NAU

Flying Squirrel

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Background and Problem Statement

- More than 795,000 strokes occur per year in the U.S. [1]
- The *Hamster* exercises horizontal arm movement in debilitated patients
- More compact and affordable than alternatives
- 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

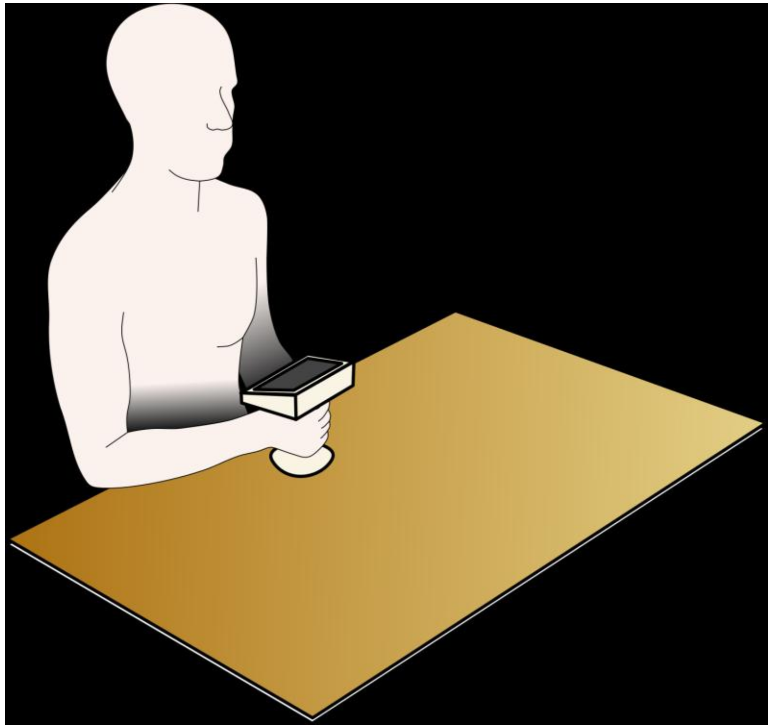

Figure 1: Representation of Hamster in Use

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Top Level

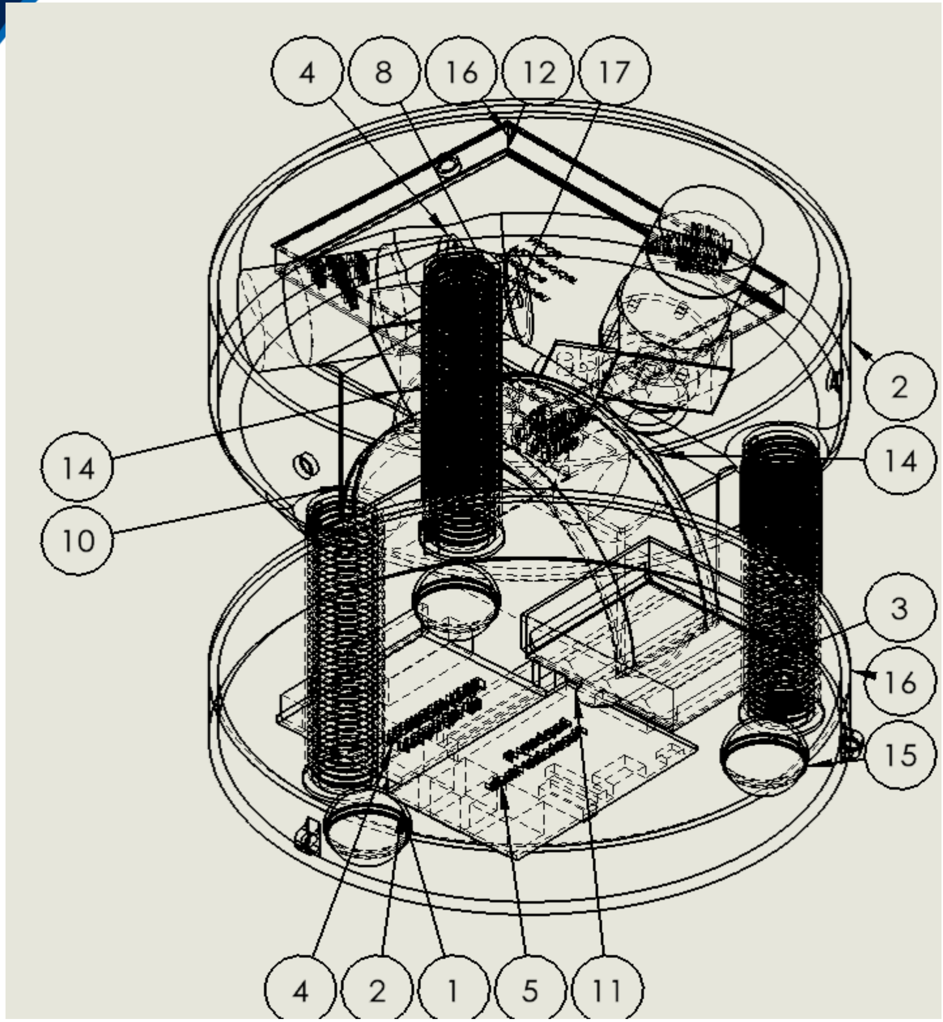

Figure 2: Top level

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
2	Body_Bottom	Bottom Shell	1
4	Arduino_Placeholder	Microcontroller (Arduino)	1
14	Motor_Placeholder	Optical Encoder Motor	3
4	Motor Mount	Motor Mount	3
17	Winch	Motor Winch	3
12	Body_Lid	Lid for Top Shell	1
16	Touchscreen_Placeholder	Touchscreen Interface	1
2	Base_Bottom	Bottom Base	1
3	BatteryPack	Battery pack	1
5	RaspPi_Placeholder	Microcomputer (Raspberry Pi)	1
11	Battery_Cover	Battery Lid	1
14	Motor_Driver_Placeholder	Motor Driver	3
1	Wheel	Roller Bearing	3
15	Wheel_Washer	Roller Bearing Washer	3
16	Base_Lid	Base Lid	1
8	Corkscrew	Lifting Screw	3
10	Handle	Handle	1

