Tilt by EverCanopy
Final Report

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Executive Summary

Many wheelchair users struggle to operate their umbrella in the rain, and there are few viable solutions on today's market. Current weather protection solutions for wheelchairs do not provide optimal protection from the rain, limiting a user's mobility and autonomy.

Figure 1. Three of the most common solutions for wheelchair weather protection in today's market. Current solutions are inconvenient, require outside assistance to set up, or do not provide enough coverage.

EverCanopy's proposed product is a simple wheelchair attachment that automatically tilts an umbrella canopy in the direction of wind/rain without user input. The attachment is conveniently mounted to the user's wheelchair (Figure 2) and provides a 21% greater total rain coverage than a standard umbrella.

Figure 2: Proposed wheelchair attachment demonstrating tilt

The target market is wheelchair users who desire greater mobility and independence. Tilt will be retailed for $175. According to a survey statistic, 22% of individuals ages 18-64 would be willing to pay this amount for Tilt (Figure 3).

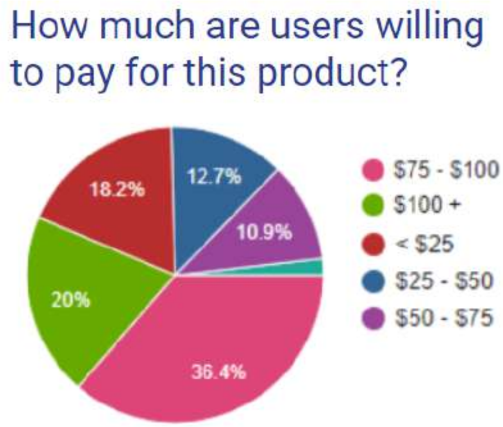


Figure 3: Survey of price individuals are willing to pay for Tilt

This gives EverCanopy a profit margin of 27.7%, much of which can be used to improve the product. Future goals include acquiring FDA approval so insurance companies can subsidize the cost; however the product can currently be marketed to healthcare clinics.

The device utilizes a pan-and-tilt and stowing mechanism. The former uses a screw and coupler system to provide a 30 degree ROM and a motor that pan 360 degrees, while the latter stores the device at the side of the wheelchair, allowing the user to extend the umbrella to a comfortable position using locking hinges (Figure 4).

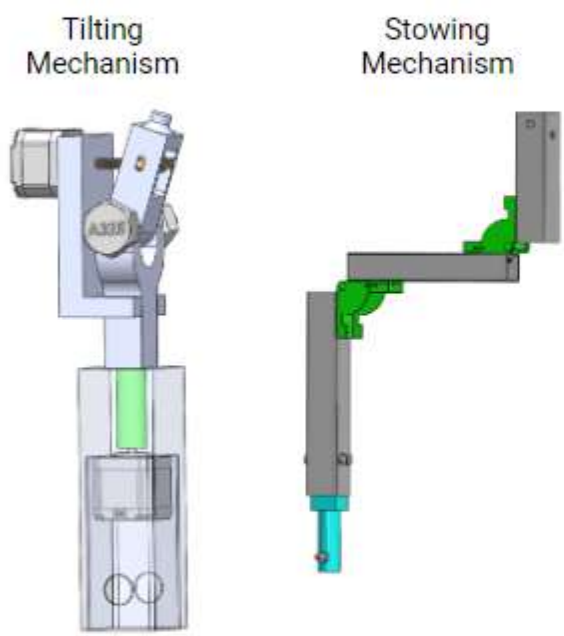


Figure 4: Tilting and Stowing Mechanisms.

Tilt also utilizes eight load cell sensors, an Arduino microcontroller, two motor drivers, and two bipolar DC stepper motors. The embedded code determines which sensors receive the largest load input and directs the pan-and-tilt motors to readjust the canopy position accordingly.

Three tests were conducted to evaluate the effectiveness of the product, which is summarized below in Figure 5.

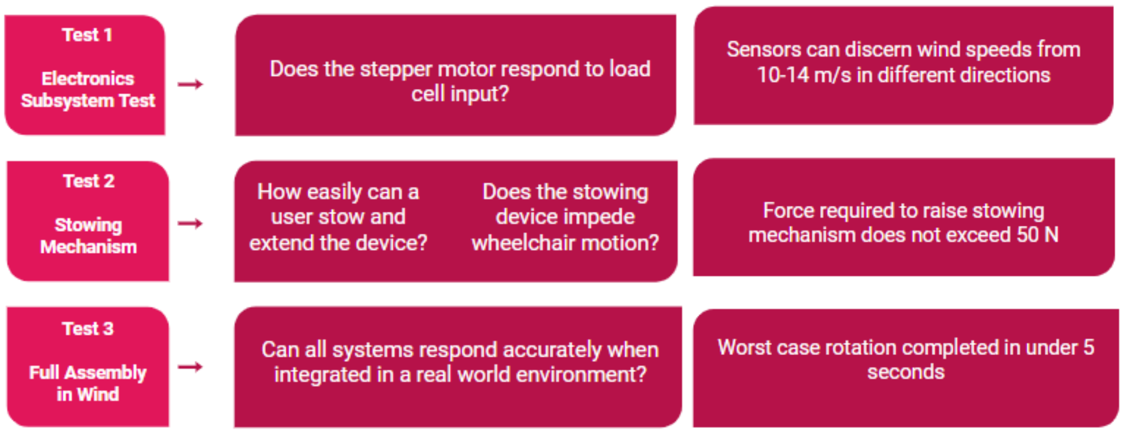


Figure 5: Tests corresponding to project's functional requirements. For each test, column two describes the objective and column three lists the corresponding functional requirements.

Test results showed that Tilt met two of the three functional requirements. Test 1 showed that the stepper motor and load cells were adequately responsive. In Test 2, the stowing mechanism functioned properly but required slightly more force to operate than desired (~75 N vs. 50 N). However, the housing for the linear actuator cleared the wheels of the wheelchair completely, with no interference of motion. Figure 6 depicts results for Test 3, where a few canopy reaction times were marginally slower than desired for certain movements.

	Yaw 90° at 30° pitch [sec]	Yaw 90° at 15° pitch [sec]	Pitch Down 15° [sec]	Pitch Up 15° [sec]	Yaw 180 at 30° pitch [sec]
Average Response Time	2.1	1.3	1.6	4.2	4.8
Desired Response Time	2.1	1.5	1.5	3.6	4.4

Figure 6: Test of five separate movements of the final assembly. 90 degree rotation at 30 and 15 degree pitch, pitch up, pitch down, and 180 degree rotation with 30 degree pitch were tested.

The umbrella reaction time was 9% slower than desired, though the mechanism reacted appropriately to sensor inputs. This is evident in some tests, such as pitching up, likely due to the weight of the assembly the motors must overcome. The stowing mechanism performed well and will likely meet design requirements after tolerances are adjusted and lubrication is added. Potential improvements to the product include increasing canopy response speed, using lighter materials for the tilting and stowing mechanisms to reduce the prototype's overall weight, and designing an appropriate housing for the electronics to reduce wire clutter.

Test results have confirmed that *Tilt* is an functional and innovative product that can likely improve the quality of life for wheelchair users desiring greater independence. Team EverCanopy formally requests further funding to continue research and development.

Appendix A: Team Members and Organization Structure

Team Member	Role
Yovan Chu	Project Manager, Research Lead
Adam Razak	Manufacturing Manager, CAD Lead
Karen Yee	Buyer, Business Manager
Kar Men Lo	Electronics Lead, Validation Lead
Patrick Tirtapraja	Chief Engineer, Computer Engineering Lead
Meghana Krishna	Analysis/Simulation Lead, Customer Eyes

Figure A.1: Team members and organization structure

Appendix B: Project Charter

ME 463 Senior Design

Project Title: *tilt*
Team Name: Less Wet
Team Members: Yovan Chu, Kar Men Lo, Karen Yee, Adam Razak, Meghana Krishna, Patrick Tirtapraja

Vision Statement: Improve user's outdoor experience by providing innovative weather protection solutions

Problem Statement (Current State)

Currently, no solution exists in the market for an automated adaptive umbrella. The purpose of this project is to create an umbrella that incorporates rain sensors and actuators to automatically tilt in the direction of the rain/wind, to more effectively shield the user from oncoming rain and prevent the umbrella from inverting.

Project Scope

IN Scope	OUT of Scope
Meet technical requirements regarding power, size/weight, controllability	Mass Production
Shield the user from more rain than a standard umbrella (% body area)	Tilt continuously without returning to home position
Tilt 10 degrees from normal	Price <50$
Maintain neutral position when wind speed <5 m/s	
Maximum weight of 2lbs	

Business / Society Benefit (Future State)

Aims to benefit anyone who uses an umbrella, especially the elderly, small children, and persons in wheelchairs by eliminating the need to exert wrist strength to adjust the tilt of their umbrella.

