Flying Squirrel

Jonathan Avila, Ryan Donnellan, Justin Joy, Owen Kehl, Joey Mathews

Background and Problem Statement

- Nearly 800,000 strokes occur annually in the U.S. with almost ¾ being new cases
- Basic rehabilitation takes a long time, up to 12-18 months
- Devices for rehabilitation are often expensive and cumbersome
- The Hamster trains arm movement at a lower cost and in a more compact package, but cannot move vertically
- The *Flying Squirrel* incorporates vertical motion in addition to the features of its predecessor
- Sponsored by Dr. Razavian, who specializes in robotics and control algorithms

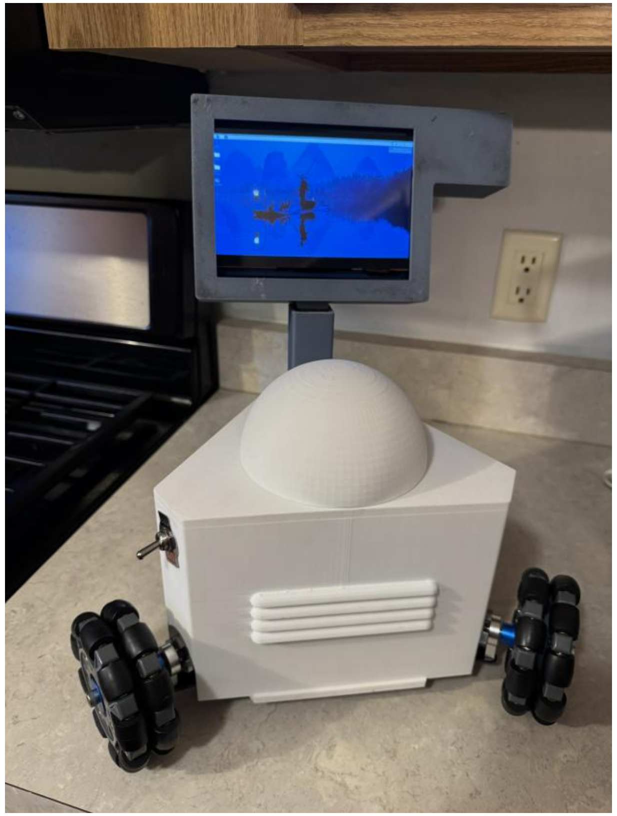

Figure 1: Hamster Rehabilitation Device

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Project Description

SPONSOR

- Dr. Razavian
- Raz Labs

CUSTOMER NEEDS

- Therapeutic stroke patient device
  - Table-top cable-driven robot
- At home, easy and fast to setup, inexpensive
  - Less than production cost $1000
  - Less than 1 minute for setup
- Next generation of "Hamster"
  - Improved from 2D movement to 3D

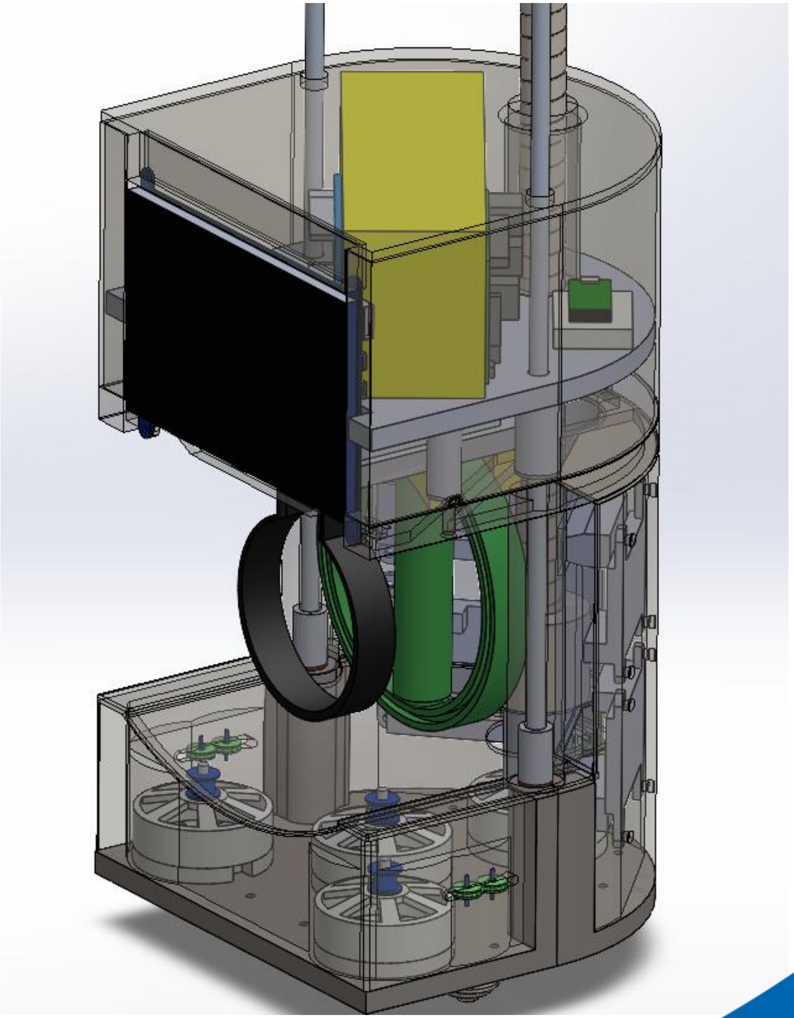

Figure 2: Flying Squirrel Cad model

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Design Requirements

Customer Requirements	Engineering Requirements
CR1- Affordable	**ER1**- Range of Motion (2'x1'x1' envelope)
CR2- 3D Movement	**ER2**- Size (8"x8" overhead area limit)
CR3- Precise and Accurate	**ER3**- Speed (1m/s in any direction)
CR4- Relatively Compact for Storage	**ER4**- Force (Produce 10N in any direction)
CR5- Long Battery Life	**ER5**- Sensing and Control Accuracy (<0.1mm and 0.1N sensing, <0.5mm and 1N control)
CR6- Aesthetically Pleasing	**ER6**- Battery Life (30 minutes of use)
CR7- User Friendly	**ER7**- Production Cost (<$1000, later removed)
	ER8- Set-up Time (1 minute)

Table 1: Design Requirements

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QFD

			Technical Requirements				
	Customer Needs	Customer Weights (1-5)	Production Cost	Speed	Force	Control and Detection*	Device Size*
1	Affordability	5	9			3	3
2	3rd Dimension Movement	4	3	1	1		1
3	Precision and Accuracy	3	3	9	9	9	
4	Size	4	3	1			9
5	Cosmetics	1	1				1
6	User Friendliness	5	3				9
	Technical Requirement Units		Dollars ($)	Meters per Second (m/s)	Newtons (N)	Millimeters (mm)	Inches (in)
	Technical Requirement Targets		1000	1	10	0.1	8x8x19
	Absolute Technical Importance		31	42	35	93	100
	Relative Technical Importance		5	3	4	2	1

Table 2: QFD

Initial Benchmarks

- A production cost of $1000
- Capable of 10 Newtons of force
- A device size concentrate of 8x8x8
- Accurate position tracking with a tolerance of 0.1 mm

Adjustments

- Cost adjusted to budget total of $3750 due to price of parts
- 8-inch height restriction adjusted for lift to reach 12 inches from stowed position.

Background & Benchmarking

Armeo SpringPro

Figure 3: Armeo SpringPro

- Works in x,y,z planes
- Full arm support
- Large footprint
- Complex 3D motion
- Rent: $1000 per month

ArmMotus M2 Pro

Figure 4: ArmMotus M2 Pro

- Works in x,y,z planes
- Forearm support
- Very large footprint
- Simple 3D motion
- $10000-$30000

The Hamster

Figure 5: The Hamster

- Works in x,y planes
- No arm support
- Compact footprint
- Simple 2D motion
- ~$500

Literature Review

Books, Chapters, and Articles

Books/Chapters

- Rehabilitation Robotics: Technology and Application
- Atlas of Orthoses and Assistive Devices

Papers/Journals

- Wrench feasibility workspace analysis and adaptive rotation algorithm of cable-driven upper limb rehabilitation robot
- Control of a large redundantly actuated cable-suspended parallel robot
- String-man: A new wire robot for gait rehabilitation

Other Resources

Online Articles

- Rehabilitation robot," Rehabilitation Robot - an overview
- Garrett Brown's skycam history
- Fish Line Strength Charts
- "How skycam works,"

Literature Review

Books, Chapters, and Articles

Books/Chapters

- Arduino robotic projects: build awesome and complex robots with the power of Arduino
- Raspberry Pi 3 cookbook for Python programmers : unleash the potential of Raspberry Pi 3 with over 100 recipes

Articles

- Modeling Cable-Driven Robot With Hysteresis and Cable-Pulley Network Friction
- Permanent magnet DC motor control by using Arduino and motor drive module BTS7960
- Design and Evaluation of a Bowden-Cable-Based Remote Actuation System for Wearable Robotics

Other Resources

Online/Conferences/Gov.

- Robot-assisted Therapy in Stroke Rehabilitation
- A novel cable-driven robotic training improves locomotor function in individuals post-stroke
- How to Use Raspberry Pi and Arduino Together

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Literature Review

Books, Chapters, and Articles

Books/Chapters

- Encyclopedia of Smart Materials
- Chapter 5 - Robotics and rehabilitation: the role of robot-mediated therapy post stroke

Articles

- Upper Limb Robot Mediated Stroke Therapy—GENTLE/s Approach
- Multi-sensor fusion for body sensor networking medical human–robot interaction scenario
- Development of an Integrated Haptic Sensor System for Multimodal Human–Computer Interaction Using Ultrasonic Array and Cable Robot

Other Resources

Online/Conferences/Gov.

- Adaptive Robot-Assisted Feeding: An Online Learning Framework for Acquiring Previously Unseen Food Items
- Adaptive assistive robotics: a framework for triadic collaboration between humans and robots
- A State-of-the-Art Review on Robots and Medical Devices Using Smart Fluids and Shape Memory Alloys

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Literature Review

Books, Chapters, and Articles

Books/Chapters

- Chapter 6 - Robotics in Rehabilitation Medicine: Prosthetics, Exoskeletons, All Else in Rehabilitation Medicine
- Chapter 3 – Sensors and Transducers

Articles

- Forces and Moments Generated by the HumanArm: Variability and Control
- Force Control and Degree of Motor Impairmentsin Chronic Stroke
- A Low-Dimensional Representation of ArmMovements and Hand Grip Forces in Post-StrokeIndividuals

Other Resources

Online Sources

- Human Body Mass Distribution
- Understanding Force Sensors: How They Work and Measure Force
- Accurate Tracking: A Look at Position and Distance Sensors

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Literature Review

Books, Chapters, and Articles

Books/Chapters

1. Raspberry Pi Robotic Projects
2. Hands-on robotics programming with C++ : leverage raspberry pi 3 and C++ libraries to build intelligent robotics applications.

Articles

1. ToF 3D Vision Algorithms in C++ for Robotic Applications
2. Gesture Control Robot with Arduino
3. Path Following System for Cooperative Mobile Robots

Other Resources

Online Sources

1. Wire Robots Part I: Kinematics, Analysis & Design
2. Robot dynamics and control
3. Controlling Tensegrity Robots through Evolution

Mathematical Modeling

Mathematical Modeling	Why	Result
Wire Tension	To determine needed wire strength	Stress = 3,157 Kilopascal
Total Battery Capacity Required	Battery selection	amp-hours required= 5.85 A-h
Torque	Minimum diameter motor required for the minimum torque	D = 10mm
Necessary Lifting Strength	Determine force required from lift system	F = 14.5N
Vector Analysis for Motion and Motion Tracking	To understand wire movement scheme	ΔL = 9.7in