Figure 3:BOM

Top Level

One-line wire diagram

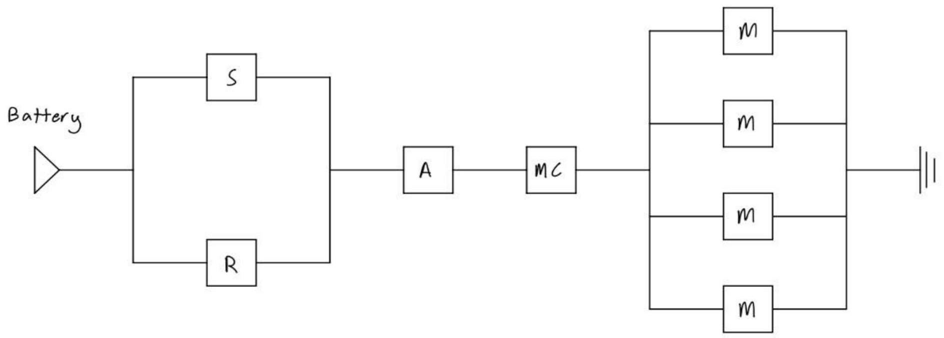

Figure 4: One Line diagram

Wire Gauge

- Approximately 10 amps running through robot.
- 16-gauge wire necessary

Functions

- Moves horizontally through wire tension
- Moves vertically by screw rotation
- Performs routines based on user input (Touch screen)
- Detects user force application through force sensor
- Slides on roller bearings