Key Milestones

Code (2/6)	Sensor code Actuator Control code
Electrical Design (2/6)	Arduino microcontroller setup All circuit wiring
Mechanical Design (before spring break)	Modifying umbrella to fit electrical components
Begin Manufacturing (after spring break)	All machining and fabrication work
Prototype (April)	Functioning prototype
Improvements (April - May)	

Key Assumptions & Risks

Current umbrellas do not provide optimal wind/rain protection
Will not complete in time
Not having good battery life
Slow control response time
Aesthetics
Inadequate motor strength
Exceed desired weight
Fragile

Team Members & Roles

Yovan Chu - Project Manager, Research Lead
Patrick Tirtapraja - Chief Engineer
Karmen Lo - Electronics Lead, Validation Lead
Adam Razak - Manufacturing Manager, CAD Lead
Meghana Krishna - Analysis/Simulation Lead, Customer Eyes
Karen Yee - Buyer, Business Manager

Key Resources Required

Arduino circuitboard
Machining tools
Umbrellas

Figure B.1: Project charter

Appendix C: Project Budget

These are the purchases already ordered. We used $549.46 of the budget.

PURDUE MECHANICAL ENGINEERING

ME 463 Senior Design

PURDUE UNIVERSITY

Team Name: Ever Canopy **Date:** 17-Apr-2019

COMPLETED ORDERS

Item Description	How will the item be used for the project?	Vendor	Item Cost	Shipping Cost	Purchase date
Integrated Circuit Chip INA125 – Amplifier chip for sensor signal (INA125UA-ND)	It will amplify the signal from the load sensor	Digi-Key Electronics	$ 6.54	$ 0.65	31-Jan-2019
Elenco 25' #22 Gauge Black Hook-up Wire (RB-Ibo-84)	It will be used to connect sensors to microcontroller	Robot Shop	$ 2.95	$ 0.30	31-Jan-2019
65x22 Gauge Assorted Jumper Wires (RB-Cix-01)	It will be used to connect sensors to microcontroller	Robot Shop	$ 3.95	$ 0.40	31-Jan-2019
2 X Mini Load Cell - 100g, Straight Bar (TAL221)	It will measure the force of wind to calculate the direction for the umbrella	SparkFun Electronics	$ 17.90	$ 1.79	31-Jan-2019
Integrated Circuit Chip INA125 – Amplifier chip for sensor signal (INA125P-ND)	It will amplify the signal from the load sensor	Digi-Key Electronics	$ 6.89	$ 0.69	8-Feb-2019
14 X Mini Load Cell - 100g, Straight Bar (TAL221)	It will measure the force of wind to calculate the direction for the umbrella	Robot Shop	$ 98.00	$ 9.80	22-Feb-2019
12 X Integrated Circuit Chip INA125 – Amplifier chip for sensor signal (INA125P-ND)	It will amplify the signal from the load sensor	Digi-Key Electronics	$ 82.68	$ 8.27	8-Mar-2019
6061 Aluminum 2" x 2", Length 3 ft (9008K53)	Material to manufacture tilting device	McMaster Carr	$ 78.72	$ -	8-Mar-2019
18-8 Stainless Steel Dowel Pin, 1/4" Diameter, 1" Long (90145A542)	To create coupler	McMaster Carr	$ 6.52	$ -	8-Mar-2019
Routing Clamp 304 Stainless Steel, 2 Mounting Points, 1-3/16" ID (8874T44)	To attach for stowing device to wheelchair	McMaster Carr	$ 6.06	$ -	8-Mar-2019
18-8 Stainless Steel Button Head Hex Drive Screw 1/4"-28 Thread Size, 2-1/2" Long (92949A848)	Screw for tilting mechanism	McMaster Carr	$ 5.60	$ -	8-Mar-2019
Zinc-Plated Steel Coupling Nut Low-Strength, 1/4"-28 Thread Size (90264A440)	Nut for tilting mechanism	McMaster Carr	$ 1.35	$ -	8-Mar-2019
Extra-Wide Galvanized Steel Hex Head Screw for Structural Applications, 3/4"-10 Thread, 3-1/4" Long (91583A181)	Screw for tilting mechanism	McMaster Carr	$ 6.48	$ -	8-Mar-2019
Medium-Strength Steel Hex Nut Grade 5, Zinc-Plated, 3/4"-10 Thread Size (95462A538)	Nut for tilting mechanism	McMaster Carr	$ 13.98	$ -	8-Mar-2019
Folding Table Leg Bracket for Square Legs (18095A51)	Bracket for stowing device	McMaster Carr	$ 12.58	$ -	8-Mar-2019
Low-Carbon Steel Square Tube 0.060" Wall Thickness, 1-1/4" x 1-1/4" Outside Size, Long, Length 1 ft (6527K184)	Material to manufacture stowing device	McMaster Carr	$ 7.99	$ -	8-Mar-2019
Low-Carbon Steel Square Tube 0.083" Wall Thickness, 1-1/2" x 1-1/2" Outside Size, Long, Length 1 ft (6527K274)	Material to manufacture stowing device	McMaster Carr	$ 11.24	$ -	8-Mar-2019
410 Stainless Steel Quick-Release Connector Single-Button, for 1/2" to 1-1/4" Round Tubing ID (92988A530)	Connectors for stowing device	McMaster Carr	$ 10.63	$ -	8-Mar-2019
Easy-to-Weld 4130 Alloy Steel Round Tube 0.083" Wall Thickness, 1-1/4" OD, Length 1 ft (89955K669)	Material to manufacture stowing device	McMaster Carr	$ 16.90	$ -	8-Mar-2019

STEPPERONLINE 19:1 Planetary Gearbox High Torque Nema 17 Stepper MotorDIY CNC Camera Telescope (17HS19-1684S-PG19)	Power the pan of the umbrella at the specific speed desired	STEPPERONLINE	$ 47.00	$ -	25-Mar-2019
Low-Carbon Steel Square Tube 0.083" Wall Thickness, 1-1/2" x 1-1/2" Outside Size, Long, Length 1 ft, (6527K274)	Used to manufacture for stowing device	McMaster Carr	$ 11.24	$ -	29-Mar-2019
0.84 fl. oz. 5-Minute Plastic Welder (Model # 84145 Internet #205905894 Store SKU #1002752774)	Hold together acrylic pieces	Home Depot	$ 23.88	$ -	4-Apr-2019
High Energy Alkaline AA/1.5 Volt Battery (10-Pack) (Model # 815-10TJ Internet #207208531 Store SKU #850827)	Power motor and arduino	Home Depot	$ 6.97	$ -	4-Apr-2019
8mm Bore Set Screw Hub (545636)	Couple gearbox and bottom of tilting device	Amazon	$ 4.99	$ 6.99	29-Mar-2019
3X DRV8825 Stepper Motor Driver Carrier, High Current (2133)	Supply enough current to the stepper motors to drive and control them	Pololu	$ 26.85	$ 2.69	29-Mar-2019
		TOTAL	**$ 517.89**	**$ 31.57**	**$ 549.46**
		GRAND TOTAL	**$ 517.89**	**$ 31.57**	**$ 549.46**