Table 3: Hamster Rehabilitation Device

Functional Decomposition

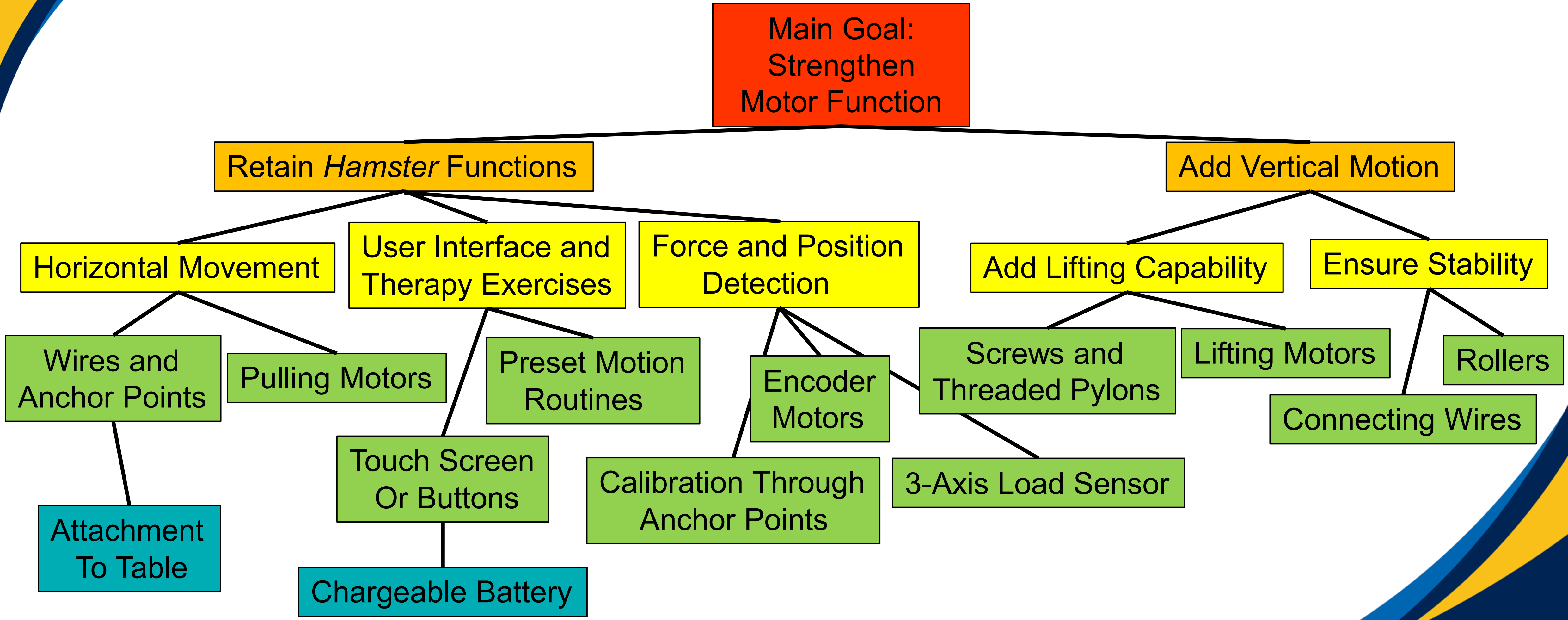

Figure 6: Functional Decomposition

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Design Evolution

Final Design of The Flying Squirrel

- Lead screw in rear for lift
- Touch screen user interface
    - Simple and easy to use
    - Start/stop program buttons
- Motors on bottom connected to wires for tabletop movement
- Attached to guide pulleys on anchors
- Anchors have suction cups and C-clamps for different table surfaces
- Rotating handle connected to force sensor
- Wrist strap provides arm support for user