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Top Level

Suction cup

Figure 5: Suction Cup

Clamp

Figure 6: C Clamp

Control Scheme

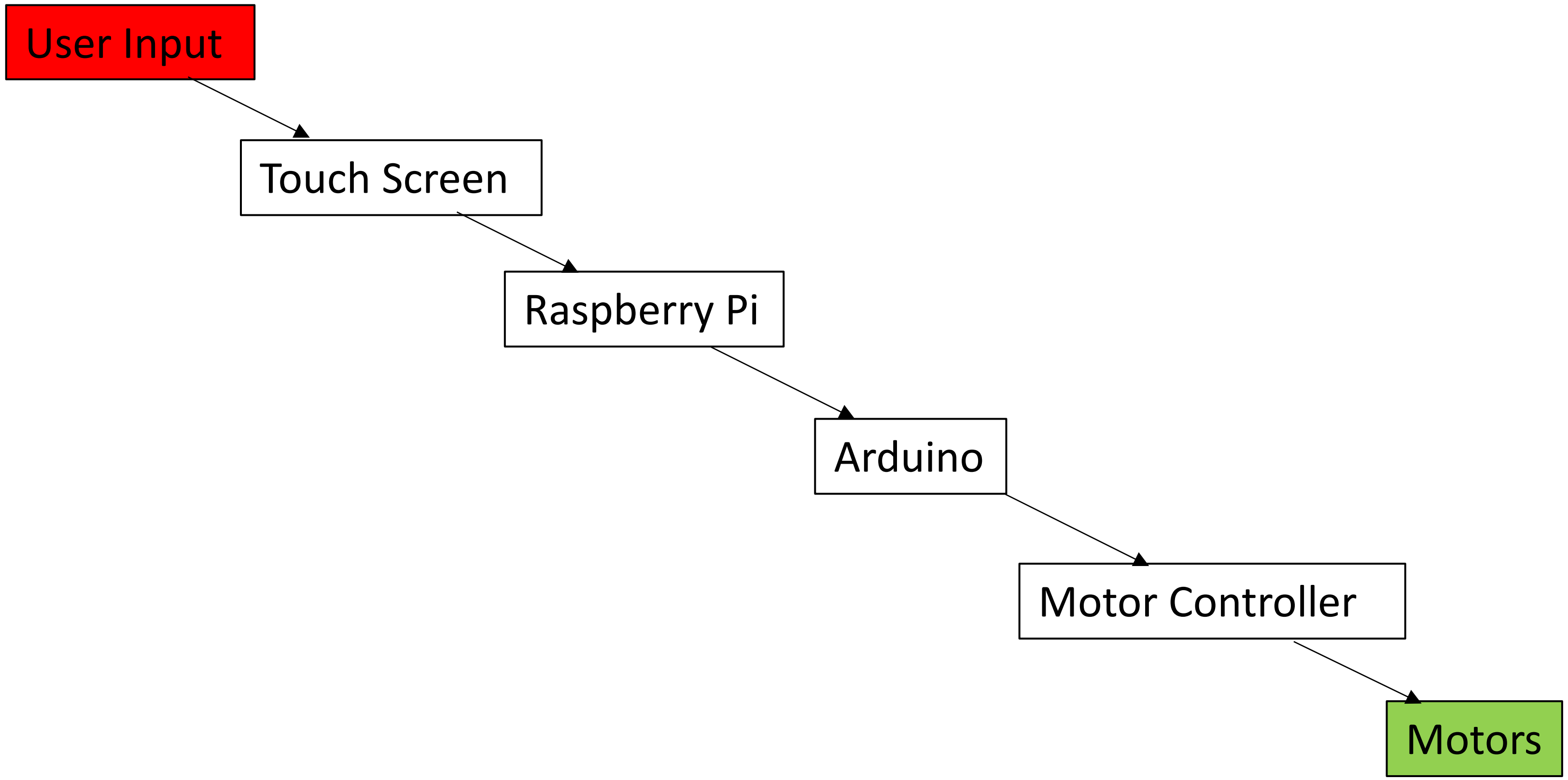

Figure 7: Control Scheme

Important Sub-Assemblies

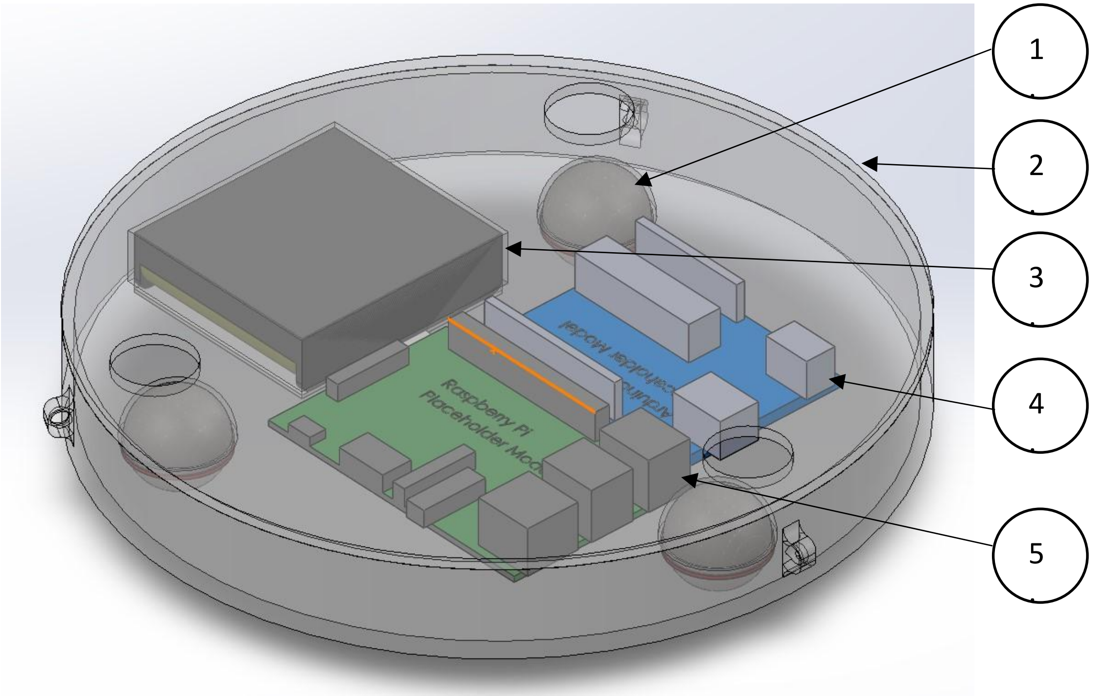

Figure 8: Sub-Assemblies Bottom

Bottom Sub-Assembly

1. Rollers/Bearings
2. Body Shell
3. Batteries
4. Microcontroller (Arduino)
5. Microcomputer (Raspberry pi)
6. Lift Motor
7. Drive Belt

