/html?lang=en (accessed Sep. 19, 2023).
  - Provides more information on exoskeletons and different materials to build the devices out of.
- [2] X. Wang, S. Guo, B. Qu, M. Song, and H. Qu, "Design of a Passive Gait-based Ankle-foot Exoskeleton with Self-adaptive Capability - Chinese Journal of Mechanical Engineering," SpringerOpen, https://cjme.springeropen.com/articles/10.1186/s10033-020-00465-z (accessed Sep. 19, 2023).
  - Has a good schematic on how a motor assembly has worked for published designs.
- [3] Orekhov, Greg & Fang, Ying & Cuddeback, Chance & Lerner, Zachary. (2021). Usability and performance validation of an ultra-lightweight and versatile untethered robotic ankle exoskeleton. Journal of NeuroEngineering and Rehabilitation. 18. 10.1186/s12984-021-00954-9.
  - This publication is a previous one from Dr. Lerner, provided a schematic of the motor assembly the client has used in the past and materials used.
- [14] T. Philpot and J. S. Thomas, *Mechanics of Materials: An Integrated Learning System*. Estats Units d'Amèrica: Wiley, 2020.
  - Used to learn about different material properties
- [15] W. D. Callister and D. G. Rethwisch, *Materials Science and Engineering: An Introduction*. Milton, QLD: John Wiley and Sons Australia, Ltd, 2021.
  - Used for equations to calculate the thickness needed