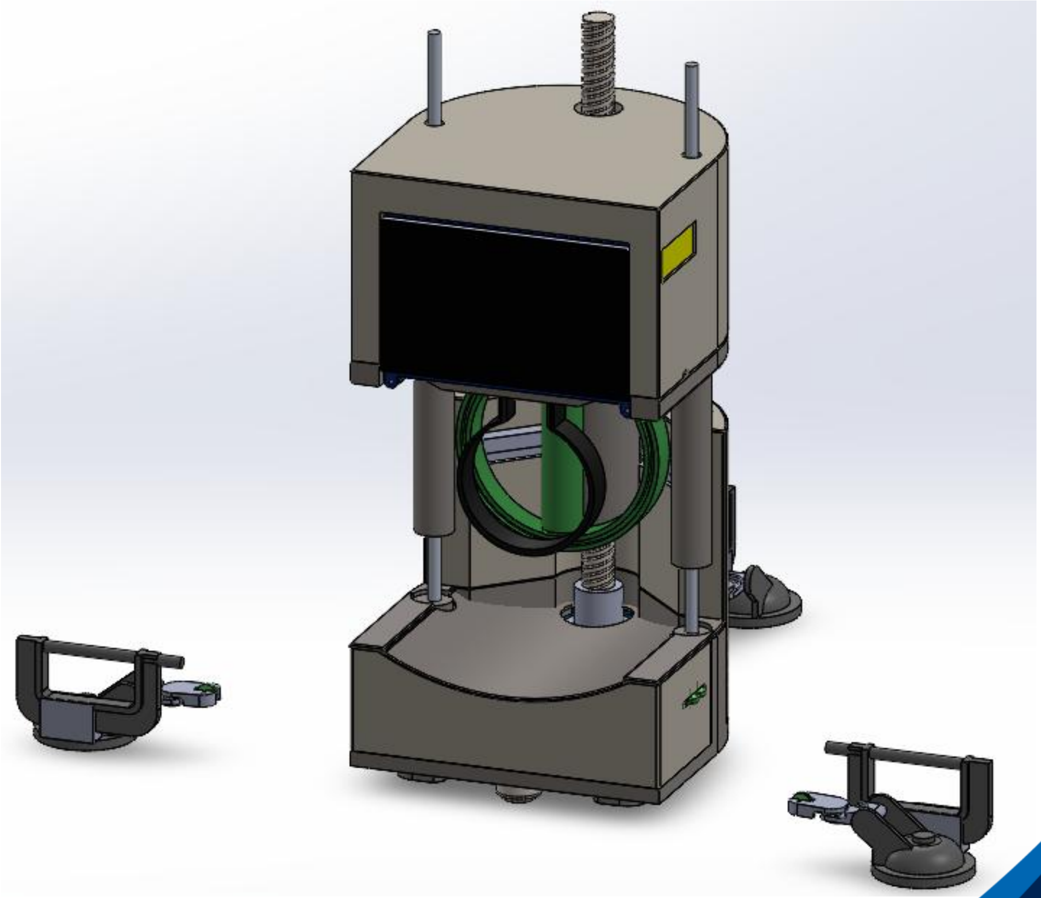

Figure 7: Final Product CAD Model

Design Evolution

Designs from First Round of Team Concept Generation

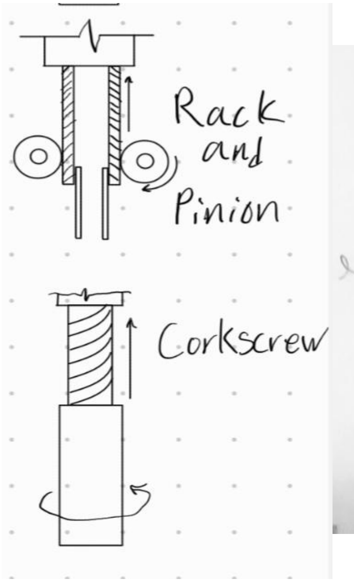

Figure 8: Lift Mechanism Concepts

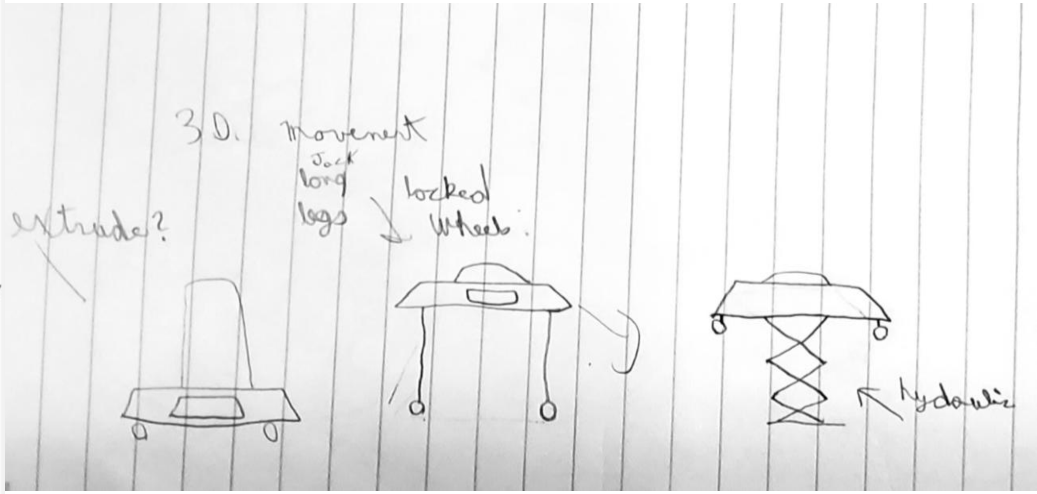

Figure 9: Initial Robot Concepts

Client's Design Request

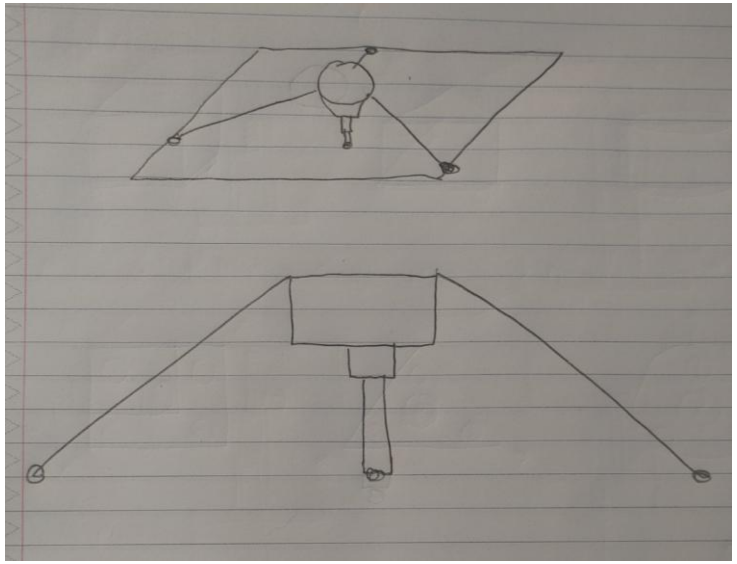

Figure 10: Dr. Razavian's Design Request Based on Feedback

Design Evolution

Designs from Second Round of Team Concept Generation

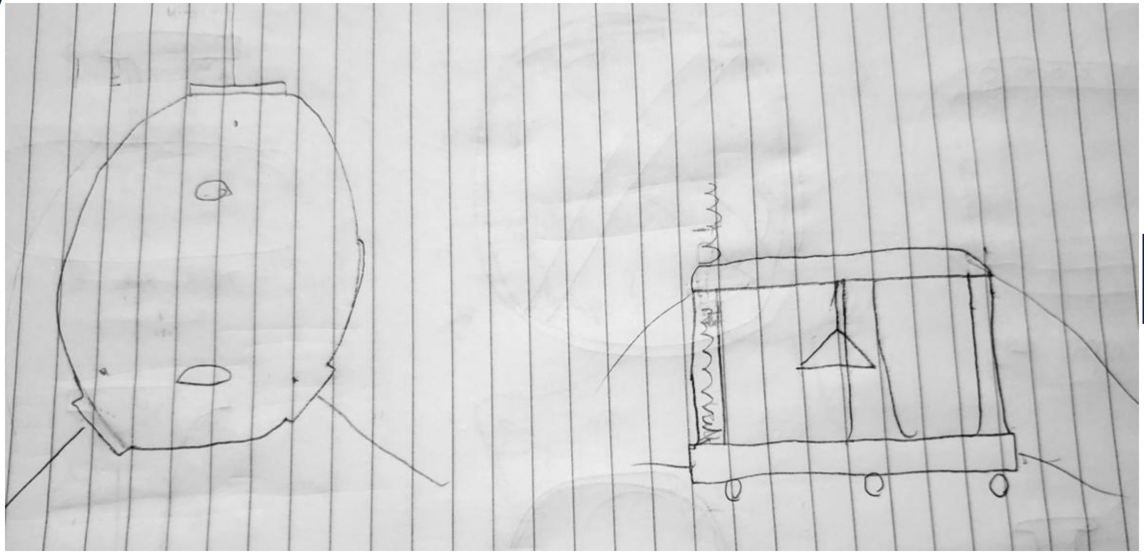

Figure 11: Robot Concept Based on Client Feedback and Suggestions

Initial CAD Design and Anchor Concept

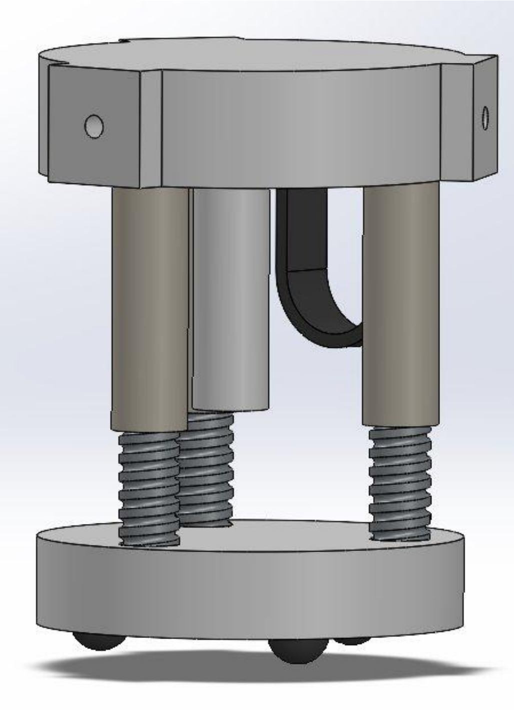

Figure 12: CAD Rough Draft

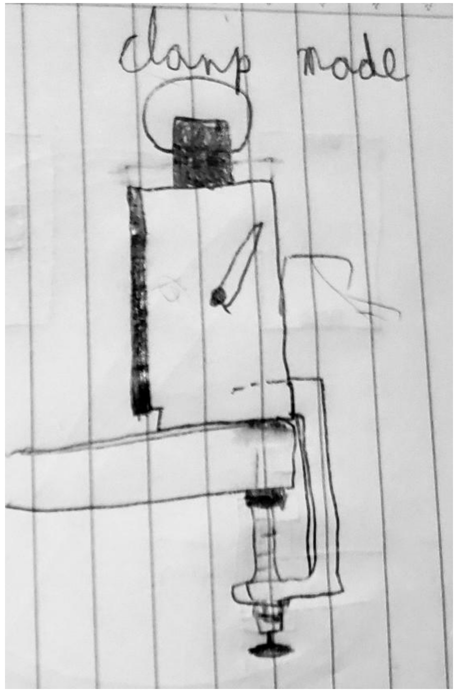

Figure 13: Anchor Concept

Design Evolution

Final Design- Spring 2025 Semester

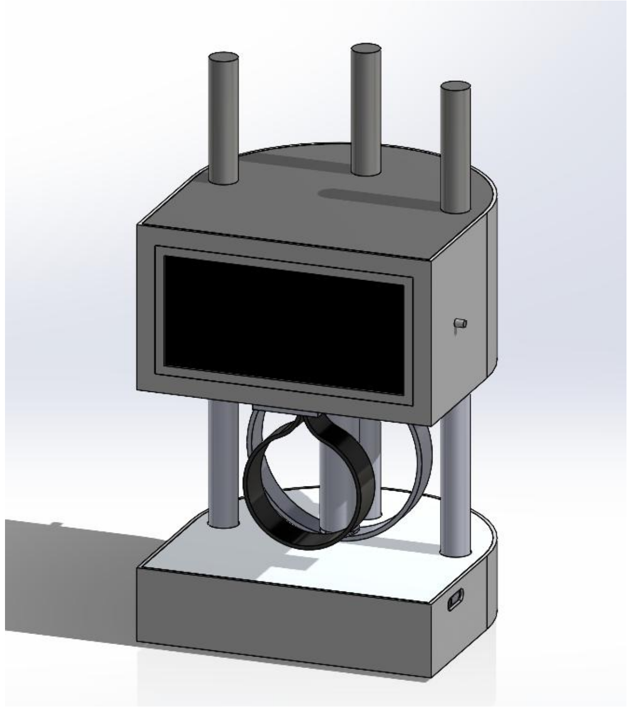

Figure 14: Final Model for Capstone 1

Final Design- Fall 2025 Semester

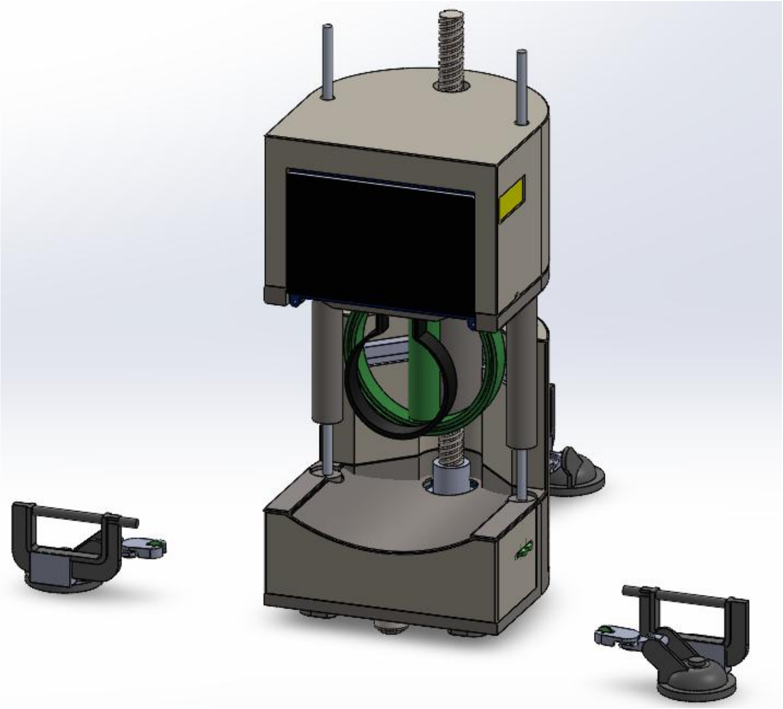

Figure 15: Final Model for Capstone 2- Final Design

Engineering Calculations

Engineering Calculations	Why	Result
Angle to Anchor Point	To find the angles for the movement code	Line 1: 11.31°ccw Line 2: 13.63° cw Line 3: 2.84° ccw
Minimum Tension in Cables	Minimum force to keep tension	2.2 lbs
Downward Force From Wires	Max and Min force of the cables	Fmin= 14.55 N Fmax= 70.55
Wire Max stress	Wire selection	Stress= 26,308 MPa
Ball Bearings Lifetime Estimation	Ball bearing selection	Lifetime= 150,000 hours
Battery Power	Battery selection	Min Amp hour= 5.85
Anchor Distance for Motor with 1200 RPM max and 1m/s speed	Max angle to maintain 1m/s movement	113 degrees
Pulling Force for 4 Wires	Force acting of the robot	For dr= 0.0254m and dA= 0.9144, F_c= 35.26N
Maximum Torque	Motor selection	τ = 0.2 Nm

Table 4: Engineering Calculations

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Calculations Table

Calculations Table			
Equation	How it's applicable.	What requirements these equations meet.	How we validated the answers obtained.
t = I * h	Calculating minimum battery required to achieve desired run time.	Minimum run time of 30 minutes.	Obtained average power draw from online sources and used those to calculate time
θ = arctan(y / x)	Calculating position of robot as it moves closer to boundary	Position accuracy of 0.1mm	Solved equations by hand and used scale model to test angles
S=(F*nf) / A = (T*nf)/ A	Calculates the minimum amount of stress our cable needs to able to withstand	To be able to withstand 10 N of Force	By finding the amount stress induced we can select an appropriate wire
∑MA=0	Calculates the minimum amount of tension in cables	Minimum tension needs to be 2.2lbs or nearly 10 N	Using structural analysis, the equation can be solved by hand
τ = F*r	Calculates the estimated maximum applied torque	Finding a motor that can output the required 10 N of force	Using a MATLAB script to calculate the torques at all positions the robot could be at
τadjusted = F.O.S. * τ	Calculates the estimated maximum applied torque using the factor of safety	Finding a motor that can output the required 10 N of force accounting for a factor of safety	Using a MATLAB script to calculate the torques at all positions the robot could be at
$M = MP_{hm}g(L(1-0.5P_{hl})) + MP_{fm}g(L(0.5P_{fl}+P_{al})) + MP_{am}g(L(0.5P_{al}))$	Calculates net upward force needed to move an extended arm	Moving user's hand with an upward force of 10 newtons	Used human body mass percentages and solved by hand
$F_y = F_t * \cos(\theta)$	Calculates downward force due to wire tension	Applying 10N force in horizontal and vertical directions	Solved by hand using force diagrams and position assumptions

Table 5: Calculations Table

Calculations Table

Calculations Table			
Equation	How it's applicable.	What requirements these equations meet.	How we validated the answers obtained.
L10 = (C/P)^3*10^6	Calculates the amount of roations a ball bearing will do in it's lifetime.	1m/s robot speed and lifetime of the bearings	solve by hand and by diagram
N=(v*60)/(pi*D)	Calculates a bearings RPM	1m/s robot speed	solve by hand and by diagram
L10h=L10/(60*N)	Caluates how many lifetime hours a bearing has	1m/s robot speed and lifetime of the bearings	solve by hand and by diagram
(v/C)x60	Convert velocity to revolutions per minute	determining winch diameter and anchor point distance	solve by hand and verify angles and distance in CAD
θ=arccos(Winch RPM/Max motor RPM)	determines the max angle of cable at max motor RPM	Selecting winch diameter	solve by hand and CAD
sin(A)/a=sin(B)/b (law of sines)	Calculates minimum anchor point distance while robot is at center.	Cable length and motor torque calculations	solve by hand and verify angles and distance in CAD
$M = MP_{hm}g(L(1-0.5P_{hl})) + MP_{fm}g(L(0.5P_{fl}+P_{al})) + MP_{am}g(L(0.5P_{al}))$	Calculates net upward force needed to move an extended arm	Moving user's hand with an upward force of 10 newtons	Used human body mass percentages and solved by hand
$F_y = F_t * \cos(\theta)$	Calculates downward force due to wire tension	Applying 10N force in horizontal and vertical directions	Solved by hand using force diagrams and position assumptions

Table 5 Cont.: Calculations Table

Pugh Chart

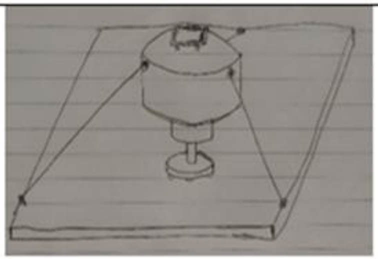
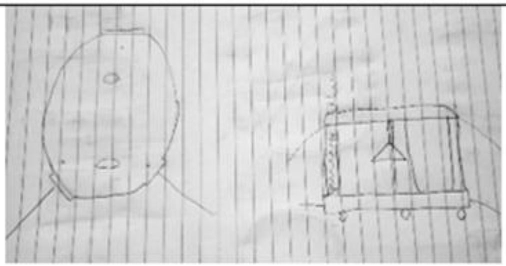
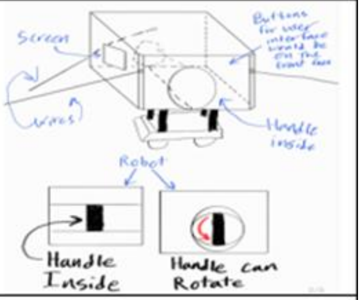
Criteria			
Design	1	2	3
Production cost	+ Smaller device	S	Datum
Speed of the Robot	-It has a smaller base to work with	+The base and double wire allow for fast accurate movement	Datum
Device Size	+ It has a small frame	+ it is more compact than the Datum	Datum
Position Tracking	S	S	Datum
Force	-Smaller base to account from moment	S	Datum
User Friendliness	-Setup difficulties from base size and user touchscreen.	+It has a fast and easy set up with a screen	Datum
Total +	2	3	
Total S	1	3	
Total -	3	0	

Table 6: Pugh Chart

Design 2 is our best design according to the Pugh Chart

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Benchmarking

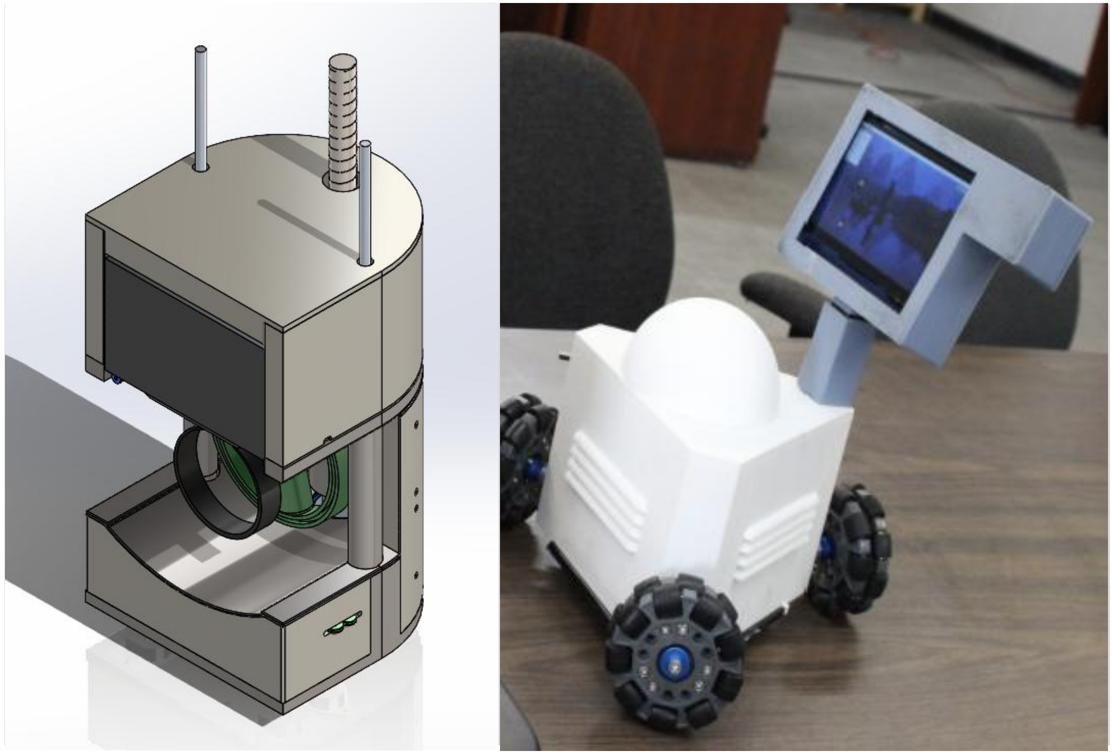


Figure 16: Current CAD iteration compared to Hamster

Comparison to Other Products

- Compact in stowed configuration
- More affordable than other available models
- Easily moveable for setup
- Fast setup process
- Comparatively simple motion design
- Provides partial arm support
- Provides vertical motion