Important Sub-Assemblies

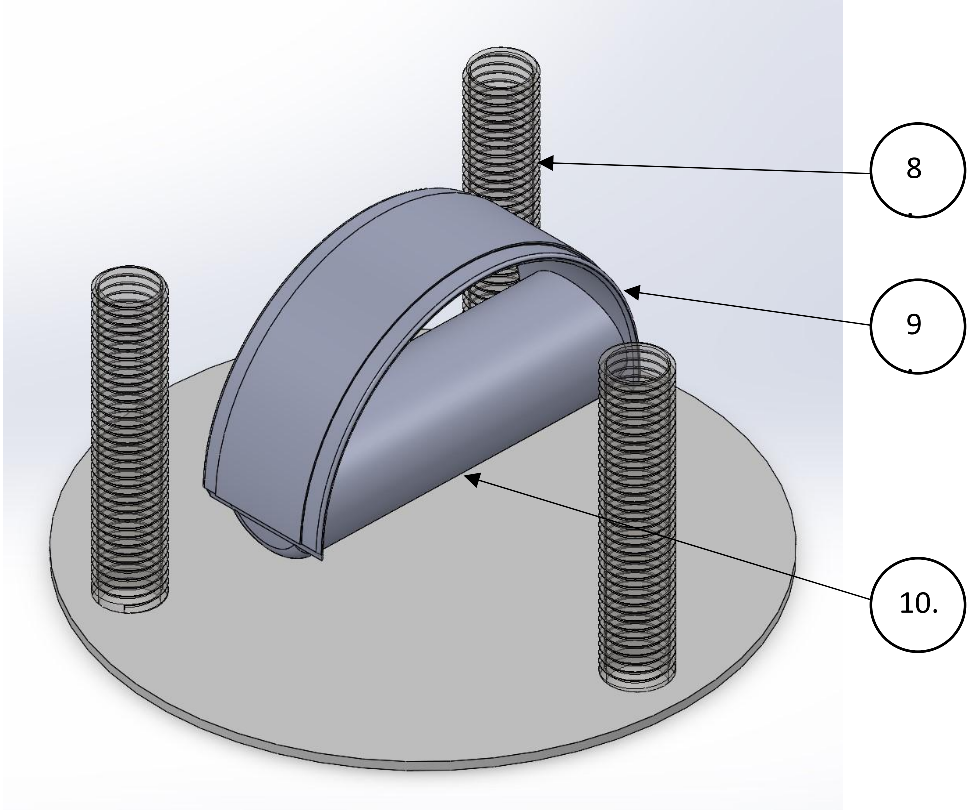

Figure 9: Sub-Assemblies Middle

Center Sub-Assembly

8. Lifting struts
9. Handle rotation mechanism
10. Handle

Important Sub-Assemblies

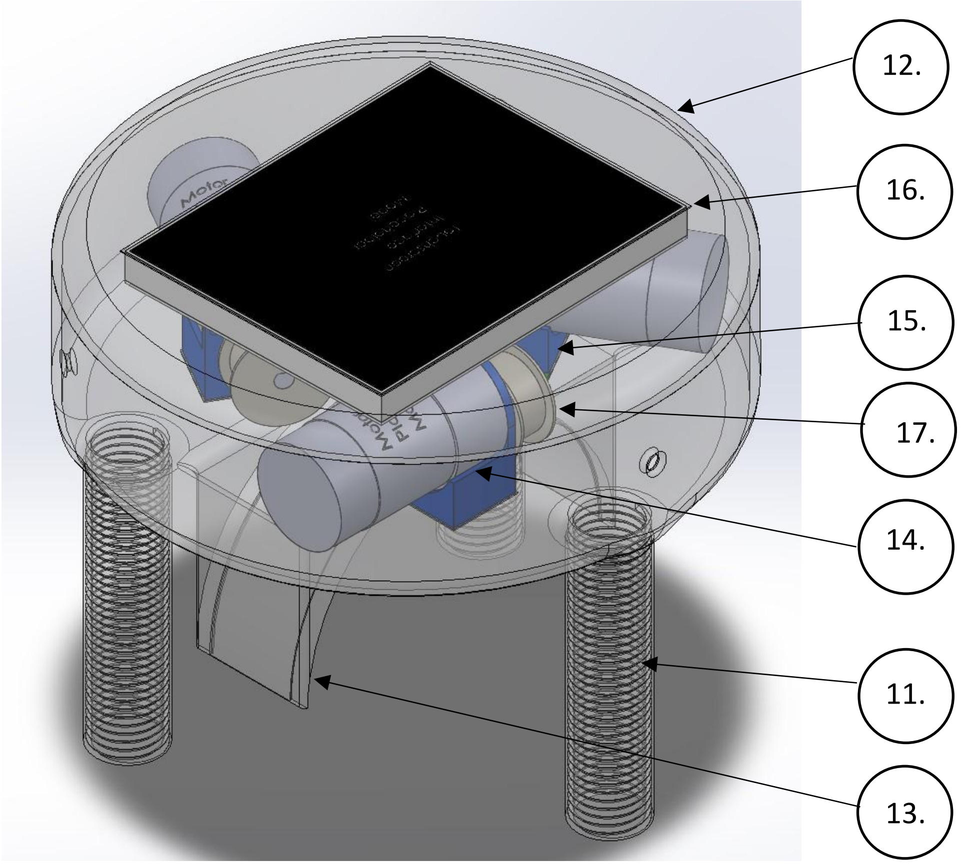

Figure 10: Sub-Assemblies Top

Top Sub-Assembly

11. Capture strut
12. Body shell
13. Handle Mount
14. Drive motor
15. Motor controller
16. Touch screen
17. Winch pulley

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Updated QFD

		Technical Requirements							Competitive Analysis				
Customer Needs	Customer Weights (1-5)	Production Cost	Speed	Force	Position Tracking*	Device Size*	N/A	N/A	*1 Poor*	*2*	*3 Acceptable*	*4*	*5 Excellent*
Affordability	5	9			3	3			AB				C
3rd Dimension Movement	4	3	1	1		1			C				AB
Precision and Accuracy	3	3	9	9	9						C		AB
Size	4	3	1			9			B		A		C
Cosmetics	1	1				1				C	B		A
User Friendliness	5	3				9				A		B	C
Technical Requirement Units		Dollars ($)	Meters per Second (m/s)	Newtons (N)	Millimeters (mm)	Inches (in)							
Technical Requirement Targets		1000	1	10	0.1	8x8x8							
Absolute Technical Importance		31	42	35	93	100							
Relative Technical Importance		5	3	4	2	1							

Relationships:			
9	3	1	
Strong	Moderate	Weak	None
Legend:			
A	Armeo SpringPro		
B	ArmMotus M2 Pro		
C	The Hamster		

Table 1: Updated QFD

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Engineering Calculations

Ball Bearings Lifetime Estimation

Assumptions

The weight of the average male arm is 5.7 pounds a female is 4.97.
The fastest the ball bearings will be spinning is 1m/s
Accounting for the estimated weight of the robot, the equivalent dynamic load is 26.7 newtons split across the bearings.
(1/2 inch) ball in a bearing has an approximate C value of 500-1000 N so a C of 800 is reasonable
For this estimate p will be 3 as if it was in a cage

Equations

$$L_{10} = \left(\frac{C}{P}\right)^p \times 10^6 \text{ revolutions}$$

$$N = \frac{\text{Surface Speed} \times 60}{\pi \times \text{Ball Diameter}}$$

$$L_{10h} = \frac{L_{10}}{60 \times N}$$

Validation

$$L_{10} = \left(\frac{800}{26.7}\right)^3 \times 10^6$$

Which results in 2.686*10^10 revolutions

$$N = \frac{1 \times 60}{\pi \times 0.0127}$$

Giving 1507.96 RPM

$$L_{10h} = \frac{26.86 \times 10^9}{60 \times 1508}$$

Resulting in 298,117 hours

But since it is a loose ball bearing, we must estimate only having half this lifetime giving us 150 thousand hours roughly.

Figure 11: ball bearing validation

Engineering Calculations

Battery Power

Guiding Assumptions:

(1) Perfect cells (no variation in V or I)

(2) No cycle variation

Equation (Batteries in series)

Vtot = V X n (n is number of batteries)

Vtot = 14.8 = 3.7 X 4

Itot = I

Itot = 9,900 mA

Ahtot = Ah

Ahtot = 9,900 mAh

Validation

Part	# of Parts	Amps Req. (I)	Voltage Req. (V)	Total Amps Req.
MS9025v3 Gimbal Motor	4	1.78	7.4-24	7.12
Arduino Uno Rev 3	1	0.05	6.0-20	0.05
Raspberry Pi 5	1	5	5	1.7
LCD Display	1	1.0/2.0	12.0/5.0	1
Motor Controller (Included in Motor)	N/A	N/A	N/A	N/A
Step-Down Voltage Converter	N/A	N/A	N/A	N/A
Total	7		12	9.87

Figure 12: Individual Power Requirement

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Engineering Calculations

Anchor Distance for Motor with 1200 RPM max and 1m/s speed

Angle of cables with 1200 RPM motor & 40mm shaft

1 m/s to RPM $(v/C)x60=(1/(0.04\pi))x60=\underline{477.5RPM}$

Find θ at 1200 RPM $\theta=\arccos(447.5/1200)=66.5^\circ$

$66.5x2=\underline{113^\circ}$ Max angle to maintain 1m/s movement

Anchor distance for 12in or 30.48cm workspace

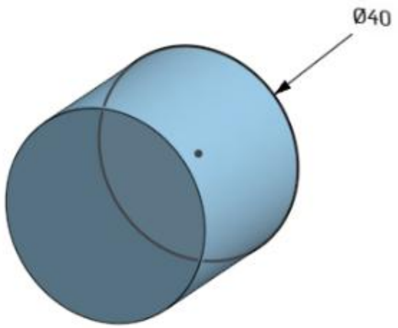
Using calculated angle value and Law of Sines