Figure C.1: Project budget

Appendix D: Bill of Materials

Item No.	Part No.	Part Name	Units	Qty	Material / Description	Source	Catalog No.	Unit Cost ($)	List Price ($)
1	M1	Eye End	in^3	1	2" X 2" X 36" 6061 Aluminum bar	McMaster Carr	9008K53	$78.72	$78.72
2	M2	Fork End	in^3	0	2" X 2" X 36" 6061 Aluminum bar	McMaster Carr	9008K53	$0.00	$0.00
3	M3	Tilt Motor Holder	in^3	0	2" X 2" X 36" 6061 Aluminum bar	McMaster Carr	9008K53	$0.00	$0.00
4	M4	Bottom Rod	in^3	0	2" X 2" X 36" 6061 Aluminum bar	McMaster Carr	9008K53	$0.00	$0.00
5	M5	Modified Coupler	in	1	18-8 1/4" Diameter, 1" Long Stainless Steel Dowel Pin	McMaster Carr	90145A542	$6.52	$6.52
6	M6	Actuator Housing	in^3	1	steel	ME Machine Shop	-	$0.00	$0.00
7	M7	Stowing L Bar Support	in^3	1	steel	ME Machine Shop	-	$0.00	$0.00
8	M8	Bottom connecter	in^3	0	2" X 2" X 36" 6061 Aluminum bar	McMaster Carr	9008K53	$0.00	$0.00
9	M9	Holder	pcs	12	Aluminum	ME Machine Shop	-	$0.00	$0.00
10	M10	Paddle	pcs	12	Acrylic	ME Machine Shop	-	$0.00	$0.00
11	P1	100g Micro Load Cell Sensor	pcs	2	load cell sensor	SparkFun Electronics	TAL221	$8.95	$17.90
12	P2	100g Micro Load Cell Sensor	pcs	14	load cell sensor	Robot Shop	RB-Phi-203	$7.00	$98.00
13	P3	Integrated Circuit Chip INA125	pcs	1	Amplifer chip for sensor signal	Digi-Key Electronics	INA125UA-ND	$6.54	$6.54
14	P4	Integrated Circuit Chip INA125	pcs	12	Amplifer chip for sensor signal	Digi-Key Electronics	INA125P-ND	$6.89	$82.68
15	P5	Elenco 25' #22 Gauge Black Hook-up wire	pcs	1	Wires	Robot Shop	RB-Ibo-84	$2.74	$2.74
16	P6	65x22 Gauge Assorted Jumper Wires	pcs	1	Jumper wires	Robot Shop	RB-Cix-01	$3.63	$3.63
17	P7	Linear Actuator	pcs	1	Linear actuator	ME E-Shop	FA-PO-240-12-8'	$0.00	$0.00
18	P8	Arduino Mega	pcs	1	Microcontroller	Personal	-	$0.00	$0.00
19	P9	Decoupling Capcitor 1 micro farad	pcs	6	For controller	ECE E-shop	-	$0.00	$0.00
20	P10	Breadboard	pcs	2	For controller	ECE E-shop	-	$0.00	$0.00
21	P11	9V Battery	pcs	4	For controller	ECE E-shop	-	$0.00	$0.00
22	P12	Load MOSFET	pcs	6	For controller	ECE E-shop	-	$0.00	$0.00
23	P13	Stepper Motor	pcs	2	Move tilting device	ME E-Shop	-	$0.00	$0.00
24	P9	Routing Clamp	pcs	3	304 Stainless steel to attach stowing device on wheelchair	McMaster-Carr	8874T44	$2.02	$6.06
25	P10	12V Battery	pcs	1	Power linear actuator	ME E-Shop	-	$0.00	$0.00
26	P11	Umbrella	pcs	1	Inverted umbrealla	Amazon	-	$21.99	$21.99
27	P12	18-8 Stainless Steel Button Head Hex Drive Screw (¼"-28 Thread Size, 2-½" Long)	pack	1	Screw for tilting mechanism	McMaster-Carr	92949A848	$5.60	$5.60
28	P13	Zinc-Plated Steel Coupling Nut (Low-Strength, ¼"-28 Thread Size)	pcs	1	Nut for tilting mechanism	McMaster-Carr	90264A440	$0.45	$0.45
29	P14	Extra-Wide Galvanized Steel Hex Head Screw (for Structural Applications, ¾"-10 Thread, 3-¼" Long)	pcs	2	Screw for tilting mechanism	McMaster-Carr	91583A181	$3.24	$6.48
30	P15	Medium-Strength Steel Hex Nut (Grade 5, Zinc-Plated, ¾"-10 Thread Size)	pack	1	Screw for tilting mechanism	McMaster-Carr	95462A538	$13.98	$13.98
31	P16	Folding Table Leg Bracket	pcs	2	Bracket for stowing device	McMaster-Carr	18095A51	$6.29	$12.58
32	P17	18-8 Stainless Steel Hex Head Screw (10-24 Thread Size, ½" Long)	pack	1	Screw for stowing mechanism	McMaster-Carr	92314A242	$8.81	$8.81
33	P18	18-8 Stainless Steel Narrow Hex Nut (10-24 Thread Size)	pack	1	Screw for stowing mechanism	McMaster-Carr	90730A011	$6.81	$6.81
34	P19	Low-Carbon Steel Square Tube (0.060" Wall Thickness, 1-¼" x 1-¼" Outside Size, Long,	pcs	1	Material to manufacture stowing device	McMaster-Carr	6527K184	$7.99	$7.99
35	P20	Low-Carbon Steel Square Tube (0.083" Wall Thickness, 1-½" x 1-½" Outside Size, Long, 1ft)	pcs	1	Material to manufacture stowing device	McMaster-Carr	6527K274	$11.24	$11.24
36	P21	410 Stainless Steel Quick-Release Connector (Single-Button, for ½" to 1-¼" Rough Tubing ID)	pack	1	Connectors for stowing device	McMaster-Carr	92988A530	$10.63	$10.63

37	P22	Easy-to-Weld 4130 Alloy Steel Round Tube (0.083" Wall Thickness, 1-¾" OD)	pcs	1	Material to manufacture stowing device	McMaster-Carr	89955K669	$16.90	$16.90	$0.00
38	P23	STEPPERONLINE 19:1 Planetary Gearbox High Torque Nema 17 Stepper MotorDIY CNC Camera Telescope	pcs	1	Power the pan of the umbrella at the specific speed desired	STEPPERONLINE	17HS19-1684S-PG19	$47.00	$47.00	$0.00
39	P24	DRV8825 Stepper Motor Driver Carrier, High Current	pcs	3	Supply enough current to the stepper motors to drive and control them	Pololu	2133	$8.95	$26.85	$2.69
40	P25	Low-Carbon Steel Square Tube, 0.083" Wall Thickness, 1-1/2" x 1-1/2" Outside Size, Long, Length 1 ft, (6527K274)	pcs	1	Used to manufacture stowing device	McMaster-Carr	6527K274	$11.24	$11.24	$0.00
41	P26	8mm Bore Set Screw Hub	pcs	1	Couple gearbox and bottom of tilting device	Amazon	545636	$4.99	$4.99	$6.99
42	P27	0.84 fl. oz. 5-Minute Plastic Welder	pcs	4	glue acryllic together	home depot	(Model # 84145 Internet #205905894 Store SKU #1002752774)	$5.97	$23.88	$0.00
43	P28	High Energy Alkaline AA/1.5 Volt Battery (10-Pack)	pcs	1	power moters and arduino	home depot	(Model # 815-10TJ Internet #207208531 Store SKU #850827)	$6.97	$6.97	$0.00
								Total ($)	$517.89	
								shipping	$31.57	
								TOTAL	$ 549.46	

Figure D.1: Bill of materials

This document shows the bill of materials for the project which is all of the purchases made and any material or product used to make the prototype. We are projected to spend $549.46, which will give us $50.45 left for any changes for future iterations.

Appendix E: Project Schedule

Activity	Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Problem Definition and Concept Review																	
Problem Definition																	
Project Initiation																	
Concept Generation																	
Determine selection and criteria																	
Market Analysis (customers + economy)																	
Project Planning																	
Research Arduino (sensor, batteries, motors, pcb)																	
Down-select top concepts																	
Oral and written report						1											
Critical Design Review																	
Choose Final Concept																	
Determine tilting mechanism																	
Choose Sensor Type																	
Code Sensor (code + debug)																	
Code Motor/Drivers (code + debug)																	
Build tilting mechanism																	
Assemble Circuits																	
MATLAB Force Analysis																	
Solidworks Force Analysis																	
Bill of Materials (full parts list + cost)																	
Pruchase Parts (electronic)																	
CAD model																	
Engineering Analysis (failure analysis, thermal simulation, solidworks simulation)																	
Manufacturing drawings																	
Oral and written report									2								
Final Design Review																	
Rapid Prototype																	
Manufacturing																	
Assembly																	
Test & Validation																	
Optimization																	
Oral and written report																	3