Gantt Chart and Schedule

1st Prototype Demo	Med Risk	All	50%	3/25/2025	7
Presentation 3	Low Risk	All	75%	3/25/2025	7
Team Feedback 3	Milestone	All	0%	3/31/2025	1
April					
Peer Eval 3	Milestone	All	0%	4/1/2025	1
Staff Meeting 7	Milestone	All	0%	4/7/2025	1
Staff Meeting 8	Milestone	All	0%	4/14/2025	1
Report 2	Low Risk	All	0%	4/12/2025	7
Final Staff Meeting	Milestone	All	0%	4/21/2025	1
Final CAD and BOM	On Track	All	20%	4/19/2025	7
HW4-Individual Analysis	Low Risk	All	0%	4/19/2025	7
2nd Prototype Demo	Low Risk	All	0%	4/22/2025	7
Proto Demo Feedback	Milestone	All	0%	4/28/2025	1
Project Management for 486C	Low Risk	All	0%	4/26/2025	7
May					
Website Check 2	Low Risk	All	0%	5/2/2025	3
Final Peer Eval	Milestone	All	0%	5/6/2025	1

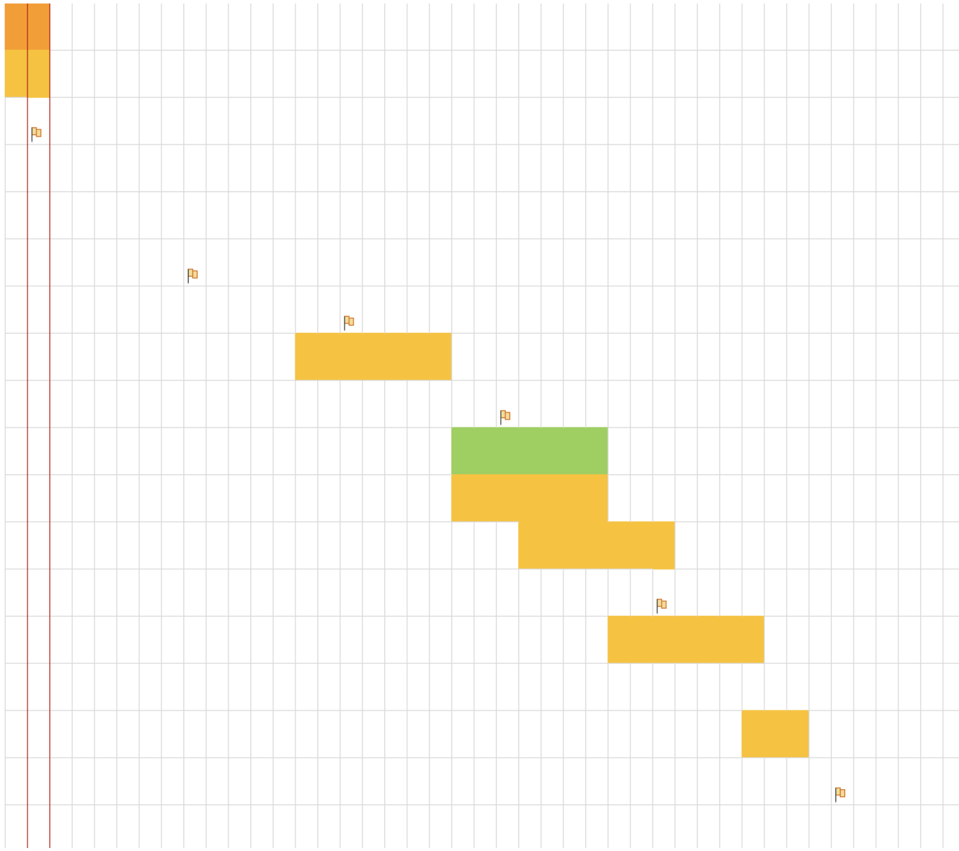


Figure 17: Partial First Semester Gantt Chart

Flying Squirrel

Project start: **Wed, 8/20/2025**

Display week: **1**

SIMPLE GANTT CHART by Vertex42.com
https://www.vertex42.com/ExcelTemplates/simple-gantt-chart.html

TASK	ASSIGNED TO	PROGRESS	START	END
August				
Define goals			8/25/25	8/25/25
Homework 00			8/25/25	9/1/25
Project Management			8/25/25	9/1/25
September				
Meetings			9/1/25	9/1/25
Self-Learning/Analysis			9/1/25	9/8/25
Client Meeting			9/4/25	9/4/25
Define scope			9/4/25	9/6/25
Engineering Calculations			9/1/25	9/8/25
Meetings			9/8/25	9/8/25
Client Meeting			9/11/25	9/11/25
Meetings			9/15/25	9/15/25
Client Meeting			9/18/25	9/18/25
Hardware Status Update			9/22/25	9/22/25
Peer Eval 1			9/22/25	9/22/25
Client Meeting			9/25/25	9/25/25

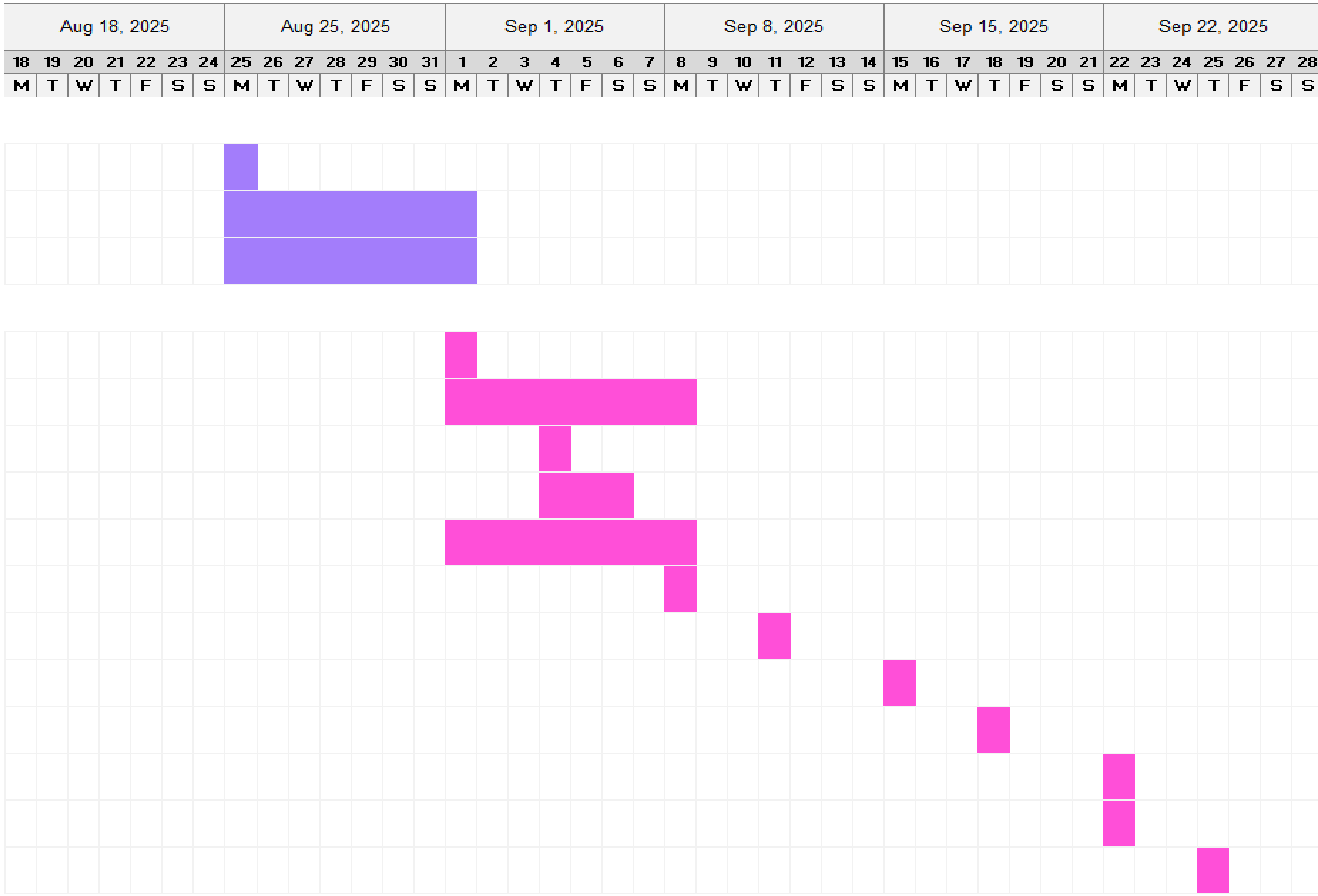
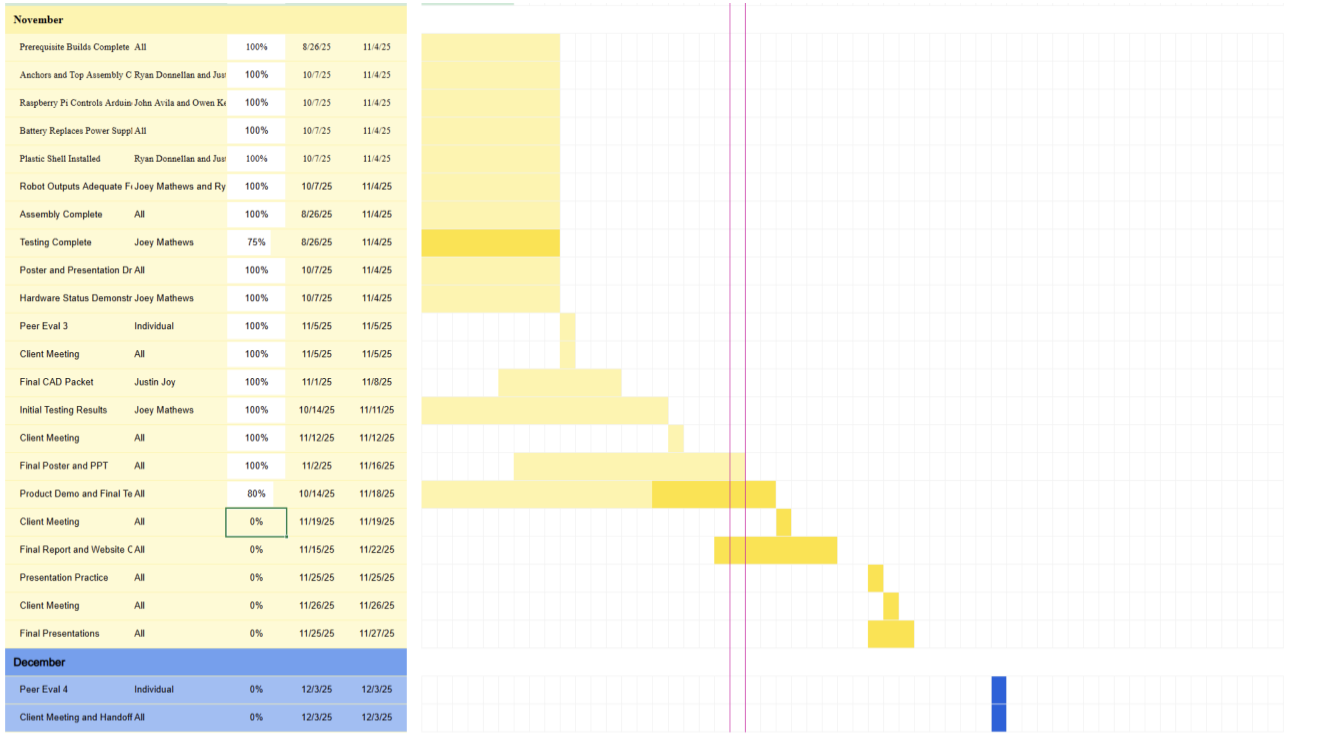


Figure 18: Second Semester Gantt Chart

Gantt Chart



November				
Prerequisite Builds Complete	All	100%	8/26/25	11/4/25
Anchors and Top Assembly C	Ryan Donnellan and Just	100%	10/7/25	11/4/25
Raspberry Pi Controls Arduin	John Avila and Owen Ke	100%	10/7/25	11/4/25
Battery Replaces Power Suppl	All	100%	10/7/25	11/4/25
Plastic Shell Installed	Ryan Donnellan and Just	100%	10/7/25	11/4/25
Robot Outputs Adequate F	Joey Mathews and Ry	100%	10/7/25	11/4/25
Assembly Complete	All	100%	8/26/25	11/4/25
Testing Complete	Joey Mathews	75%	8/26/25	11/4/25
Poster and Presentation Dr	All	100%	10/7/25	11/4/25
Hardware Status Demonstr	Joey Mathews	100%	10/7/25	11/4/25
Peer Eval 3	Individual	100%	11/5/25	11/5/25
Client Meeting	All	100%	11/5/25	11/5/25
Final CAD Packet	Justin Joy	100%	11/1/25	11/8/25
Initial Testing Results	Joey Mathews	100%	10/14/25	11/11/25
Client Meeting	All	100%	11/12/25	11/12/25
Final Poster and PPT	All	100%	11/2/25	11/16/25
Product Demo and Final Te	All	80%	10/14/25	11/18/25
Client Meeting	All	0%	11/19/25	11/19/25
Final Report and Website C	All	0%	11/15/25	11/22/25
Presentation Practice	All	0%	11/25/25	11/25/25
Client Meeting	All	0%	11/26/25	11/26/25
Final Presentations	All	0%	11/25/25	11/27/25
December				
Peer Eval 4	Individual	0%	12/3/25	12/3/25
Client Meeting and Handoff	All	0%	12/3/25	12/3/25