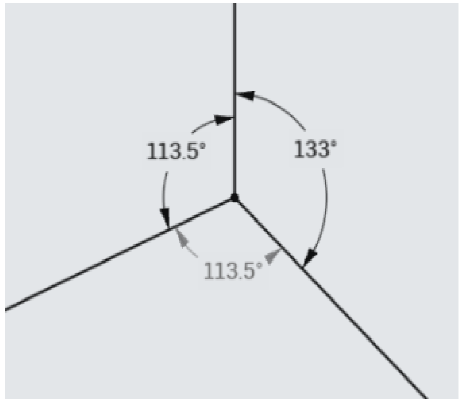
$(\sin(113.5)/x=\sin(6.5)/15.24) + 15.24cm$

Anchor point from center (x) = $\underline{125.3cm \text{ or } 46.6in}$

For $\underline{50mm}$ drum, $\theta=\underline{143^\circ}$, $(x)=\underline{27.4in \text{ or } 69.6cm}$

Validation





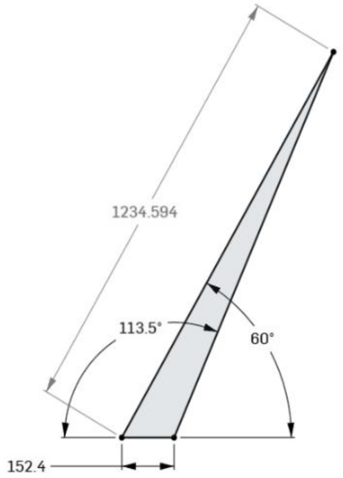


Figure 13: FBD validation

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Engineering Calculations

Pulling Force for 4 Wires

- d= diameter of robot= 8"= 0.2032m
- dr= vertical distance from robot to anchor pts
- dA= distance between anchor pts
- Assume setup is symmetrical
- $F_c = \frac{\sqrt{(0.5(dA-0.1437m))^2+(dr+0.0298m)^2}}{(dr+0.0298m)} * 5N$
- For dr= 0.0254m and dA= 0.9144, F_c= 35.26N

Validation (Done by Hand)

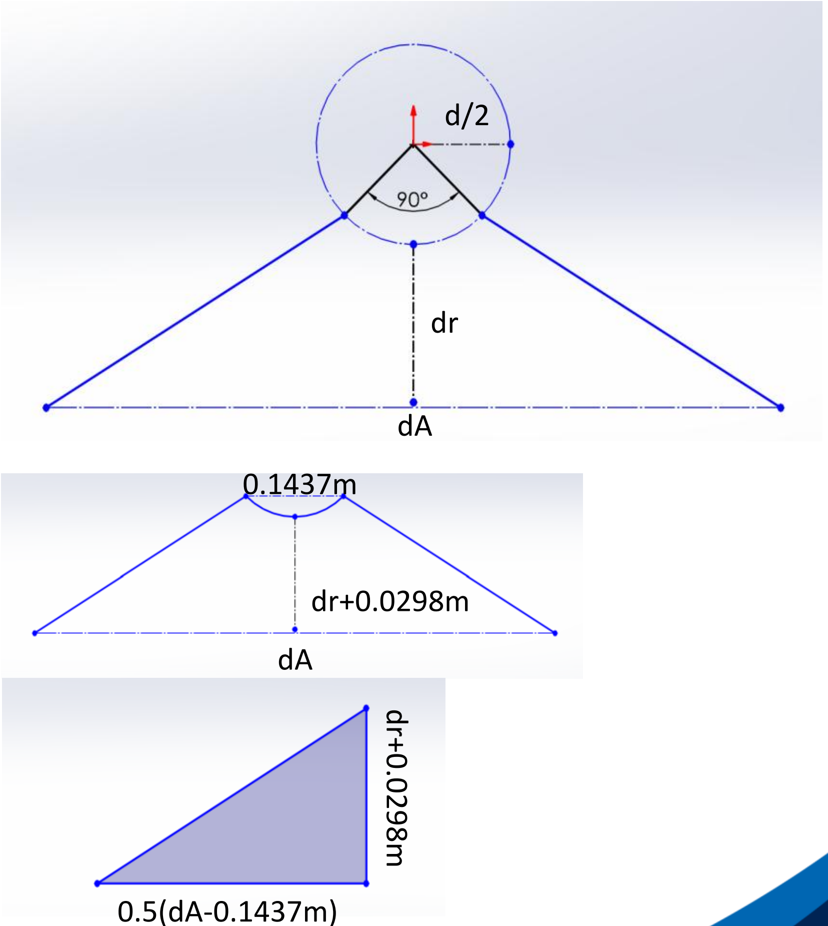

Figure 14: Pulling Force Validation

Engineering Calculations

Maximum Torque

Guiding Assumptions:
(1) Static after moving to new position
(2) Using winch diameter of 40mm
(3) Using distances calculated by Justin
(4) Tension on all cables is the desired F=10N

Calculations:

$\tau_{XY} = F_{XY} * r$

$\tau_Z = F_Z * r$

$\tau = sqrt(\tau_{XY}^2 + \tau_Z^2)$

Maximum torque each motor experiences:

$\tau = 0.2\ Nm$

Very close to our initial estimate of 0.254 Nm

Validation

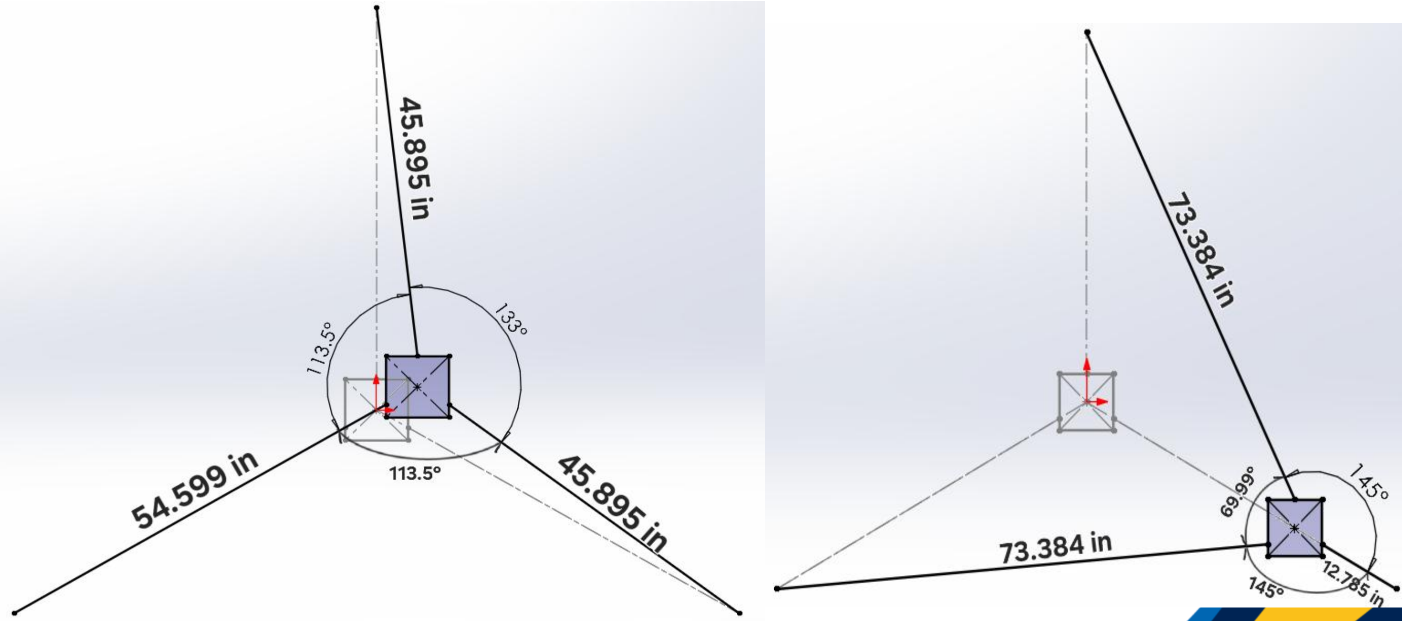

Figure 15: Pulling Force Validation

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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
$\theta = \arctan(y / x)$	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
$\sum MA=0$	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
$\tau = F*r$	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
$\tau adjusted = F.O.S. * \tau$	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 2: 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 2 Cont.: Calculations Table

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 (Arduino)	Electrical Shorting	Causes robot to become inoperable	9	Assembly error	1	Run test program	1	9	None
5 Microcomputer (Raspberry pi)	Electrical Shorting	Causes robot to become inoperable	10	Assembly error	1	Run test program	1	10	None
6 Lifting Motor	High-cycle Fatigue	Reduction in performance of z-axis movement	7	Over voltage/current	2	Test with RPM, force, and voltmeter	1	14	None
7 Drive Belt	Surface Fatigue Wear	Loss of z-axis movement	8	Poor maintenance	4	Visual inspection	1	32	Purchase high quality parts

Table 3: 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

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 Motor Controller	Electrical Shorting	Reduction in performance of all axis movement	7	Over voltage/current	2	Run test program	1	14	Purchase high quality parts
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

Testing Procedures

Methods

- Employ volunteers to test setup time
- Test manually to confirm battery life
- Use predefined position marks to test position accuracy
- Use luggage force sensor to confirm robot's ability to produce 10N
- Use robot on multiple work surfaces to test anchor integrity
- Manually confirm lack of motor backlash, use force sensor to test for internal friction
- Test lifting capability by use
- Some requirements will be automatically met during design

Acceptance

- 1 Minutes set up time.
- The battery life lasts at least 30 minutes
- It will pass the test if the robot is accurate in delivering the 10N
- If the robot is operational without external help from initial setup.
- If the motor position is acuate to within 1mm.
- If the lifting mechanics can lift 10lbs

Equipment

- Functioning prototype
- Multiple work surfaces (Rough, smooth, varying thickness)
- Way to mark position destinations on surface
- Weight sensor
- Volunteer Testers
- Electrical testing equipment
  - Battery testing equipment
  - Digital Multi-Meter
  - Battery load tester

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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

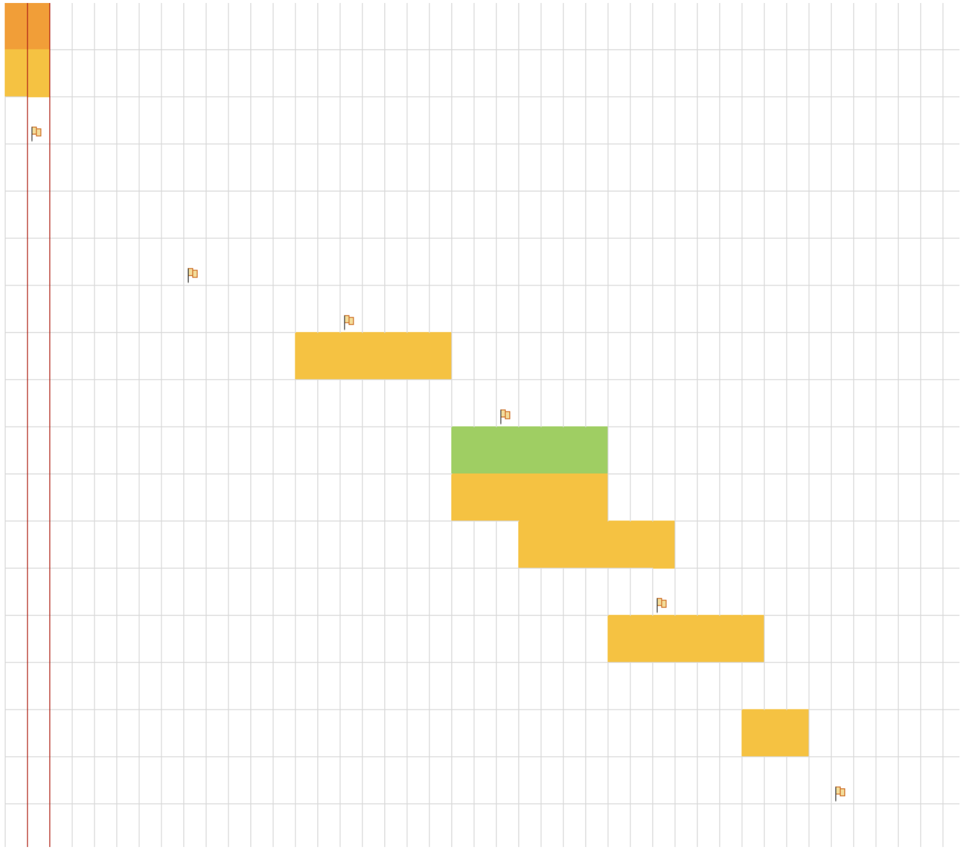

Figure 16: March, April, and May Tasks

- Start work on Report 2
- Continue client meetings
- Complete torque/force calculations
- Promote fundraiser
- Work on individual analyses
- Continue adding detail to CAD model