- Online sources used for material properties can be found on slide 23

Calculating Torque of Achilles Tendon

- Using this equation

-W*d1cos(theta)+Fa*d2cos(Theta2)=0

W=Weight/2

D1= Distance from the Balls of feet to the Tibia

Fa= Force of Achilles

D2= Distance from tibia to Achillies

Theta= angle of elevation of the heel

Theta 2= Angle of Achilles in relation to tibia

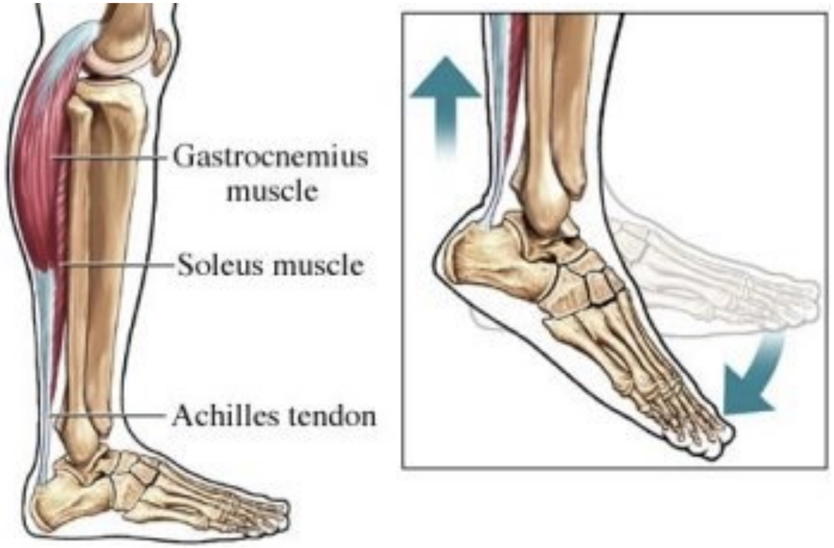


Figure 5: Diagram of how the Achilles Tendon functions

Free Body Diagram

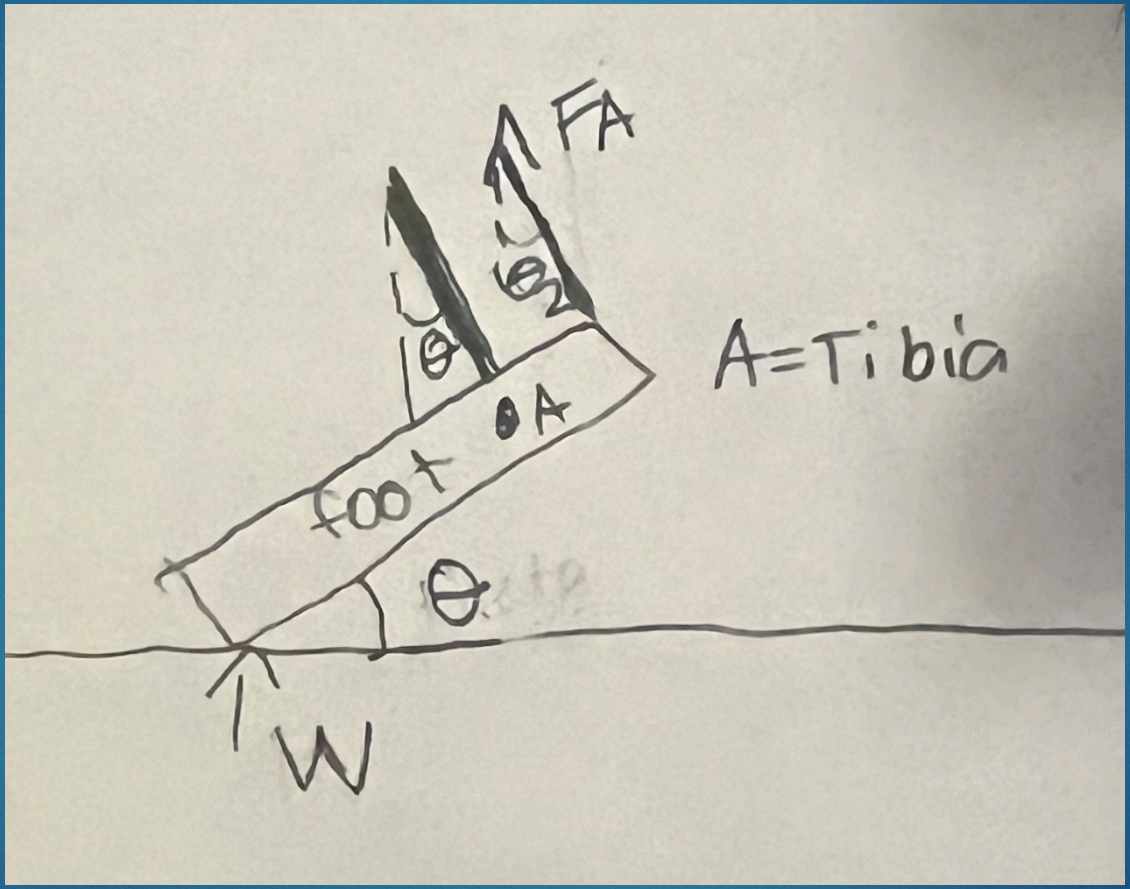


Figure 6: Free body diagram of Torque analysis

Results

- Assuming average Foot size and mass of 14-year-old male and a distance of 6 cm between tibia and Achillies
- Max torque of 47.3 NM