Figure 19: End of Semester Gantt Chart

Progress

- Build and parts are completed
- Testing has been completed

Budget

Current Project Budget	$3,750
Anticipated Expenses	-$0
Actual Expenses to Date	-$2,670.47
Resulting Balance	$1,079.53

Table 7: Budget

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Purchasing Plan/BOM

	Bill Of Materials								
	Raw Materials, Parts or Components	($) Unit Cost	make/buy	Primary vendo	Manufacturer	lead time	Part Status	QTY	($) Total cost
1	3 Axis force sensor	320.57	buy	zhimin	zhimin	Arrived	on hand	1	320.57
2	ODrive S1	59.00	buy	Odriverrobotics	Odriverrobotics	2 week	on hand	4	236
3	16384 CPR Absolute RS485 Encoder with Cable for ODrive Pro or S1	149	buy	Odriverrobotics	Odriverrobotics	2 week	on hand	4	596
4	Heat Spreader Plate	12	buy	Odriverrobotics	Odriverrobotics	3 week	on hand	3	36
5	Harness Build Kit	9	buy	Odriverrobotics	Odriverrobotics	4 week	on hand	4	36
6	Dual Shaft Motor - D5312s 330KV	59.00	buy	Odriverrobotics	Odriverrobotics	2 week	on hand	4	236
7	PLA (3Kg)	49.71	buy	Amazon	creality	2 days	on hand	1	49.71
8	drylin® lead screw, dryspin® high helix thread, right-hand thread, 1.4301 (304) stainless steel	64.8	buy	Roton	Roton	1.5 weeks	on hand	1	64.8
9	dryspin® lead screw nut, high helix thre	48.02	buy	Roton	Roton	1.5 weeks	on hand	1	48.02
10	2x OVONIC 3S Lipo Battery 15000 mAh 130C 11.1V LIPO battery with EC5 plug for 1/8 RC truck	138.38	buy	ovonic	ovonic	1 week	on hand	1	138.38
11	Raspberry Pi 5 8GB	80	buy	electromaker	raspberrypi	Arrived	on hand	1	80
12	Arduino UNO R4	27.5	buy	Amazon	ELEGOO	Arrived	on hand	1	27.5
13	Strap	8.99	buy	industrialsafety	industrialsafety	1 week	on hand	1	8.99
14	6.5x3 touch LED screen	0	buy	waveshare	waveshare	2 weeks	on hand	1	0
15	Ball bearings	8.99	buy	harborfreight	harborfreight	3 days	on hand	1	8.99
16	DC power supply	33.94	buy	Amazon	Nice-Power	3days	on hand	1	33.94
17	Suction cup	12	buy	Amazon	Airhead	3 days	on hand	3	36
18	Fishing line	10.98	buy	Amazon	yond Braid Braid	3 days	on hand	1	10.98
19	C-Clamp	5	buy	Home depot	Amerella	3 days	on hand	3	15
20	screws	18.98	buy	Home depot	Amerella	3 days	on hand	1	18.98
21	linear ball bearings	5.83	buy	misumi	misumi	1 week	on hand	1	5.83
22	Amplifier Load cell	6.99	buy	Amazon	amazon	3 days	on hand	1	6.99
23	Uxcell 10mm OD 8mm Inner Dia 400mm Length 6063 Aluminum Tube	6.22	anufacture	harfington	harfington	1 week	on hand	2	12.44
24	terminal block distribution	12.99	buy	Amazon	OOMO	3 days	on hand	1	12.99
25	Breadboard	9.99	buy	Amazon	amazon	Arrived	on hand	1	9.99

Table 8: Bill of Materials

- Approximately $2,680.10 expended with about $1,079.53 remaining in the budget

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FMEA

Flying Squirrel		Development Team: Jonathan Avila, Ryan Donnellan, Justin Joy, Owen Kehl, Joey Mathews				Page No. 1 of 3			
Bottom Plate						FMEA Number: N/A			
ALL						Date: 3/31/2025			
ALL									
Part # and Functions	Potential Failure Mode	Potential Effect(s) of Failure	Severity (S)	Potential Causes and Mechanisms of Failure	Occurrence (O)	Current Design Controls Test	Detection (D)	RPN	Recommended Action
1 Roller Bearing	Surface Fatigue	Increased force to move robot	5	Assembly error	1	Pull with force sensor	1	5	Purchase high quality parts
2 Base Shell	Brittle Fracture	Appearance	3	Impact loading	3	Visual inspection	2	18	Use high in-fill for plastic
3 Battery	High-cycle Fatigue	Gradual decrease of run time	2	Overdischarging	2	Test with voltmeter	2	8	Revised higher stress test plan
4 Microcontroller (Teensy)	Electrical Shorting	Causes robot to become inoperable	9	Assembly error	1	Run test program	1	9	None
5 Motor Controller	Electrical Shorting	Reduction in performance of all axis movement	7	Over voltage/current	2	Run test program	1	14	Purchase High Quality
6 Lifting Motor	High-cycle Fatigue	Loss of z-axis movement	8	Over voltage/current	2	Test with RPM, force, and voltmeter	1	14	None
7 Drive Motor	High-cycle Fatigue	Loss of xy-axis movement	8	Over voltage/current	2	Test with RPM, force, and voltmeter	1	32	None

Table 9: FMEA

FMEA

Flying Squirrel		Development Team: Jonathan Avila, Ryan Donnellan, Justin Joy, Owen Kehl, Joey Mathews	Page No. 2 of 3
Center Structure			FMEA Number: N/A
ALL			Date: 3/31/2025
ALL			

Part # and Functions	Potential Failure Mode	Potential Effect(s) of Failure	Severity (S)	Potential Causes and Mechanisms of Failure	Occurrence (O)	Current Design Controls Test	Detection (D)	RPN	Recommended Action
8 Lifting Strut	Surface Fatigue Wear	Loss of lifting performance	5	Overstressing	1	Ensure nut slides smoothly over lift screw	1	5	Purchase quality parts
9 Handle Rotation Mechanism	Surface Fatigue Wear	Increase handle rotation resistance	5	Overstressing	2	Rotate handle thorough many cycles to ensure smooth movement	1	10	Use high in-fill for plastic
10 Handle	Impact Fracture	Loss of handle	8	Impact loading	2	Visual Inspection	2	32	Use high in-fill for plastic
11 Capture Strut	Surface Fatigue Wear	Loss of lifting performance	5	Overstressing	3	Ensure nut slides smoothly over lift screw	1	15	Use high in-fill for plastic

Table 9: FMEA Cont'd

FMEA

Flying Squirrel		Development Team: Jonathan Avila, Ryan Donnellan, Justin Joy, Owen Kehl, Joey Mathews				Page No. 3 of 3			
Top Plate						FMEA Number: N/A			
ALL						Date: 3/31/2025			
ALL									
Part # and Functions	Potential Failure Mode	Potential Effect(s) of Failure	Severity (S)	Potential Causes and Mechanisms of Failure	Occurrence (O)	Current Design Controls Test	Detection (D)	RPN	Recommended Action
12 Top Shell	Brittle Fracture	Appearance	3	Impact loading	3	Visual inspection	2	18	Use high in-fill for plastic
13 Drive Motor	High-cycle Fatigue	Reduction in performance of x,y-axis movement	7	Over voltage/current	2	Test with RPM, force, and voltmeter	1	14	None
14 Microcontroller (Raspberry Pi)	Electrical Shorting	Causes robot to become inoperable	10	Assembly Error	1	Run test program	1	10	None
15 Winch Housing	Abrasive Wear	Inaccuracy of x,y-axis movement	4	Overstressing	2	Visual inspection	2	16	Use high in-fill for plastic
16 Winch Line	Creep	Inaccuracy of x,y-axis movement	5	Overstressing	3	Visual inspection	7	105	Test line weight
17 Screen	Impact Wear	Unable to program movement of robot	6	Impact loading	4	Power on	1	24	Purchase high quality parts

Table 9: FMEA Cont'd

Design Progress

- Our final, final iteration of the *Flying Squirrel* design
- Separate shell pieces have been combined for greater structural stability
- All designs finalized
- Anchor designs finalized based on Dr. Razavian's recommendations

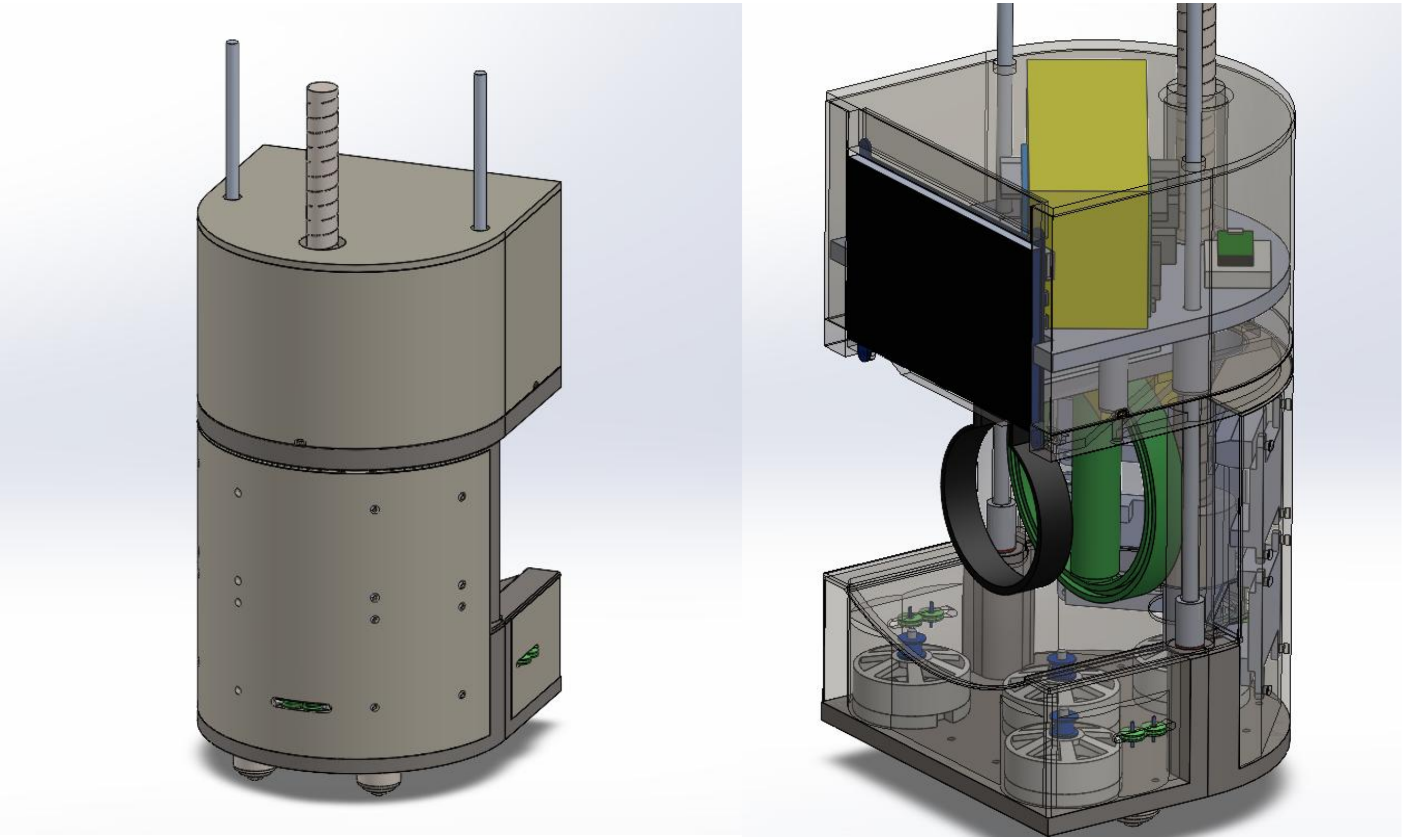

Figure 20: Back View and Internal View of Finalized Design

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Cable Anchor/Pulleys

- 3D printed bracket to mount to two different table mounts
  - C-clamp
  - Suction cup
- Rotating pulley mount on arm of suction cup
- Allows robot to operate on different type tables bases on shape and size
  - Small tables utilize clamps
  - Lage tables or desks may need both clamps and suction cups

Figure 21: Suction Cup

Figure 22: Clamp

Physical Model

- All components are present, some are not fully connected to allow manipulation and wire management
- 3D-printed lead screw nut as stopgap