Figure E.1: Project schedule

Appendix F: Work Breakdown Structure

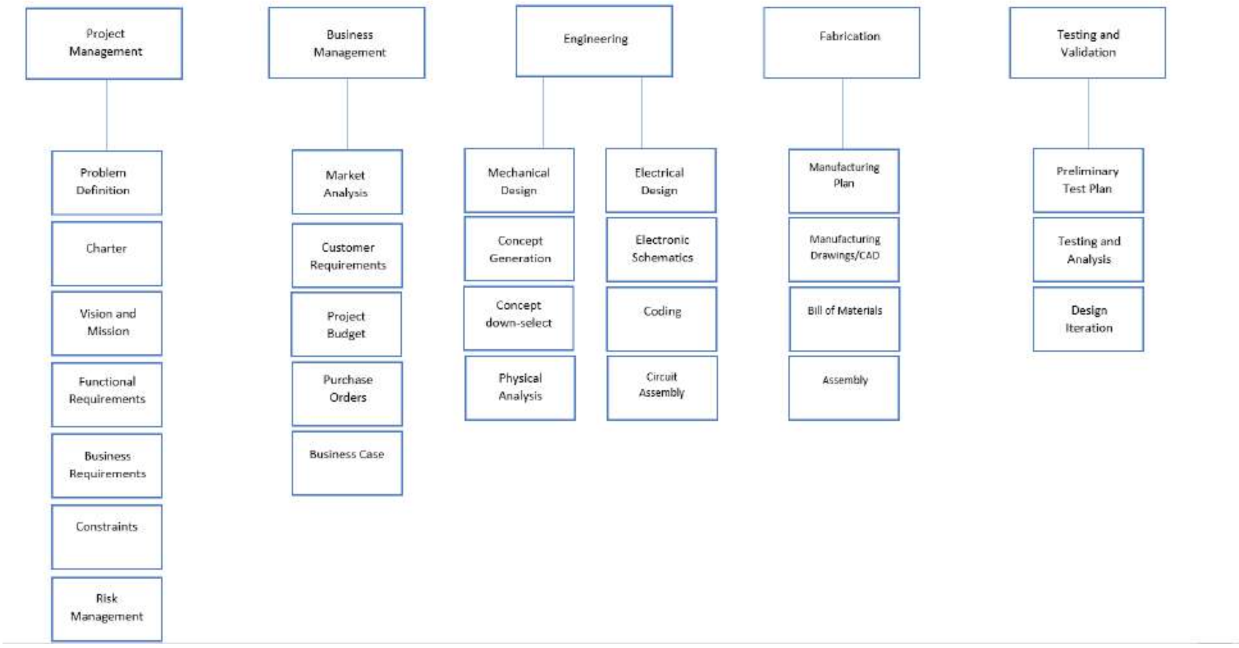


Figure F.1: Work breakdown structure

Appendix G: Network Diagram - CDR

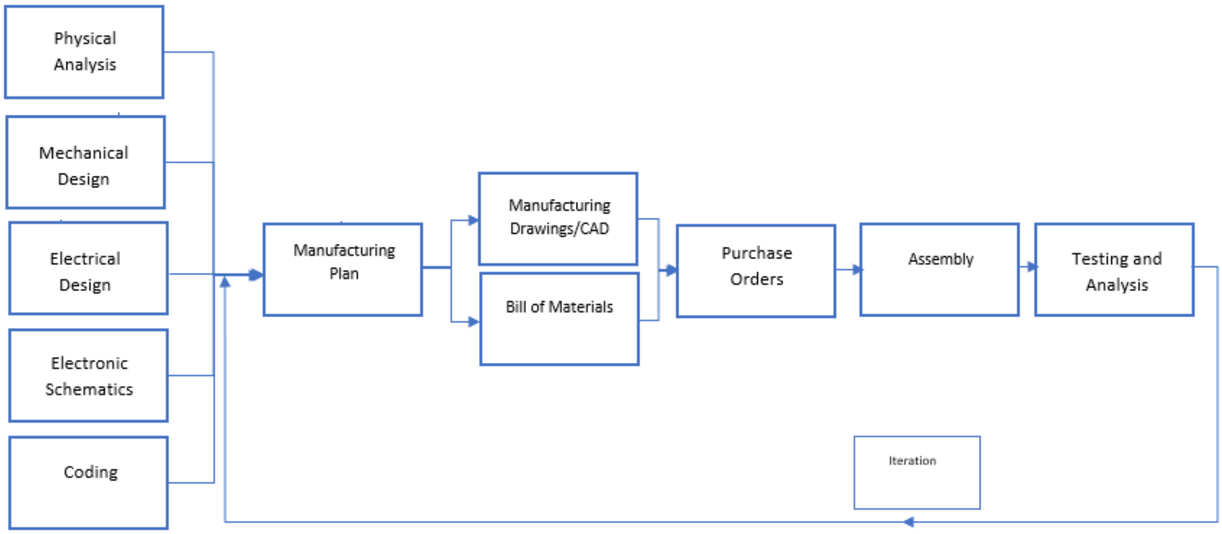


Figure G.1: Network Diagram - CDR

Above is the network diagram for the critical design review phase, showing the main tasks and goals achieved during this phase.

Appendix H: Risk Mitigation

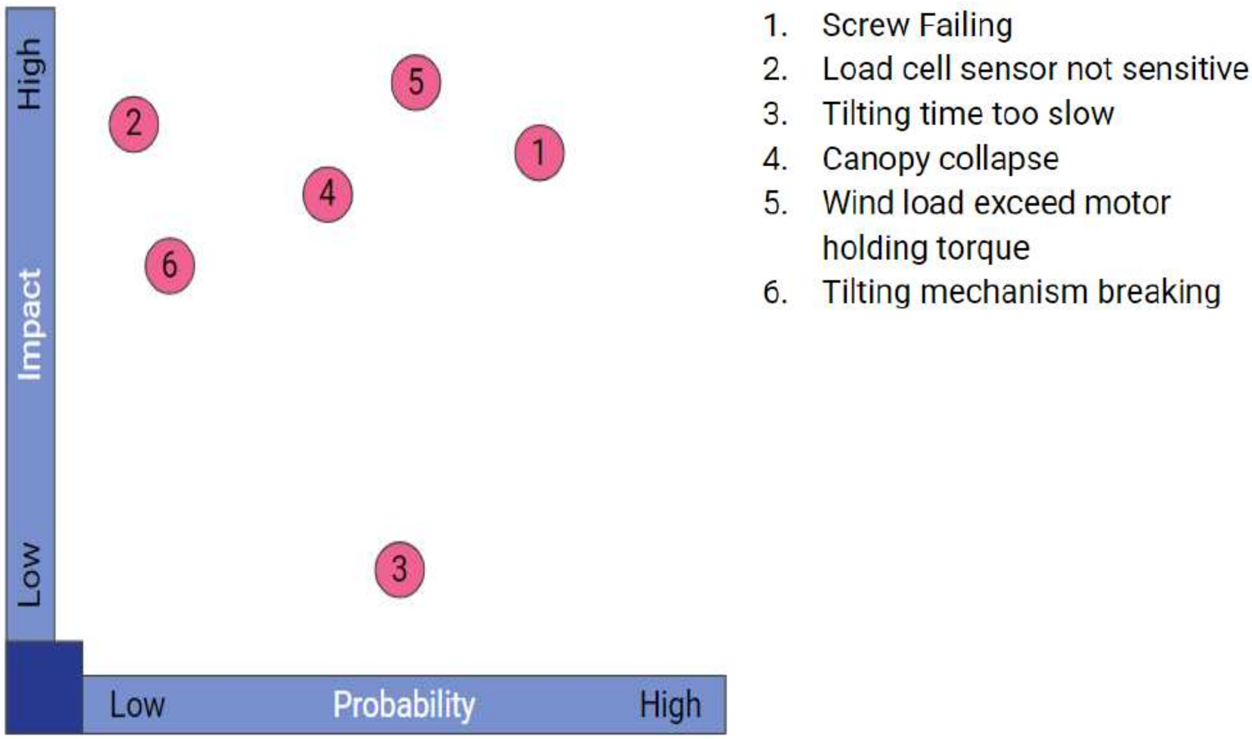


Figure H.1: Risk register for tilting mechanism and electronics

Above is the risk register for the tilting mechanism, showing that the failure that is most likely to occur is the screw failing, while the least likely failure to occur is that the load cell sensor does not sense sufficiently.