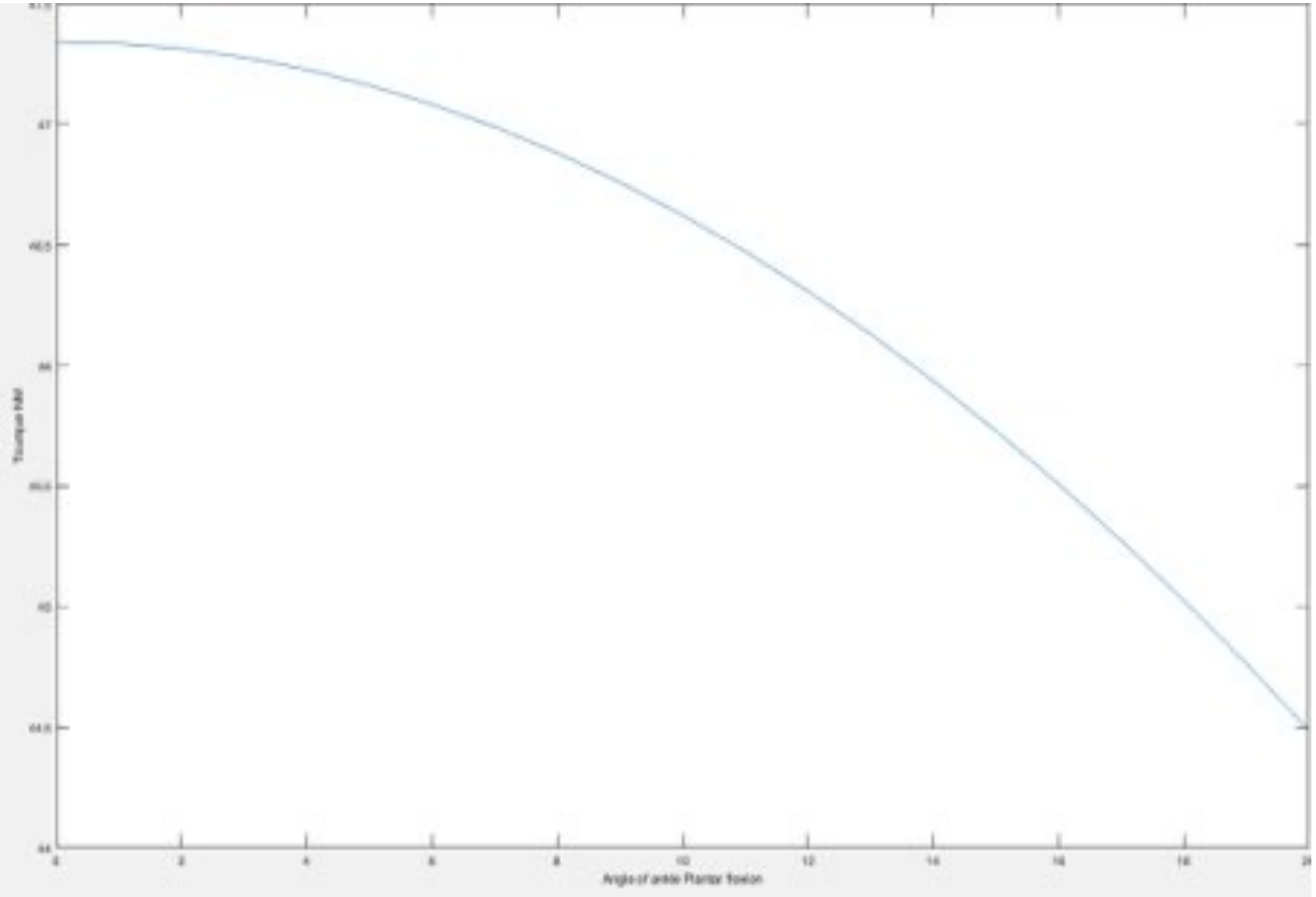