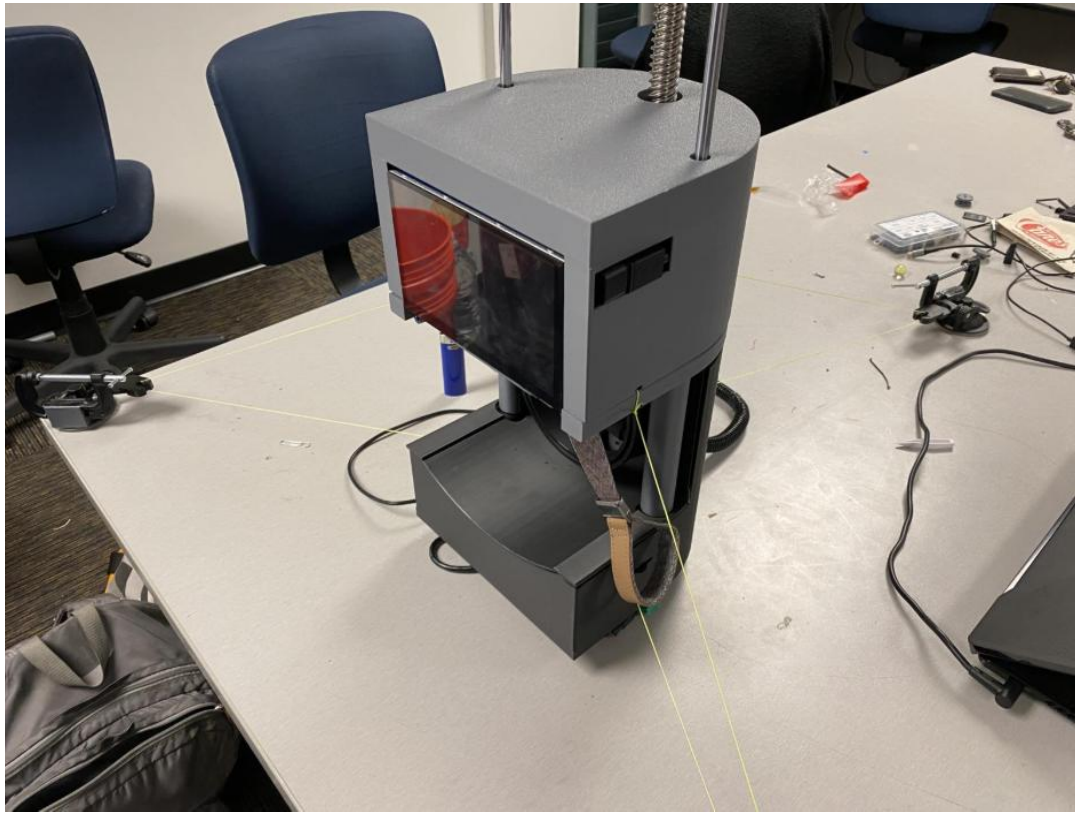

Figure 23: Current Physical Build

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Manufacturing Plan

Aspects

- All custom components are manufactured
- Most were 3d printed
- All cables and electrical components have been added to the assembly
  - Top cover removable to access battery, Raspberry Pi, and force sensor
  - Lower cover removable to access motors, motor drivers, and teensy

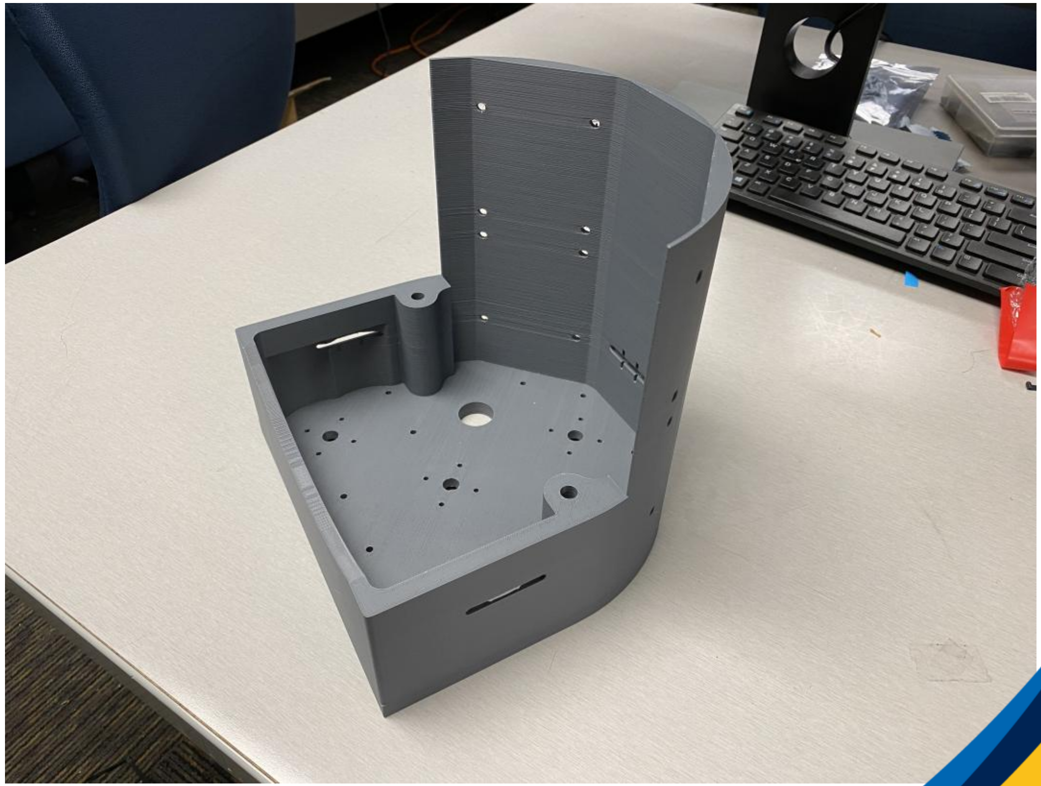

Figure 24: 3D Printed Baseplate

Manufacturing Plan

Part	Time (hours)	Manufacturing Method	Filament Used (grams)	Progress Percent (%)
Base Plate	20.76	3D Printed	745	100
Back Wall				
Base Wall Front				
Base Wall Middle	3.5	3D Printed	127	100
Bottom Back Ceiling	3.5	3D Printed	136	100
Bottom Front Ceiling				
Anchor Pully Mount	0.5	3D Printed	11	100
Anchor Clamp Mount				
Handle Plate	1.5	3D Printed	58	100
Handle	2.75	3D Printed	107	100
Handle Track	0.167	3D Printed	6	100
Top Shell Ceiling	4.5	3D Printed	268	100
Top Shell Wall				
Coupler	0.5	3D Printed	23	100
Top Plate	12.5	3D Printed	451	100
Top Mounting Plate	7	3D Printed	261	100
Motor Mounting Bracket x 4	1	3D Printed	28	100
Idler Pulley x 9	2	3D Printed	60	100
Anchor Pully Lock x 3				
Anchor Suction Cup Mount x 3				
Anchor Pully Mount x 3				
Coupler Idler Pulley				
Anchor Clamp Mount x 3				
Pulley x 3	0.25	3D Printed	4.5	100
Load Cell Fixture	43	3D Printed	1726	100
Lead Screw Nut	1.5	3D Printed	60	100
Total	104.927	All manufactured parts are 3D printed	4071.5	100

Table 10: Manufacturing Plan

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Sub-System Prototype

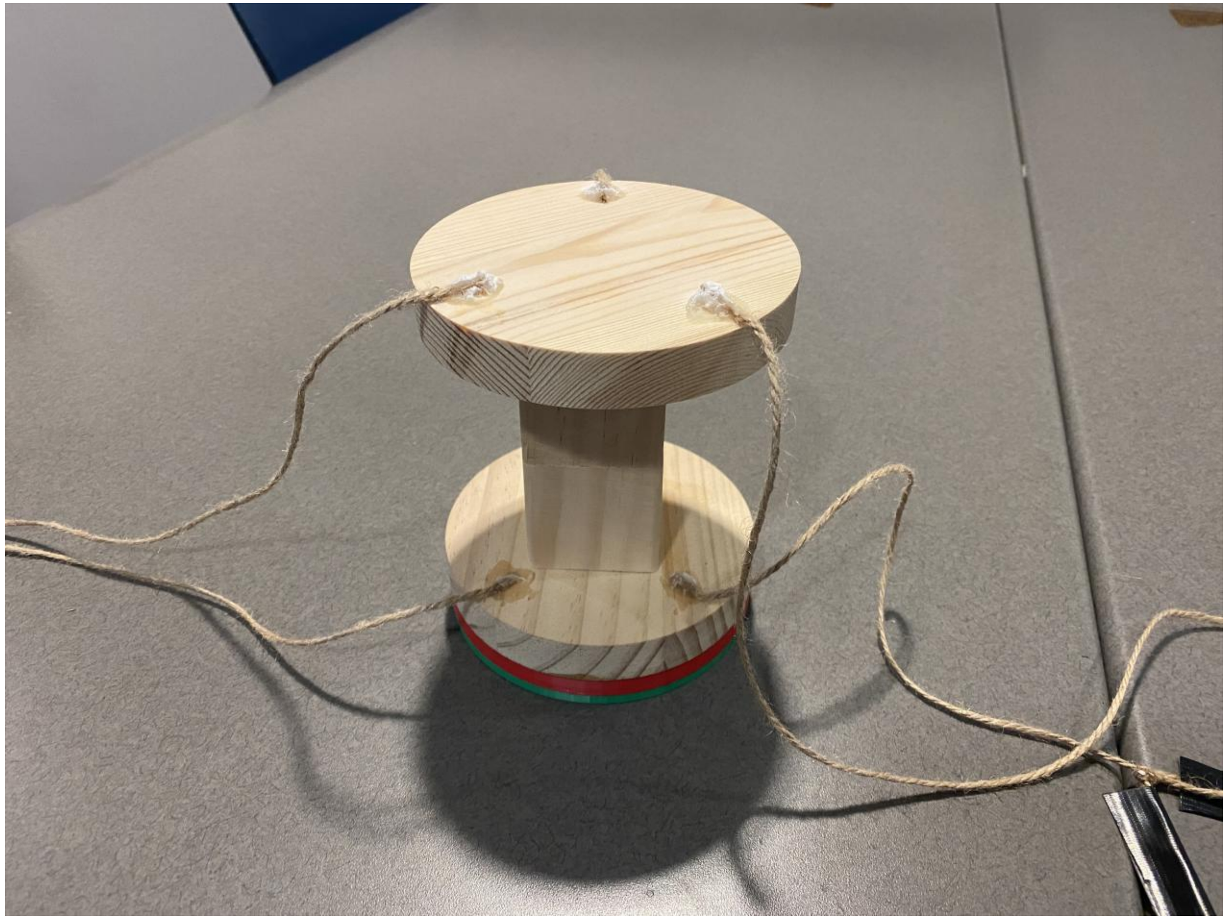

Figure 24: Face Smasha'

Approximately 13.75% Total volume of flying squirrel

Question(s) this prototype answered:

Face Smasha' ver. 1.0:
- Cables mounted on top or bottom?
- Is 4" enough for the average hand?

Face Smasha' ver. 1.01:
- Cables mounted to both top and bottom?

Face Smasha' ver. 1.1:
- How well do ball bearings roll on 3D printed surface?