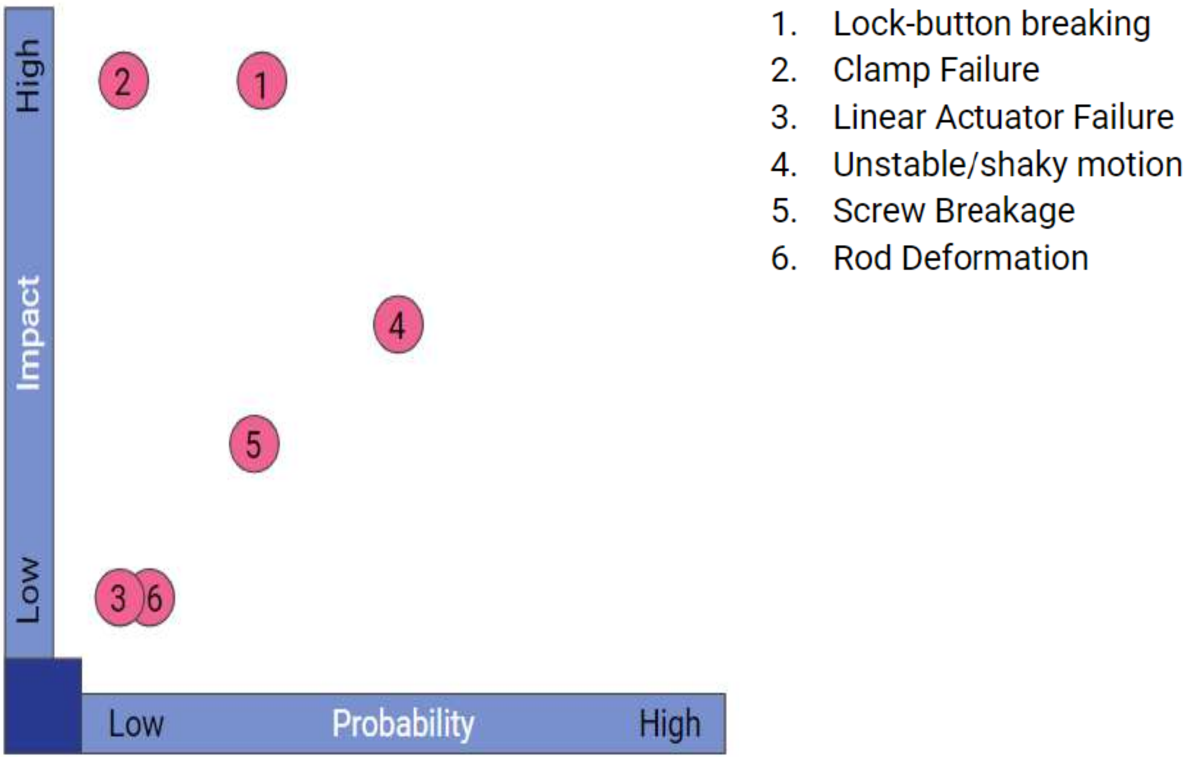


Figure H.2: Risk register for stowing mechanism

Above is the risk register of the stowing mechanism. The failure with the greatest probability is due to unstable motion in the mechanism, and the failure with the least probability is that the linear actuator will fail.

Appendix I: Mechanical Concept Generation and CAD

The complete attachment to the wheelchair was designed from two different mechanism, the tilting mechanism and the stowing mechanism.