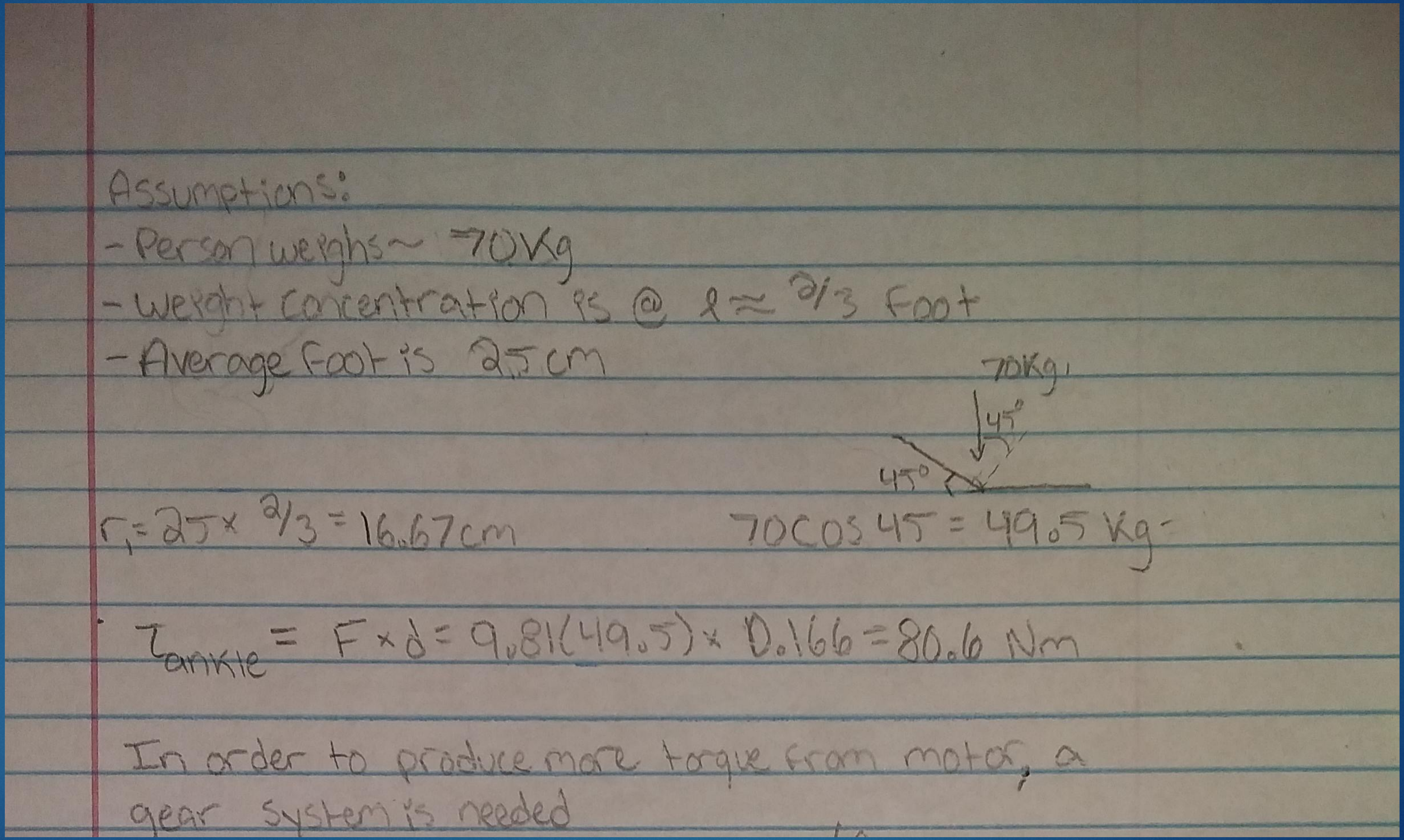