Top Level

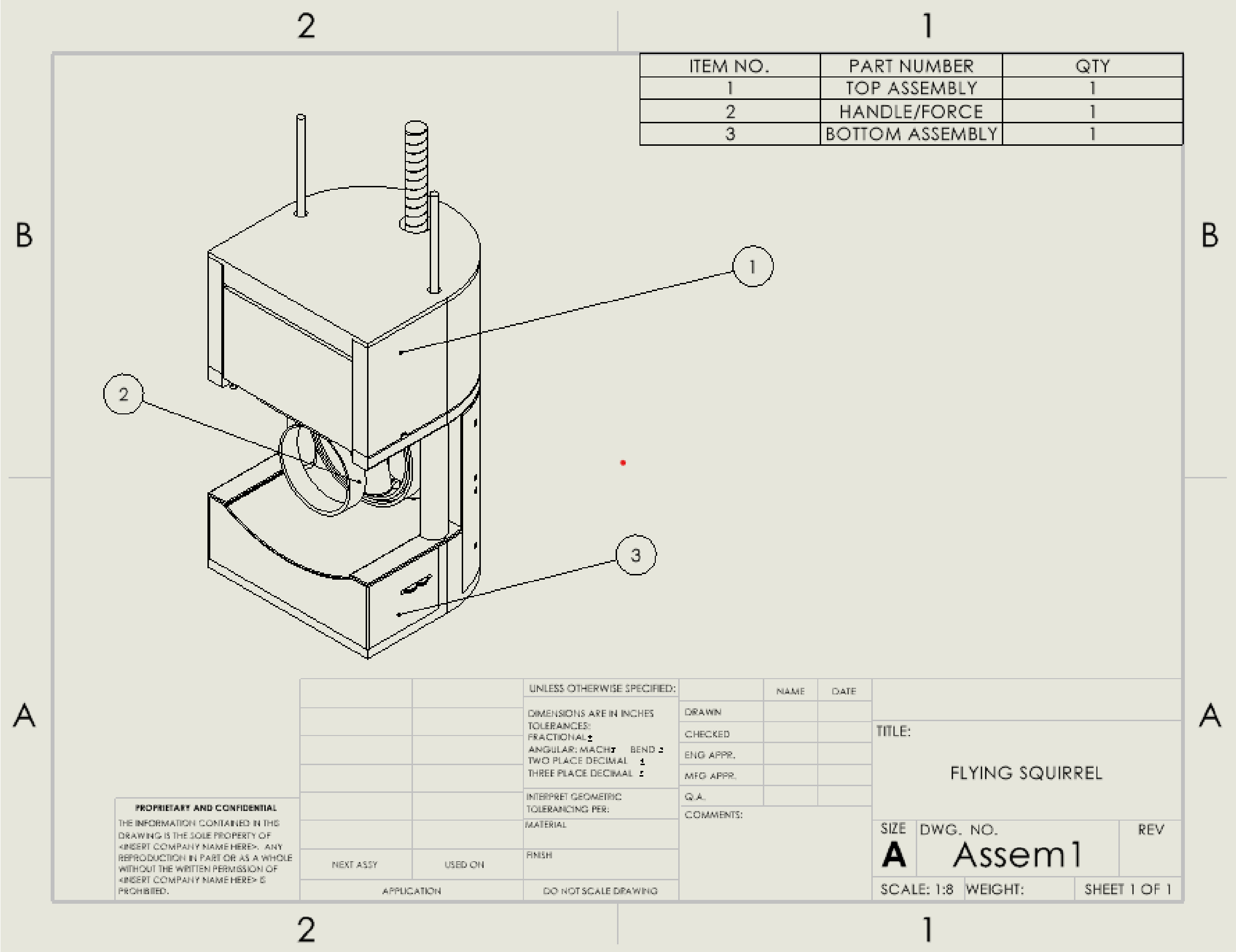

Figure 25: Top Level Engineering Drawing

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Top Level

Suction cup

Figure 26: Suction Cup

Clamp

Figure 27: C Clamp

Control Diagram

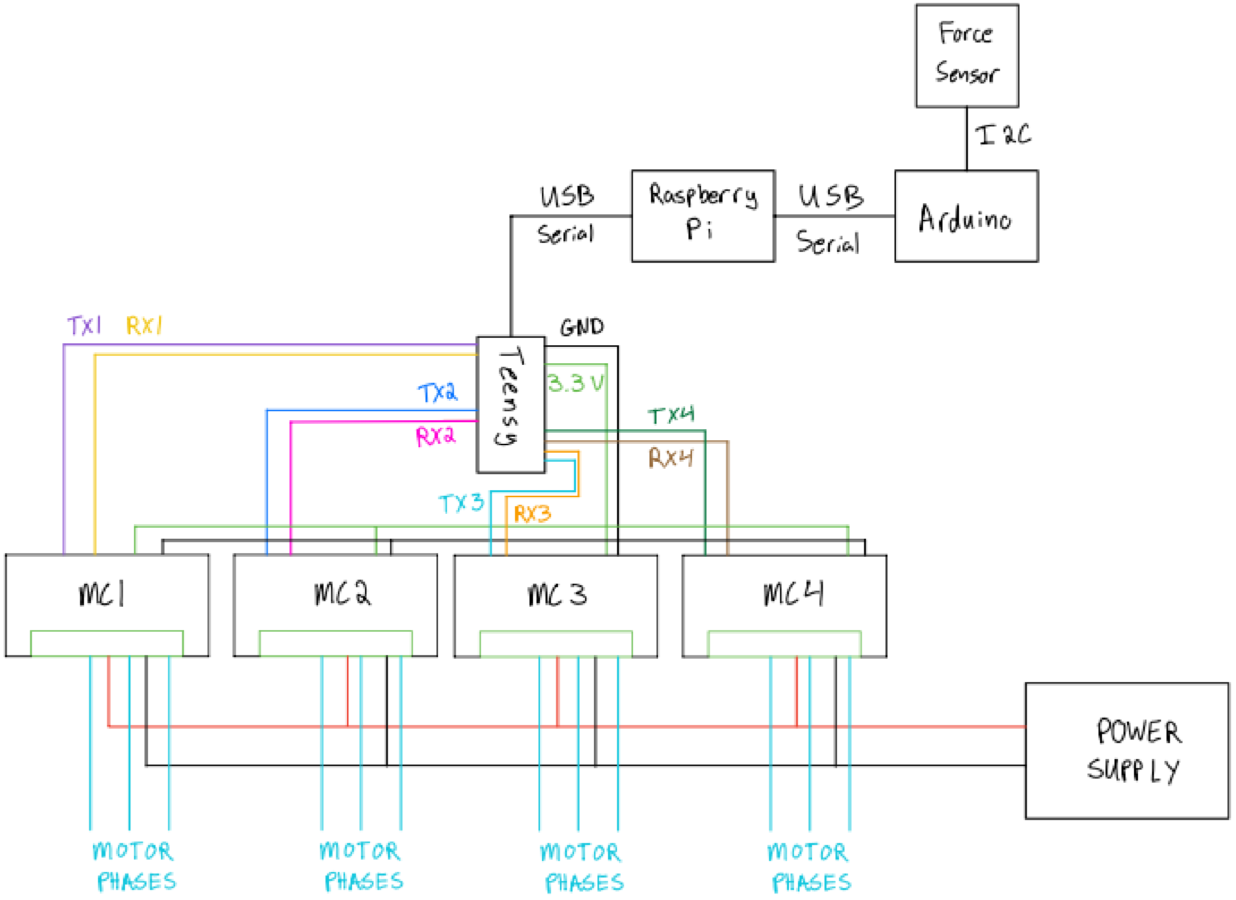

Figure 28: Control Diagram

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Important Sub-Assemblies

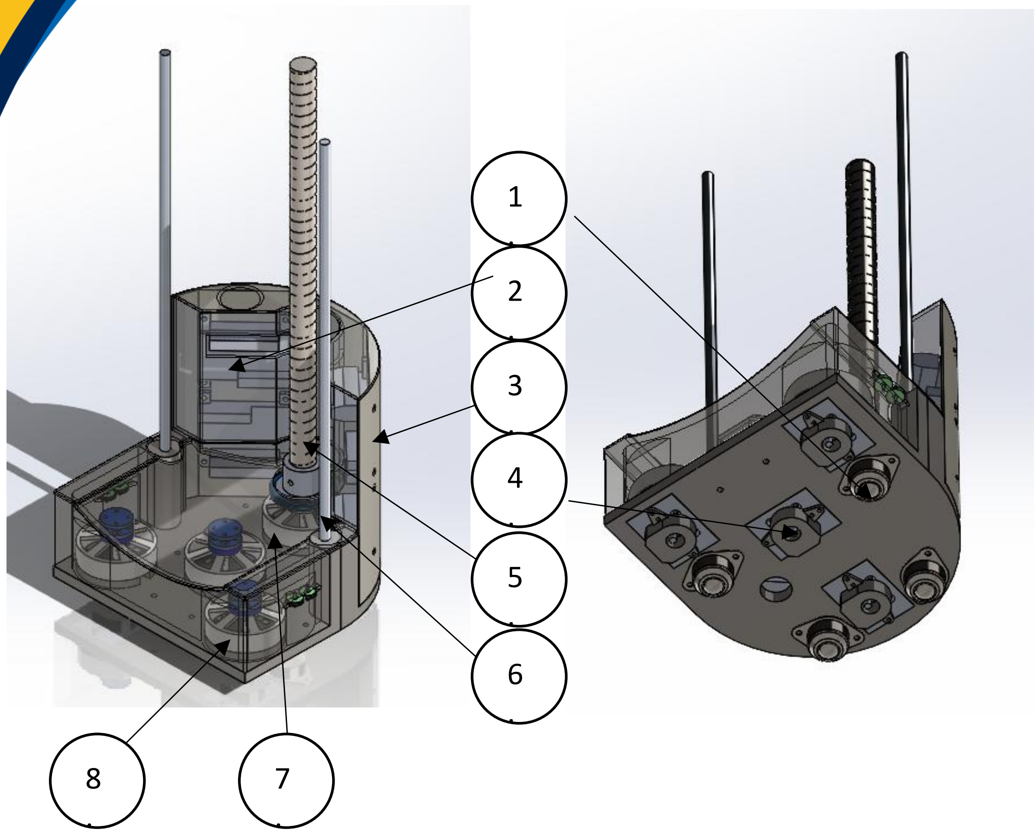

Figure 29: Sub-Assemblies Bottom

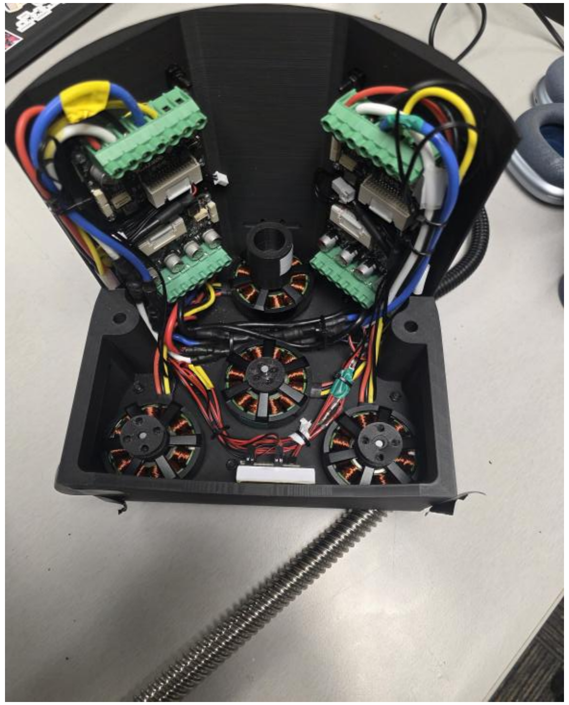

Figure 30: Bottom Assembly Build

Bottom Sub-Assembly

1. Rollers/Bearings
2. Motor driver
3. Body Shell
4. Motor encoder
5. Lift Screw
6. Support strut
7. Lift Motor (z)
8. Cable Motor (x, y)

Important Sub-Assemblies

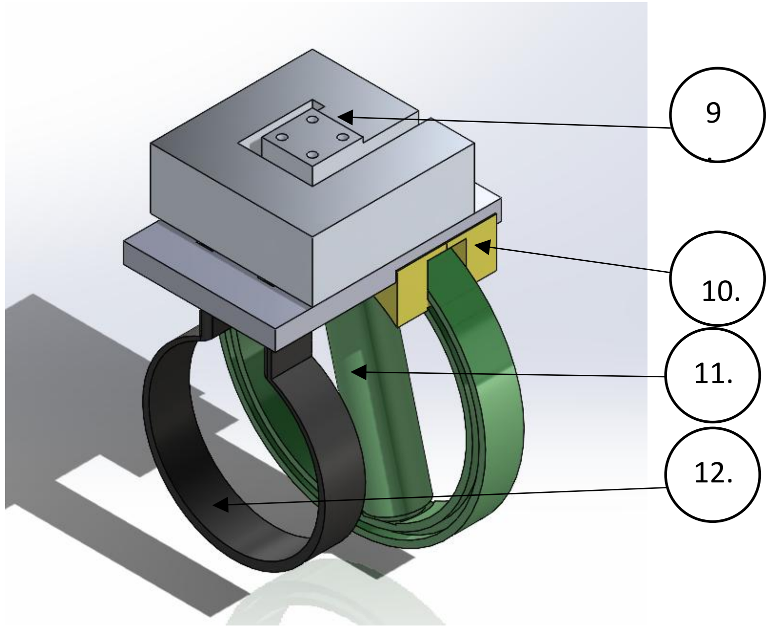

Figure 31: Sub-Assemblies Middle


Figure 32: Handle and Force Sensor

Center Sub-Assembly
9. Force sensor
10. Handle rotation mechanism
11. Handle
12. Wrist strap