Concept Generation

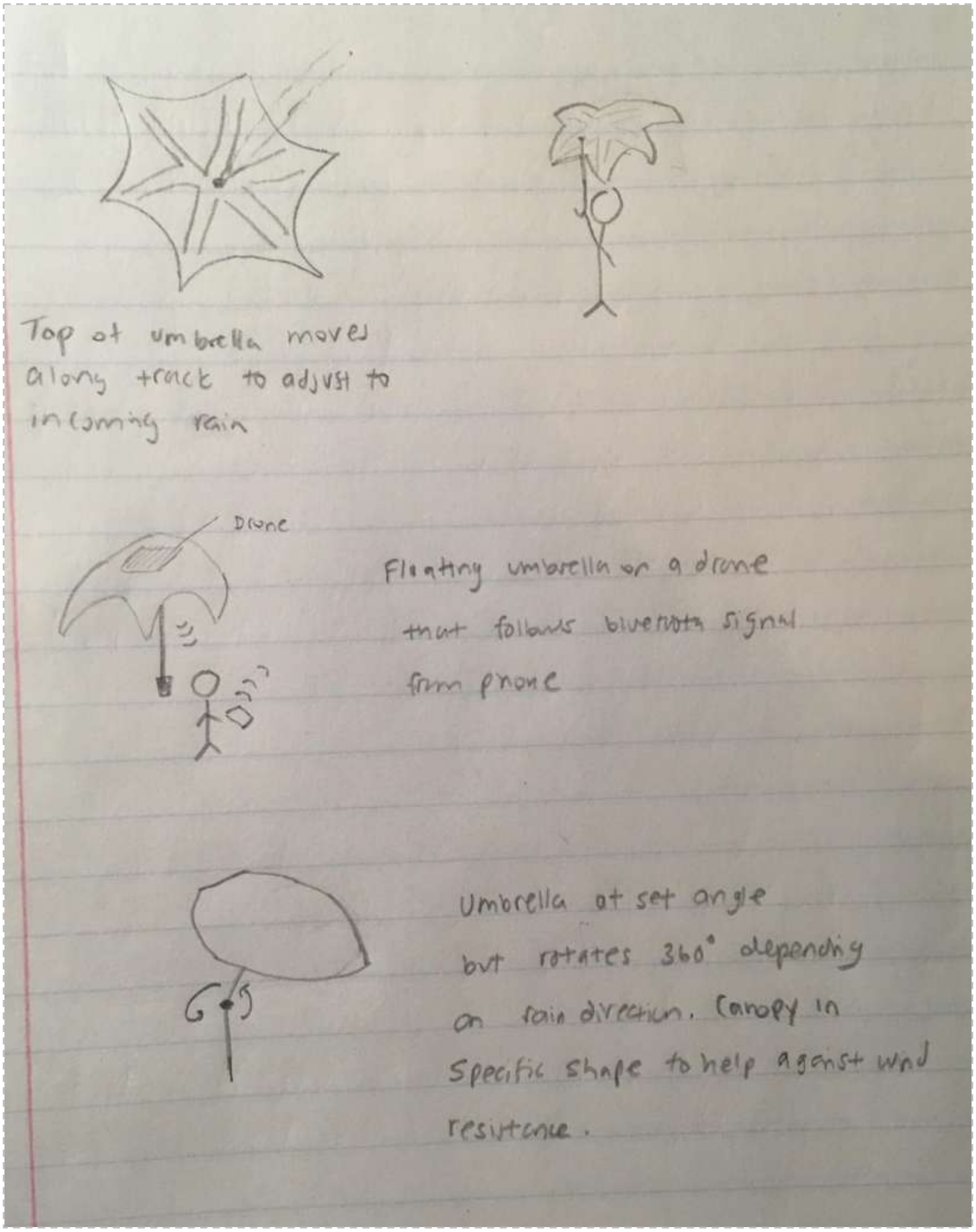


Figure I.1: Conception generation of tilting mechanism

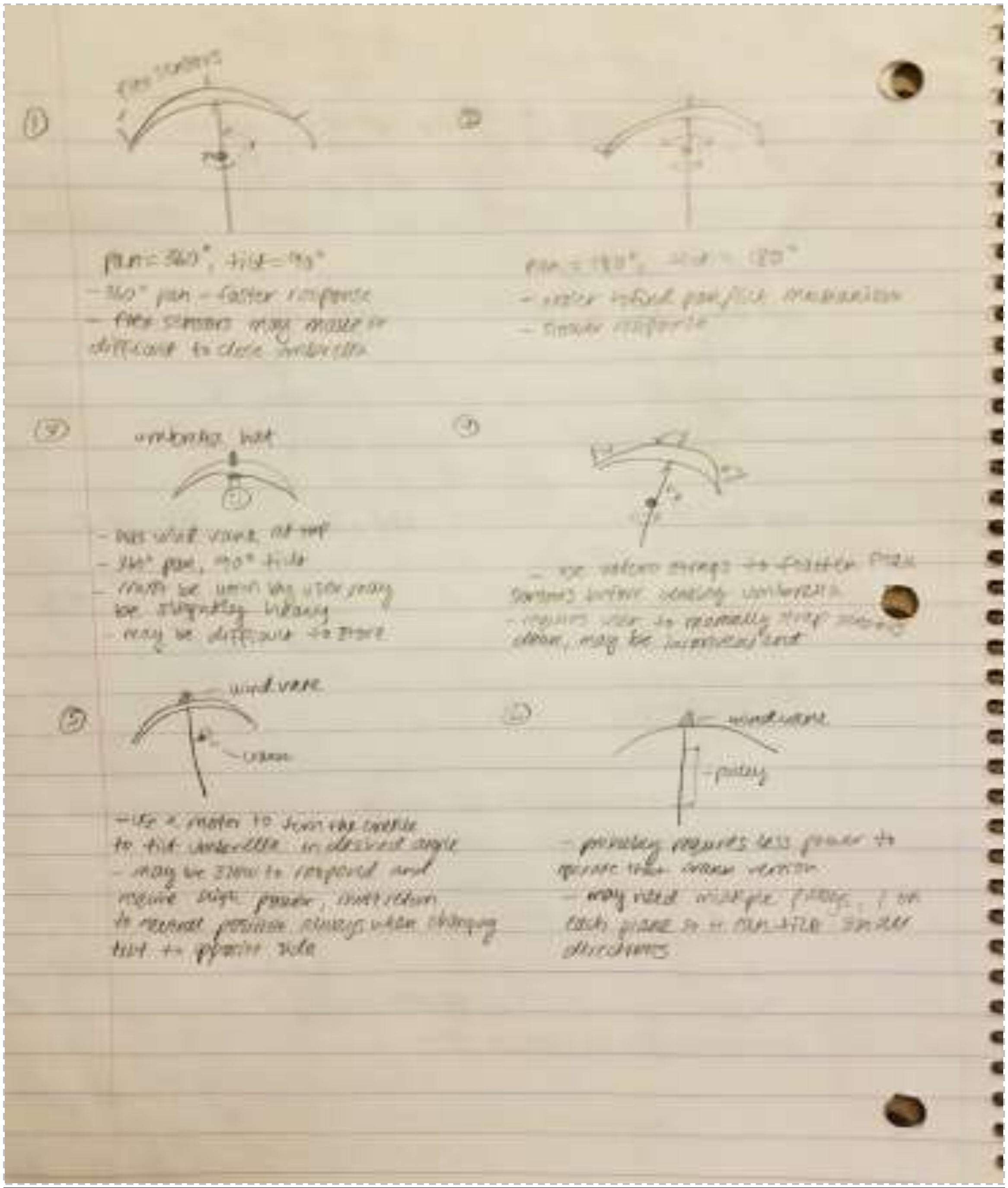


Figure I.2: Conception generation of tilting mechanism

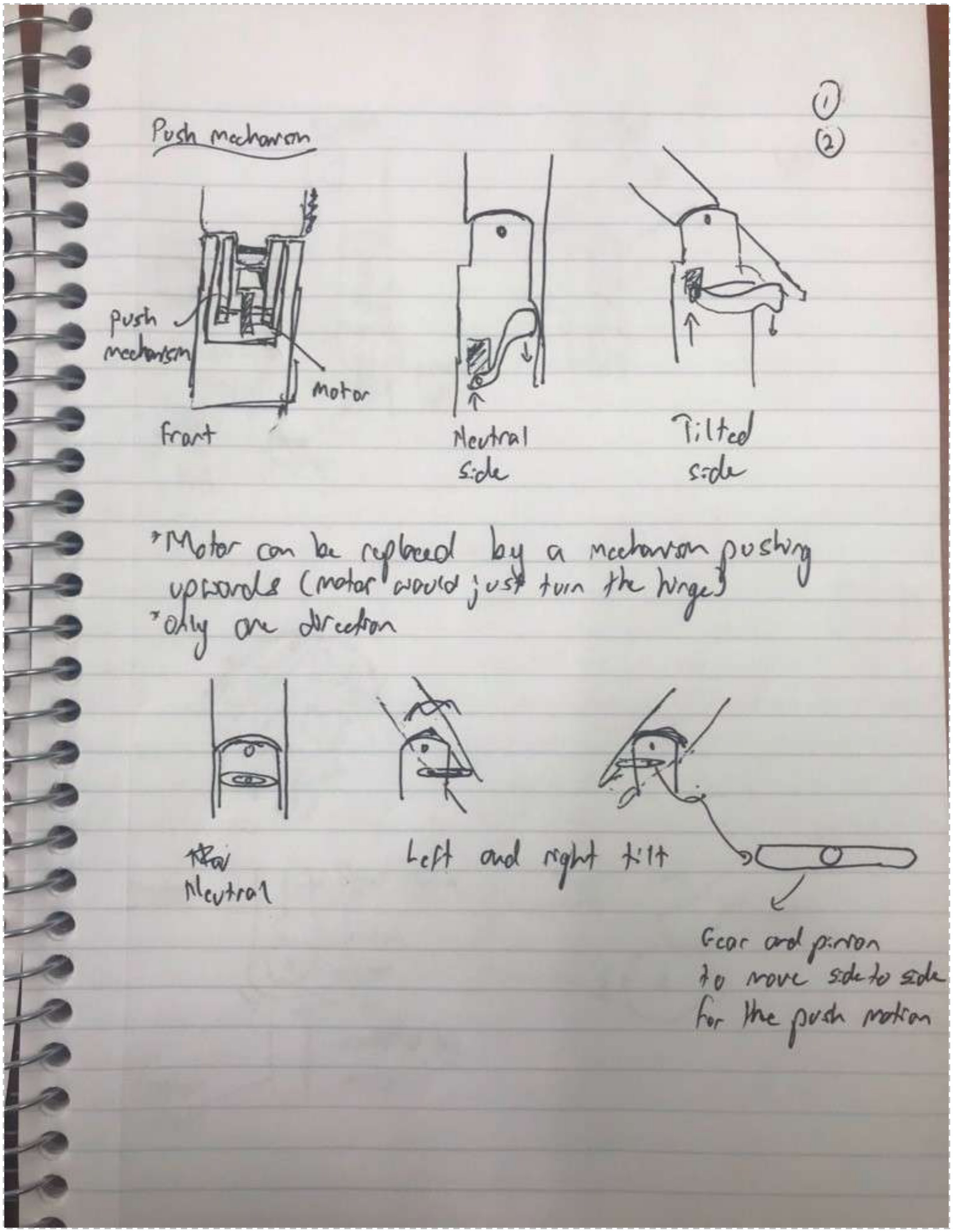


Figure I.3: Conception generation of tilting mechanism