Figure 7: Graph of results of torque and tension

Designing Gear System



Assumptions:

- Person weighs ~ 70Kg
- weight concentration is @ $l \approx 2/3$ Foot
- Average Foot is 25 cm

$r_1 = 25 \times 2/3 = 16.67\,cm$

$70 \cos 45 = 49.5\ Kg$

$\tau_{ankle} = F \times d = 9.81(49.5) \times 0.166 = 80.6\ Nm$

In order to produce more torque from motor, a gear system is needed

Figure 8: Written work from gear system analysis part 1

Designing Gear System

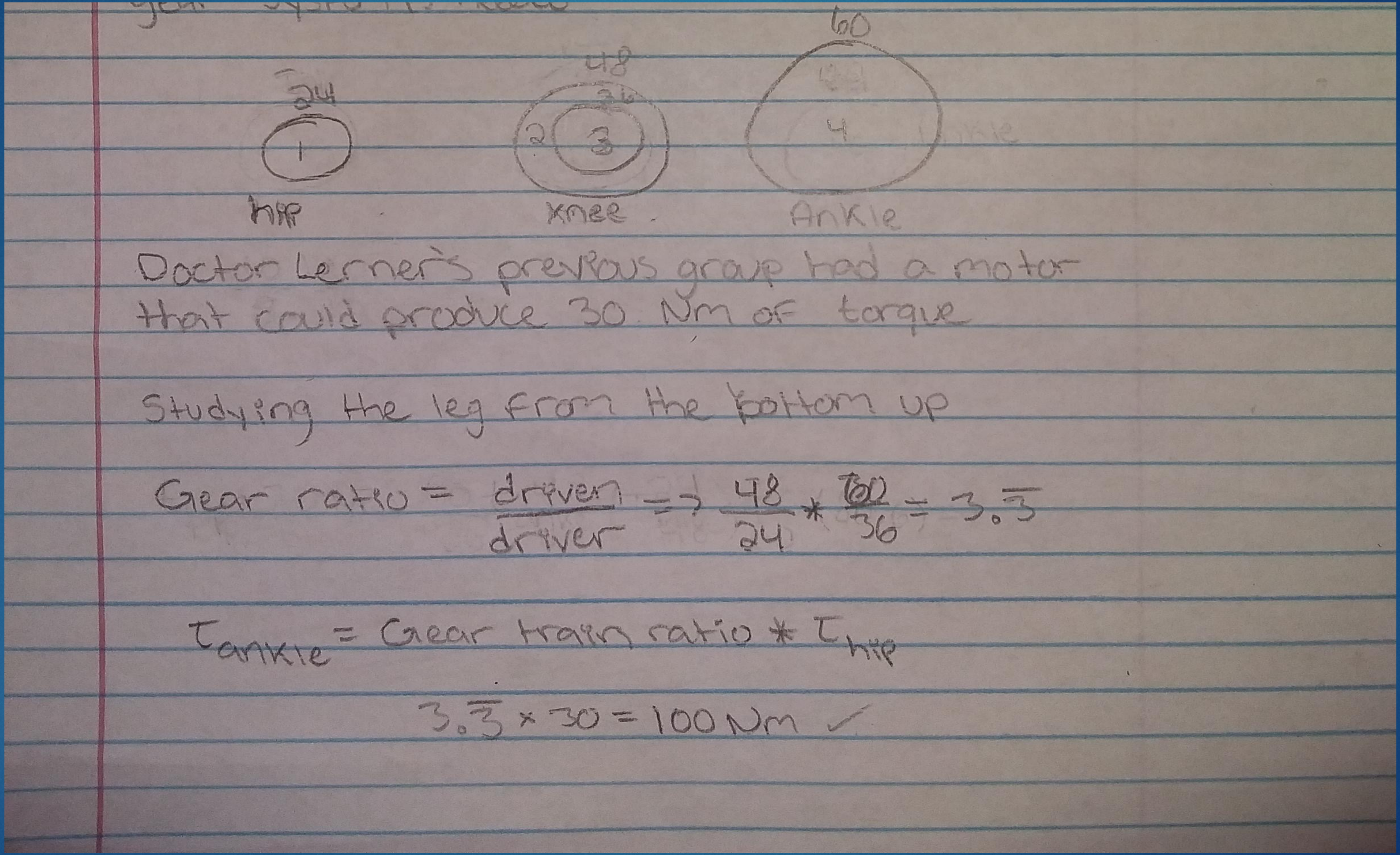


Figure 9: Written work from gear system analysis part 2

Possible Materials for Exoskeleton

- Suggested Materials from the Degruyter publication [1]
  - Aluminum 6061-T6
    - Hardness, Vickers: 107, Ultimate Tensile Strength: 310 MPa, Yield Tensile Strength: 276 MPa [3], about $4.67-$252.94 (depending on thickness) [7], density (kg/m^3): 2700 [11]
  - Steel Low Carbon
    - Hardness, Vickers: 131, Ultimate Tensile Strength: 440 MPa, Yield Tensile Strength: 370 MPa [4], about $0.55 per kg [8], density (kg/m^3): 7850 [12]
  - Steel 4140
    - Hardness, Vickers: 207, Tensile Strength: 655 MPa, Yield Strength: 415 MPa [5], about $0.55 per kg [9], density (kg/m^3): 7833 [13]
  - Titanium Grade 5
    - Hardness, Vickers: 349, Ultimate Tenslie Strength: 950 MPa, Yield Tensile Strength: 880 MPa [6], about $50 per kg [10], density (kg/m^3): 4540 [14]
- Dr. Lerner will provide a carbon fiber footplate and the calf cuff
- Carbon fiber and Aluminum

Possible Materials for Exoskeleton

- 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

Schedule

Project Item		Due Date		Days Left	Completion Status
Timecard Wk1		9/4/23	11:59 PM	-16	Completed
Staff Meeting #1		9/8/23	5:30 PM	-12	Completed
Timecard Wk2		9/11/23	11:59 PM	-9	Completed
Client Meeting #1		9/14/23	4:00-4:30 PM	-6	Completed
Staff Meeting #2		9/15/23	5:30 PM	-5	Completed
Timecard Wk3		9/18/23	11:59 PM	-2	Completed
Presentation 1		9/19/23	5:30 PM	-1	In Progress
	Project Description				
	Background & Benchmarking				
	Customer and Engineering Requirements				
	Research within Your Design Space- A Literature Review				
	Research within Your Design Space- Mathematical Modelling				
	Schedule & Budget				
Timecard Wk4		9/25/23	11:59 PM	5	
Client Meeting #2		9/26/23	3:45-4:00 PM	6	
Staff Meeting #3		9/29/23	5:30 PM	9	
Timecard Wk5		10/2/23	11:59 PM	12	
Staff Meeting #4		10/6/23	5:30 PM	16	
Timecard Wk6		10/9/23	11:59 PM	19	
Presentation 2		10/10/23	5:30 PM	20	
	Project Description				