Important Sub-Assemblies

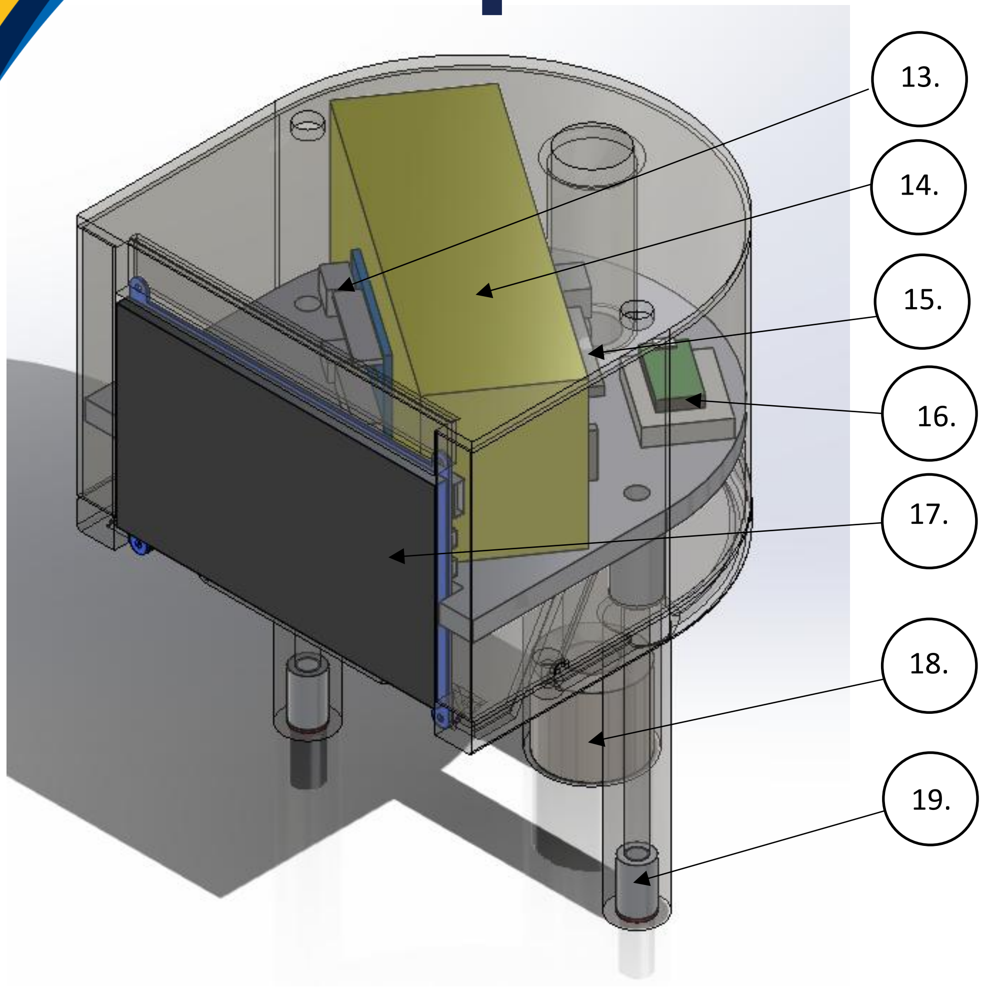

Figure 33: Sub-Assemblies Top

Figure 34: Top Assembly

Top Sub-Assembly

13. Raspberry Pi
14. Battery
15. Arduino
16. Teensy
17. Display screen
18. Lead screw
19. Linear bearing

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Top Level Testing Summary

Experiment/Test	Relevant DRs
EX1- Cable Movement Test	CR2, CR3, ER1, ER3, ER5
EX2- Lifting Test	CR2, CR3, ER1, ER3, ER5
EX3- Load Cell Test	CR3, ER4, ER5
EX4- Force Output Test	CR3, CR7, ER4, ER5
EX5- Endurance Test	CR5, ER6
EX6- Set-up Time Test	CR7, ER8

Table 11: Top level testing summary table

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Movement Test

- Test Summary
  - Tested the velocity at which the robot moves as well as how accurate and repeatable the movements are (CR2,CR3, ER1,ER3,ER5)
- Procedure
  - Place tracking dots on robot so cameras can track its movement
  - Place motion capture cameras surrounding the test area of the robot
  - Run robot and motion capture software then analyze the movements to see if the velocity and position are within specification.
- Results
  - The robot, when tested, was able to move about 1 m/s vertically and 2 m/s horizontally
  - Velocity measured using motion capture cameras with an accuracy of less than 1mm/s

Figure 35: Vertical Velocity Test

Force Output Test

- Test Summary
  - Will test force produced by the robot (ER4)
- Procedure
  - For xy motors, one team member must pull on the cable with the luggage scale while another holds the robot in place (with the motor pulling towards the robot), until the motor stalls
  - For the z motor, weights are stacked on the stripped-down top plate to simulate the weight of the top components plus ten Newtons
- Results
  - The minimum stalling force for one of the horizontal motors is approximately 29 Newtons
  - The vertical motor is able to lift the fully assembled top plate with an extra 10N of force applied, which is approximately 54N in total

Figure 36: Vertical Force Testing

Figure 37: XY Force Testing

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Load Cell Test

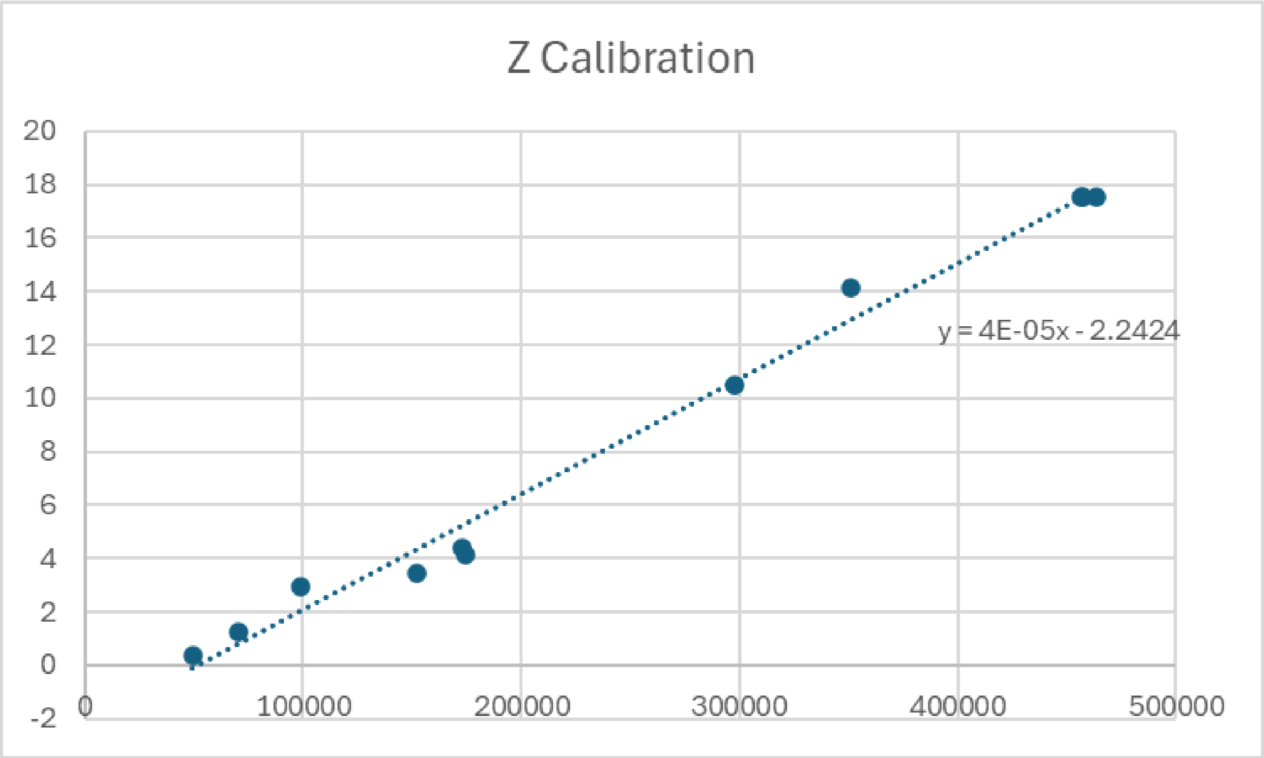

Figure 38: Calibration Data Points and Best Fit Line

- Calibration done in the Z direction by applying known weights to the top of the cell
- Best fit linear equation used in Excel to encompass the data, subsequent tests showed y-intercept to be unsound
- Ratio of full-scale outputs from manufacturer in each direction used to determine x and y calibration coefficients

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Endurance Test

- Test Summary
  - The robot's battery life while in use will be determined by this test (CR5, ER6)
- Procedure
  - We plan to run a procedure that will involve all four motors and simulate extended use by a patient
  - While the robot is continuously running, it will be monitored by either team members or the video camera for 30 minutes
- Results
  - Following the actual test, examining battery revealed that it had depleted about 15%
  - From full charge, the Flying Squirrel should be useable for around 2 hours 10 minutes before it reaches half charge
  - The battery will not reach dangerous state of charge due to depletion below 20%

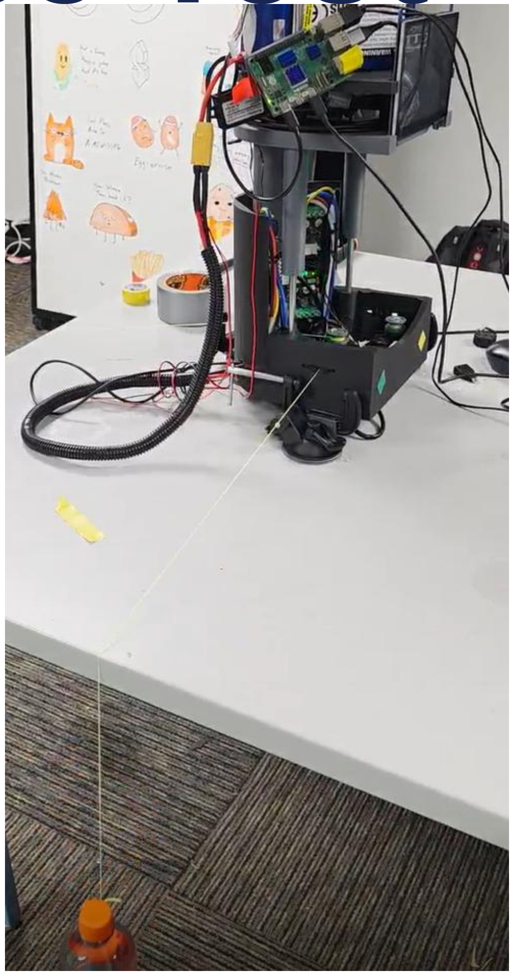

Figure 39: Endurance Test Run

Figure 40: Battery

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Setup Test

- Test Summary
  - This test will evaluate how long it takes to set up the robot from its most inactive state (CR7, ER8)
- Procedure
  - From its stowed position, one team member must carry the Flying Squirrel to a proper work surface, pull out and attach the anchors, then power it on while another team member monitors the time elapsed
- Results
  - Setting the Flying Squirrel up from its stowed configuration took approximately 43 seconds

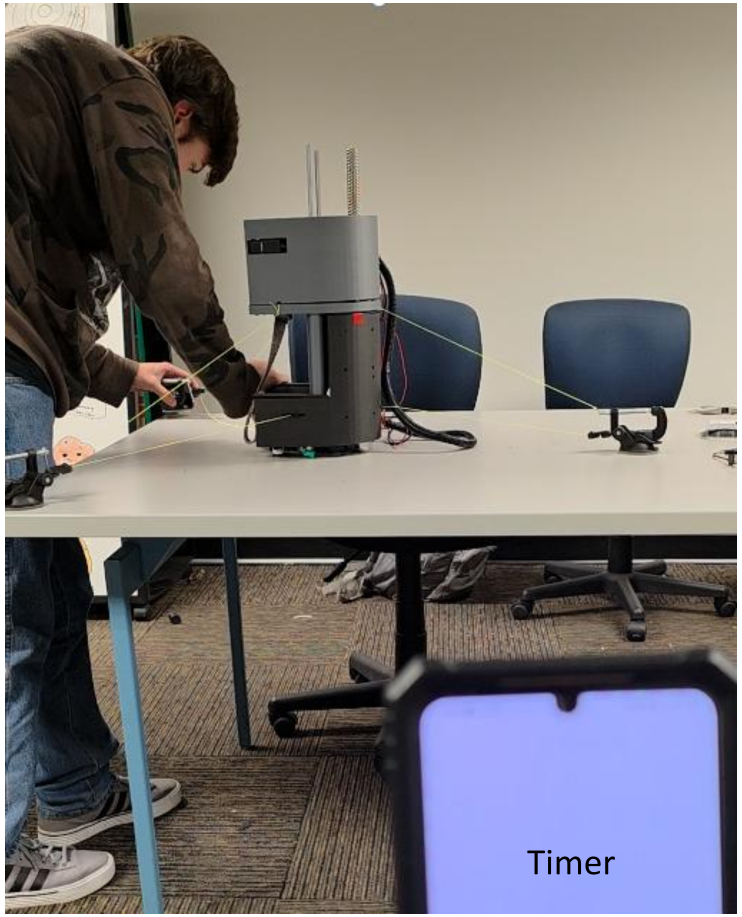

Figure 41: Setting Up the Flying Squirrel

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Finalized Specification Sheet

Customer Requirement	CR met (Y/N)	Client Acceptable (Y/N)
Affordability	N	Y
3rd dimensional movement	Y	Y
Precision and Accuracy	N	N
Cosmetics	Y	Y
Size	N	Y
User Friendliness	Y	Y
Battery Life	Y	Y

Table 12: Customer Requirement Summary

Engineering Requirements	Target	Tolerance	Measured/ calculated value	ER met? (Y/N)	Client Acceptable? (Y/N)
Range of motion	~ 2ft side to side, 1ft vertically and forward/backward	N/A	2ft side to side, 1ft vertically and forward/backward	Y	Y
Size	8x8x8in	N/A	8x8x19in	N	Y
Speed	1m/s	N/A	2m/s horizonal 1m/s vertical	Y	Y
Force	10N	±1N	10N	Y	Y
Sensing and Control accuracy	0.1mm, 0.1N (sensing), 0.5mm, 1N (control)	The targets are tolerances	N/A	N	N
Battery Life	30 minutes	-0.0 minutes, +Any amount of time	30+ minutes- 1 test & calculated validation	Y	Y

Table 13: Engineering Requirement Summary

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Future Development

- Design functions well and fulfills customer requirements, but is not perfect
- UI can constantly be altered/tuned to be more intuitive and user friendly
- Plastic shell might be redesigned to allow easier disassembly
- Further testing with actual stroke patients, if possible
- Wiring might be simplified even further
- Force sensor was taken through a basic calibration process; more advanced calibration might be possible
- Ventilation/heat dispersion for electronics can be improved
- Utilize feedback from outside test subjects
- Program movement routines that simulate common arm movements

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Thank you!

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Question?
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