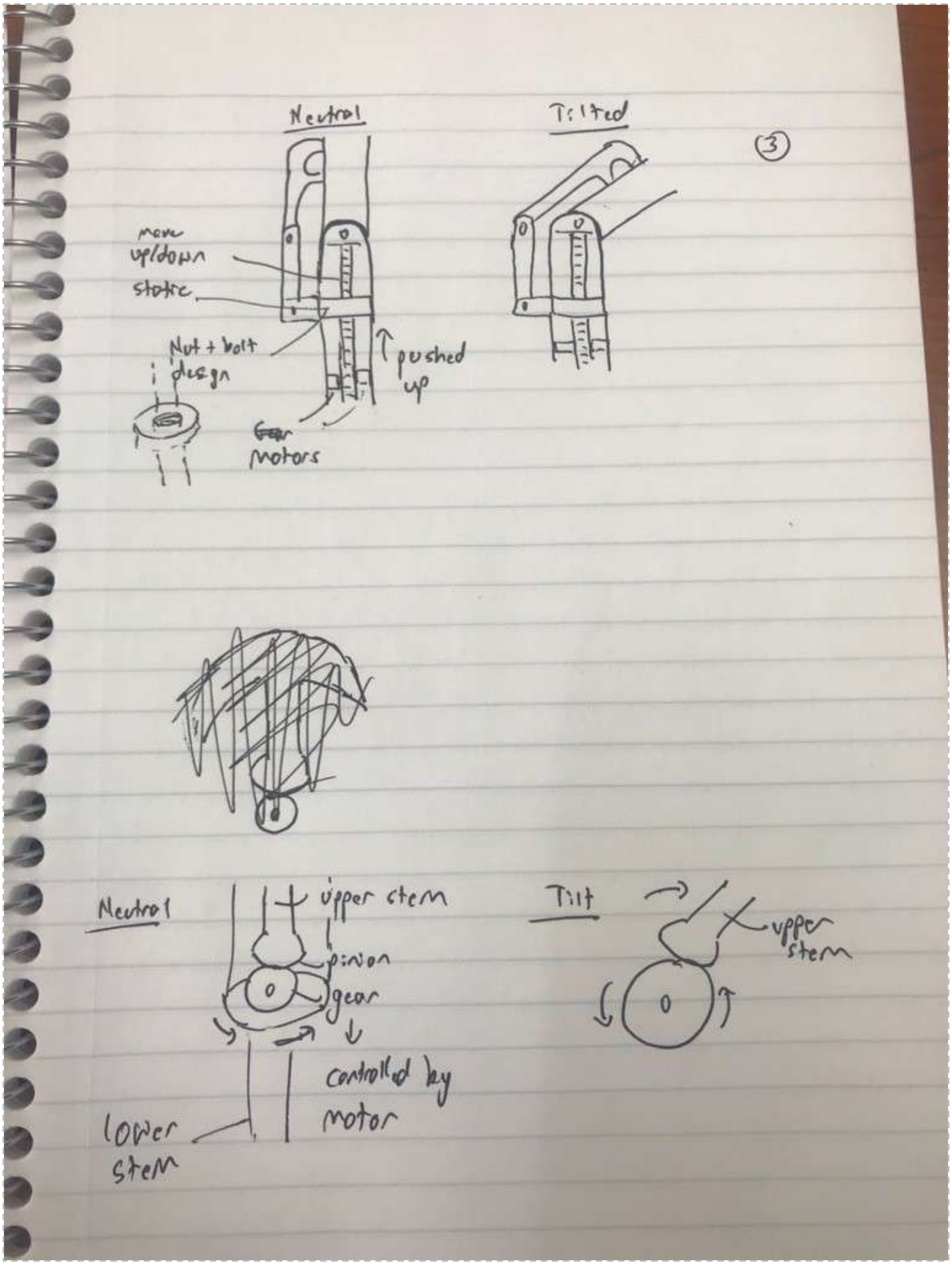


Figure I.4: Conception generation of tilting mechanism

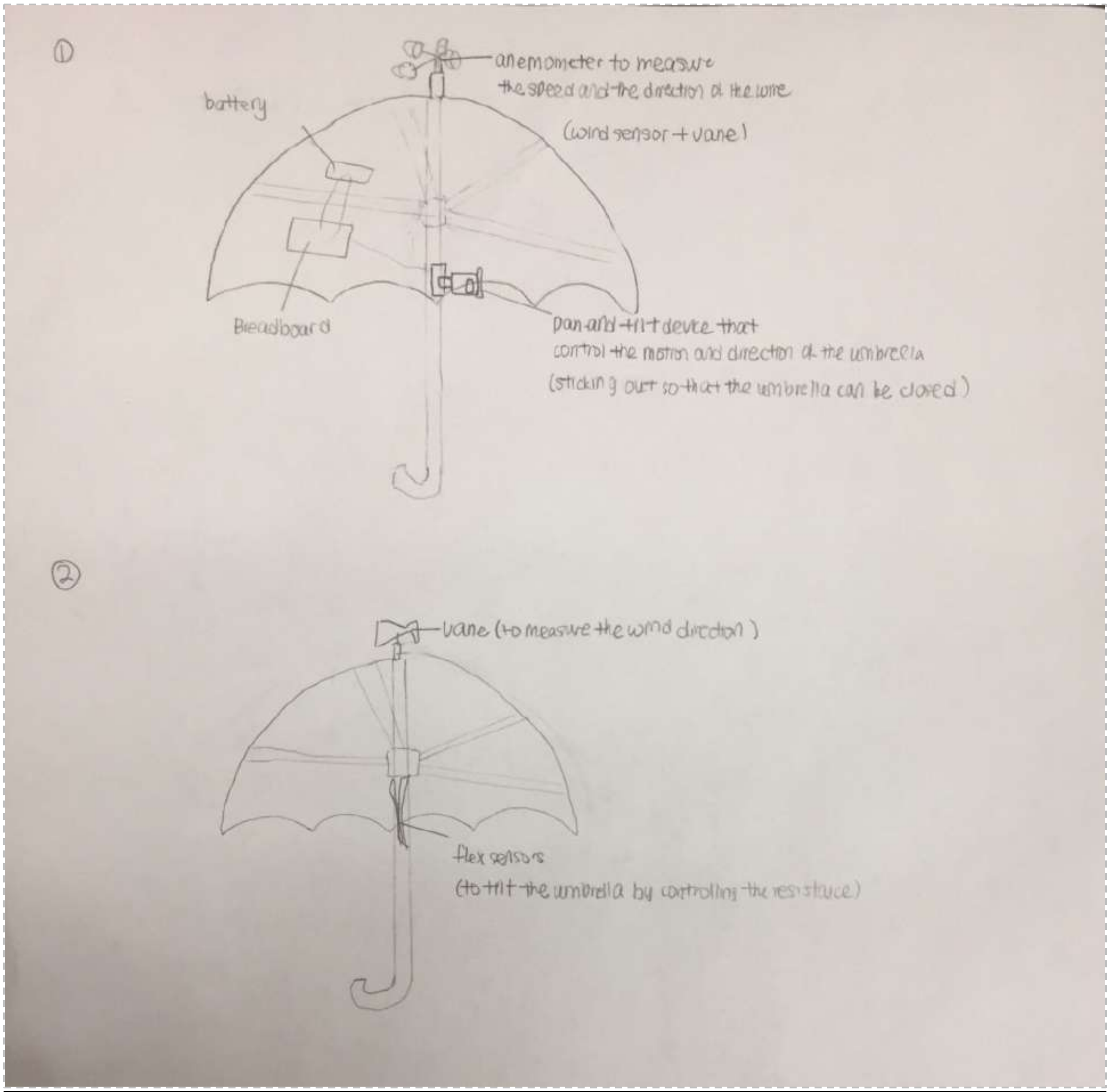


Figure I.5: Conception generation of tilting mechanism

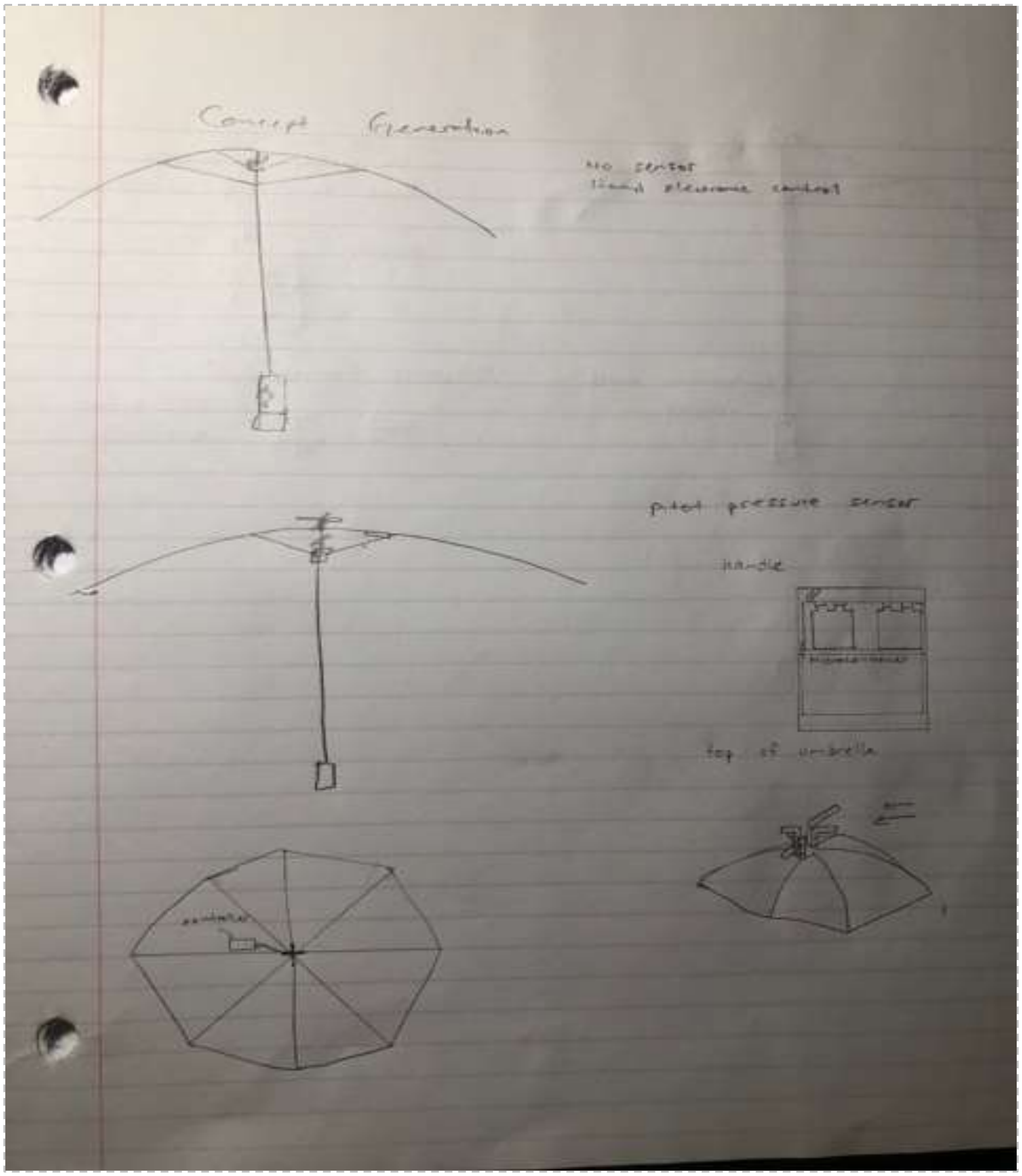


Figure I.6: Conception generation of tilting mechanism

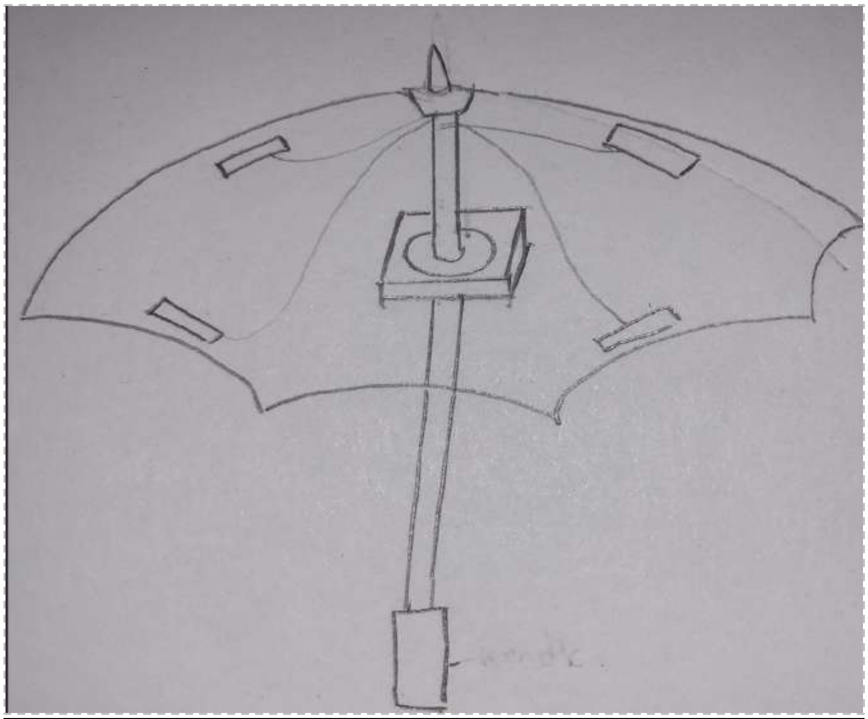