Figure 10: Small Portion of teams current schedule

Budget

- Total Budget: $4,000
- Each Leg must be <$2,000
- Based off previous designs put out by Dr. Lerner, we might need materials below, per leg
  - Torque Transducer
  - Pully System
  - Transmission Crimping site
  - Thrust Ball bearings x2
  - Shoulder Belt
  - Steel bolts x4
  - Pully Bridge

Thank You

Any Questions?

References

- [3] ASM Material Data Sheet, https://asm.matweb.com/search/SpecificMaterial.asp?bassnum=ma6061t6 (accessed Sep. 19, 2023).
- [4] F. S. S. Instruments et al., “AISI 1018 Mild/Low Carbon Steel,” AZoM.com, https://www.azom.com/article.aspx?ArticleID=6115 (accessed Sep. 19, 2023).
- [5] F. S. S. Instruments et al., “AISI 4140 Alloy Steel (UNS G41400),” AZoM.com, https://www.azom.com/article.aspx?ArticleID=6769 (accessed Sep. 19, 2023).
- [6] ASM Material Data Sheet, https://asm.matweb.com/search/SpecificMaterial.asp?bassnum=mtp641 (accessed Sep. 19, 2023).
- [7] “Aluminum Sheet/Plate 6061 T6/T651,” Aluminum Sheet 6061 T6/T651 | Online Metals, https://www.onlinemetals.com/en/buy/aluminum-sheet-plate-6061-t6-t651 (accessed Sep. 19, 2023).
- [8] “What is Price of Low-carbon Steel - Definition,” Material Properties, https://material-properties.org/what-is-price-of-low-carbon-steel-definition/ (accessed Sep. 19, 2023).
- [9] “ASTM Steel A36 Steel Plate 50mm Thick A36 S235 S355 Steel Plate Price Per Kg,” Astm Steel A36 Steel Plate 50mm Thick A36 S235 S355 Steel Plate Price Per Kg - Buy Astm Steel,Hot Rolled Carbon Steel Plate,Astm A36 Steel Plate Product on Alibaba.com, https://www.alibaba.com/product-detail/ASTM-Steel-A36-Steel-Plate-50mm_1600329933029.html?spm=a2700.7724857.0.0.2edb28558RMN1z (accessed Sep. 19, 2023).
- [10] “Titanium 6Al-4V Grade 5, UNS R56400 Titanium Grade 5 Product Supplier,” Titanium Grade 5 Ti-6A | 4V Supplier, Titanium Gr.5 Price Per Kg in India, https://www.fastwell.in/titanium-grade-5.html (accessed Sep. 19, 2023).
- [11] World Material, “Weight & Density of Aluminum 6061 g/cm3, lbs/in3, kg/m3, g/ml, lb/ft3, g/mm3, Cubic Inch,” World Material, https://www.theworldmaterial.com/weight-density-of-aluminum/ (accessed Sep. 19, 2023).
- [12] “Density of steel,” Home, https://www.pipingmaterial.ae/blog/density-of-steel/#:~:text=Density%20of%20carbon%20steel%20and,%2C%20at%207%2C860%20kg%2Fm3. (accessed Sep. 19, 2023).
- [13] “4140 Product Guide,” alloy-steel 4140 Product Guide from Online Metals, https://www.onlinemetals.com/en/product-guide/alloy/4140 (accessed Sep. 19, 2023).
- [14] Properties of Titanium - Roy Mech, https://roymech.org/Useful_Tables/Matter/Titanium.html#:~:text=Titanium%20is%20a%20light%20metal,than%20iron%20at1560oC. (accessed Sep. 19, 2023).