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

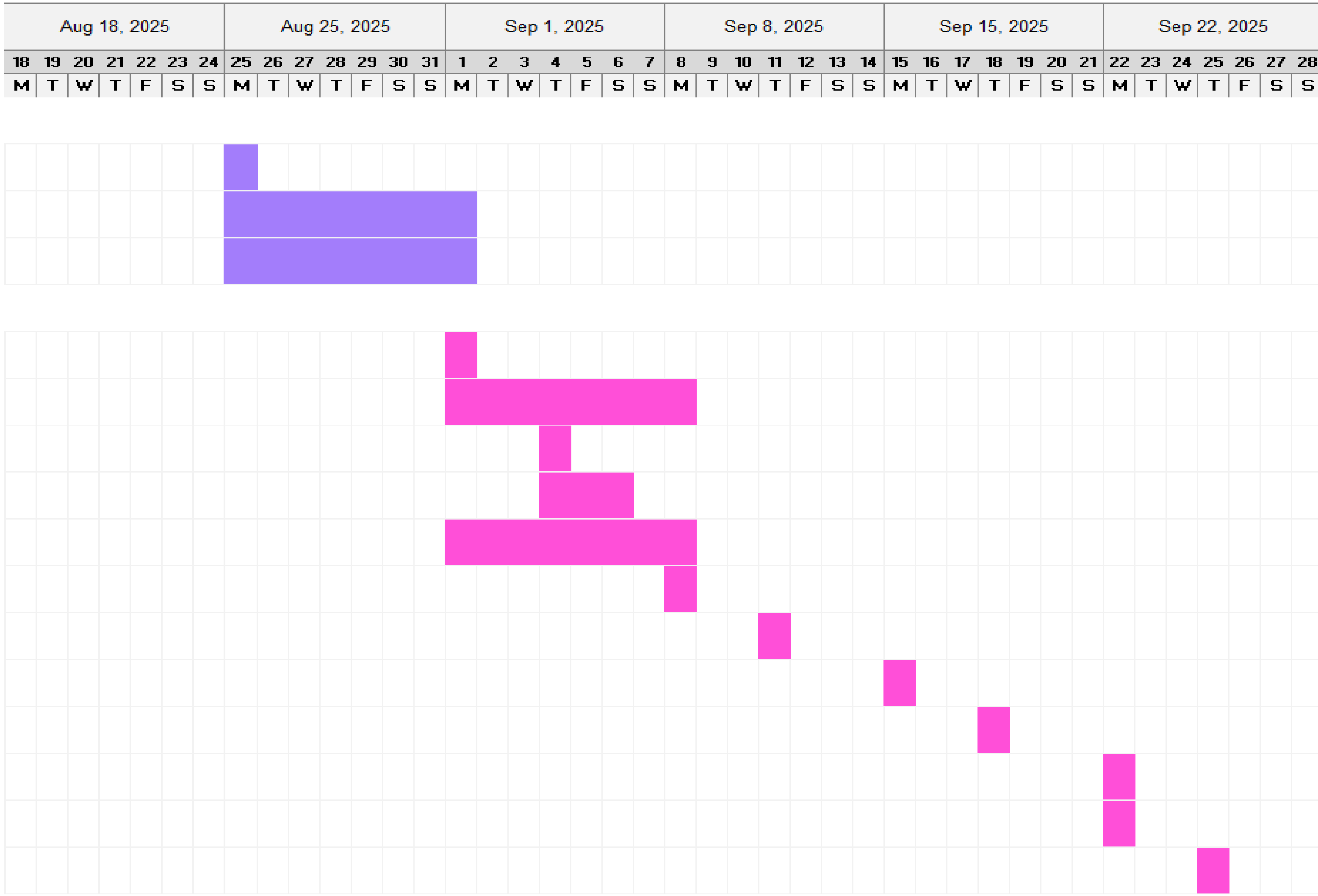

Figure 17: ME-486C Gantt Chart

Budget

Current Project Budget	$3750
anticipated expenses	-$990
Actual expenses to date	-$77.87
Resulting Balance	$2760

Table 4: Budget

Fundraising

Fundraiser at Cane's on Milton on 4/3/25.

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Fundraiser

Figure 18: Flyer

Bill of Materials

	Item	Quantity	Cost Per Unit ($)	Final Amounts($)
1	3-axis force sensor	1	290	290
2	Optical encoder motors	4	75	300
3	18650 Battery	3	25 (sold in 4 pack)	25
4	Braided Fishing Line	1	30	30
5	Circuits and wires	1 Sold as a set	45	45
6	Misc. Electronics and plastics	1	100	100
7	Stainless Steel Ball Bearings	1 sold in large set amounts	6	6
8	Suction Mechanism	3	15	45
9	C clamps	3	5	15
			Final Subtotal=	856

Table 5: Bill of Materials

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Thank You!

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Resources

[1] "Stroke Facts." CDC. https://www.cdc.gov/stroke/data-research/facts-stats/index.html (accessed February 23, 2025).

Sub-System Prototype 1

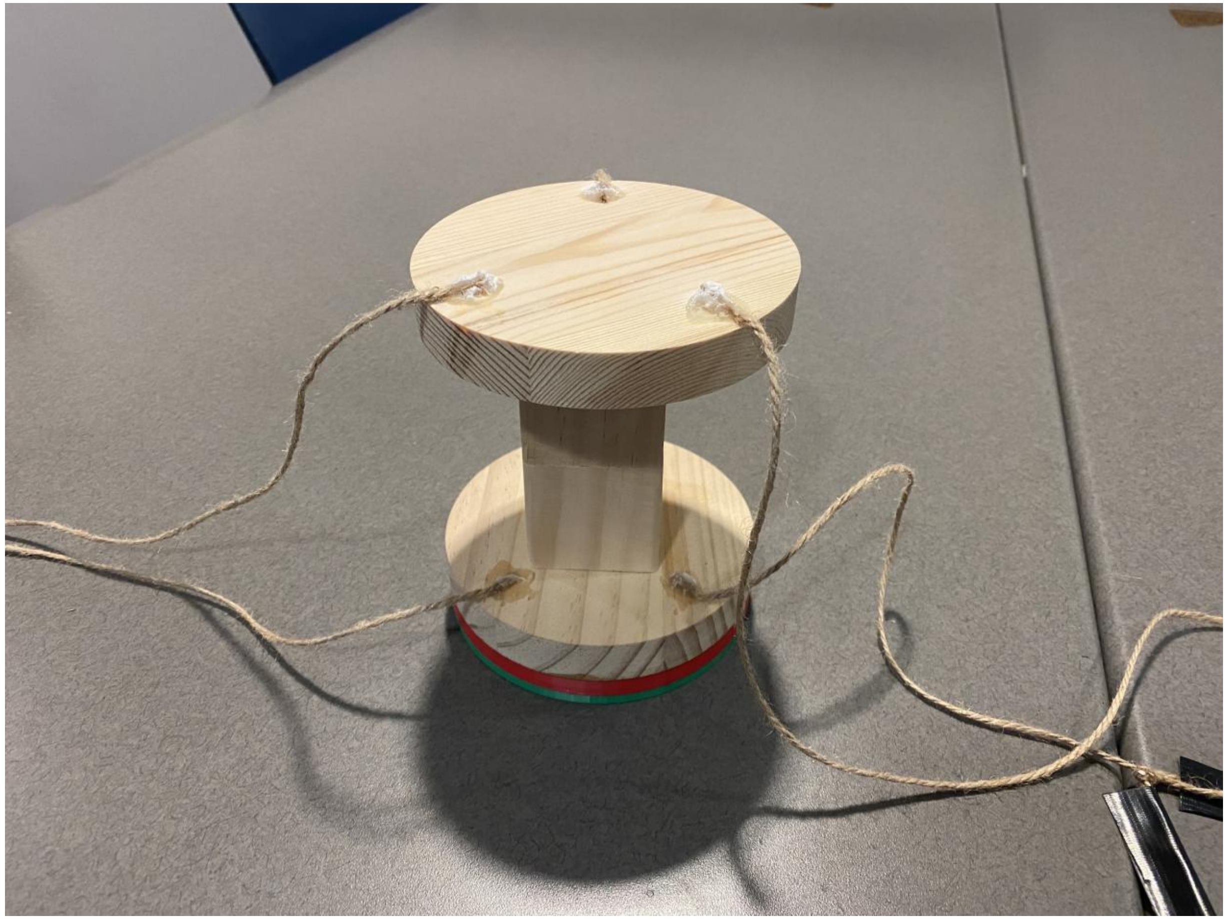

Figure 19: Taxidermy Squirrel

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?

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Sub-System Prototype 2

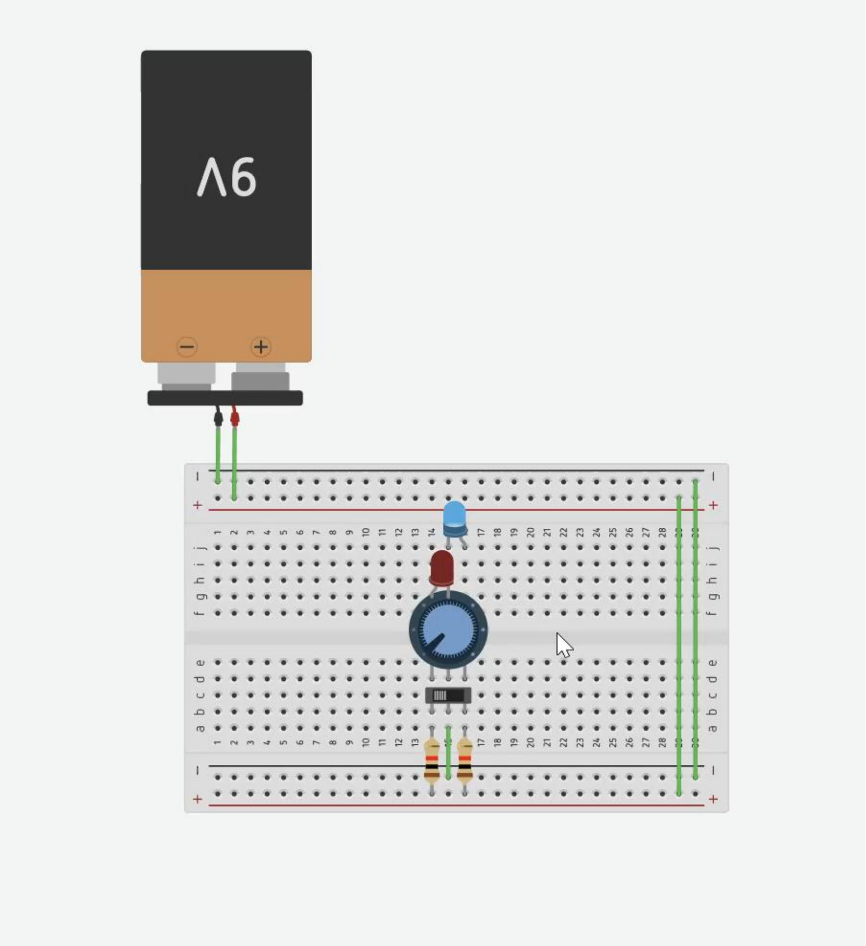

Figure 20:Sub-System Prototype 2

- Simulation uses a slideswitch, actual prototype will use H-bridge connector.
- Simulation uses a potentiometer, actual prototype will use pulse width modulation.
- Prototype should not have any mechanical switches.

Question(s) this simulation answered:

- What is the simplest circuit we can have to reverse direction of motors?

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XR Demo

Video 1 : XR Demo

Questions that this model answered:

- With the 3 lift points in a triangle pattern, will the wrist come into contact with the 2 next to it?

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Question?

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