Figure I.7: Conception generation of tilting mechanism

Figure I.8: Conception generation of tilting mechanism

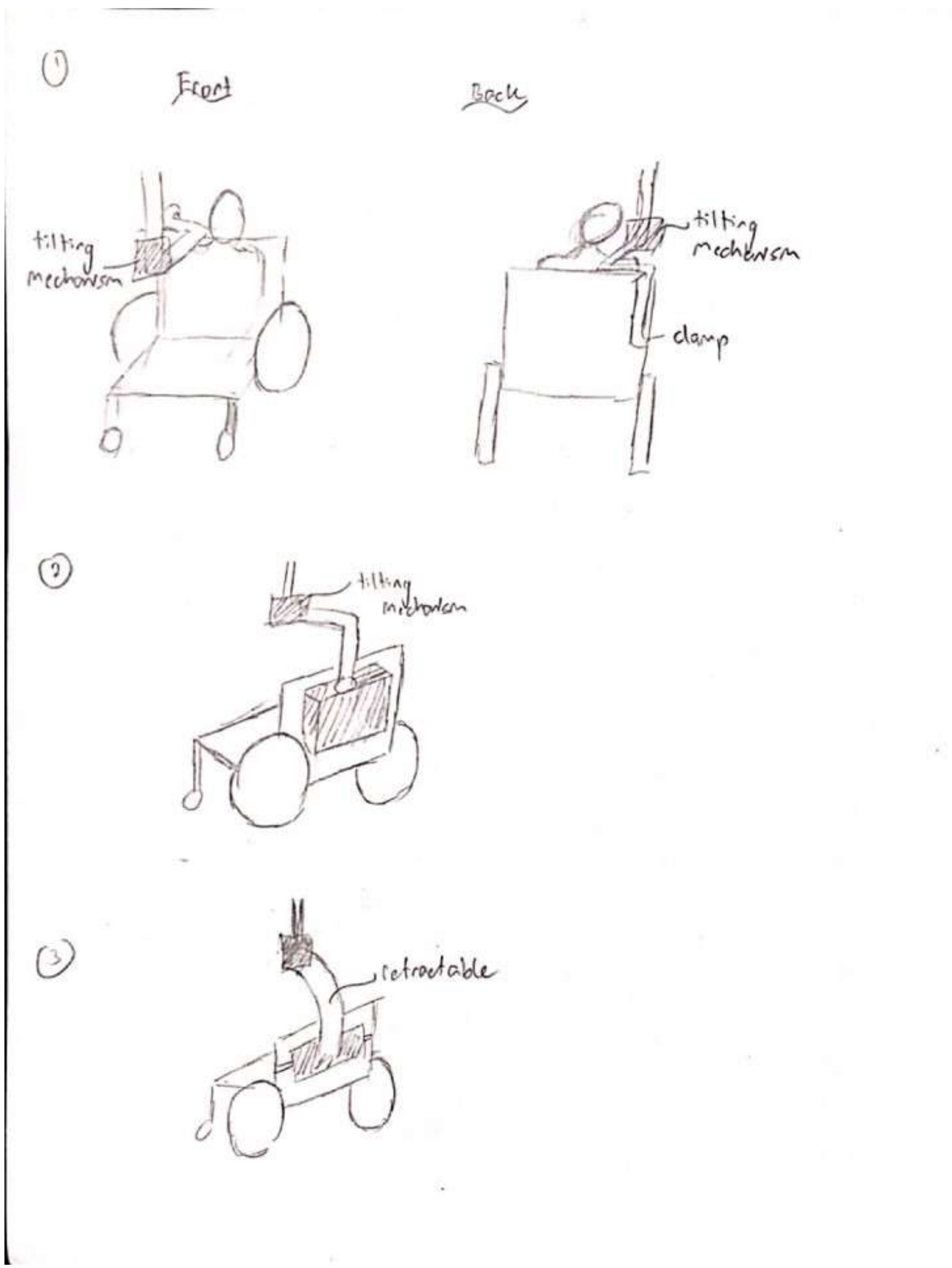


Figure I.9: Conception generation of stowing mechanism

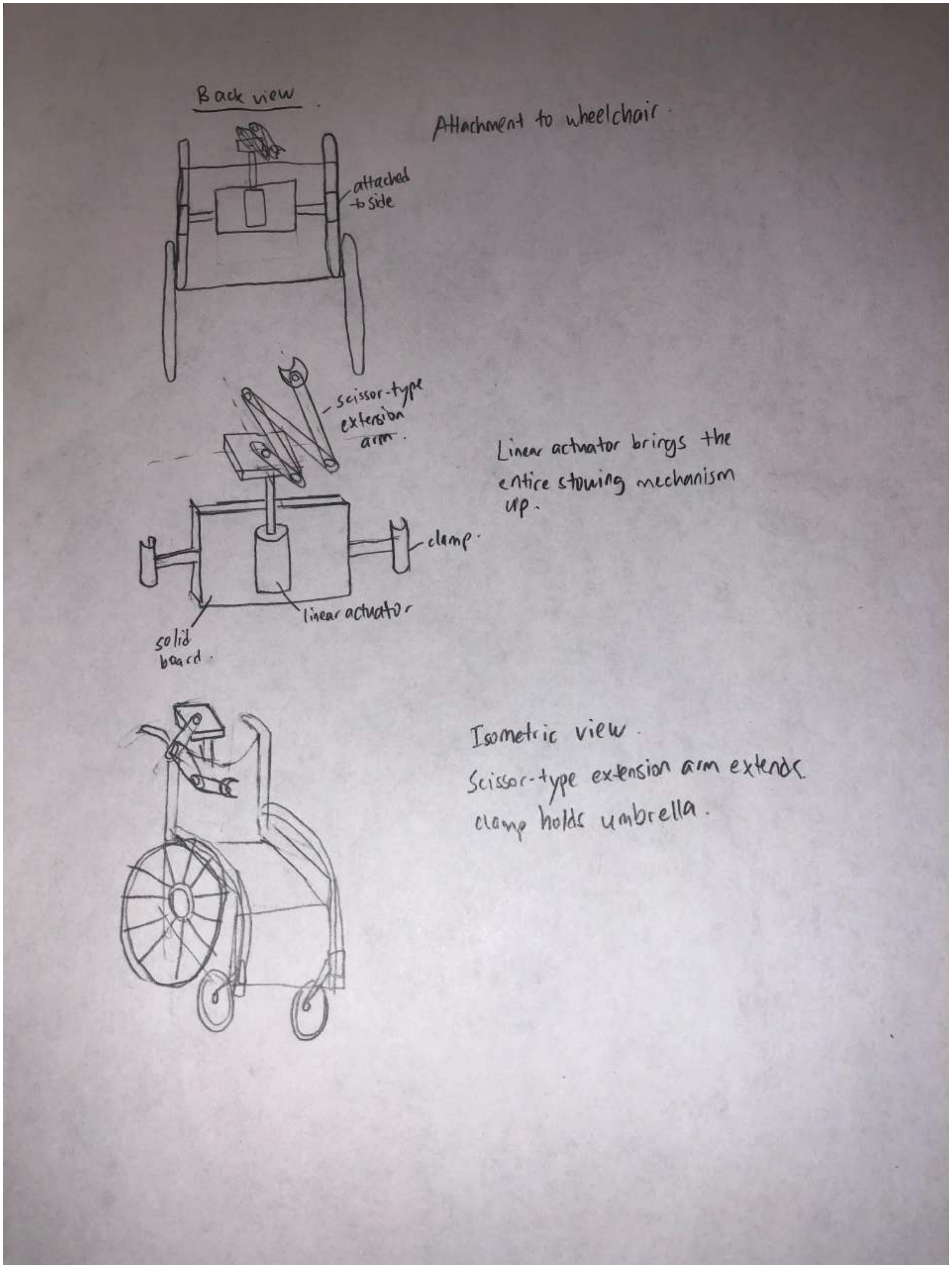


Figure I.10: Conception generation of stowing mechanism

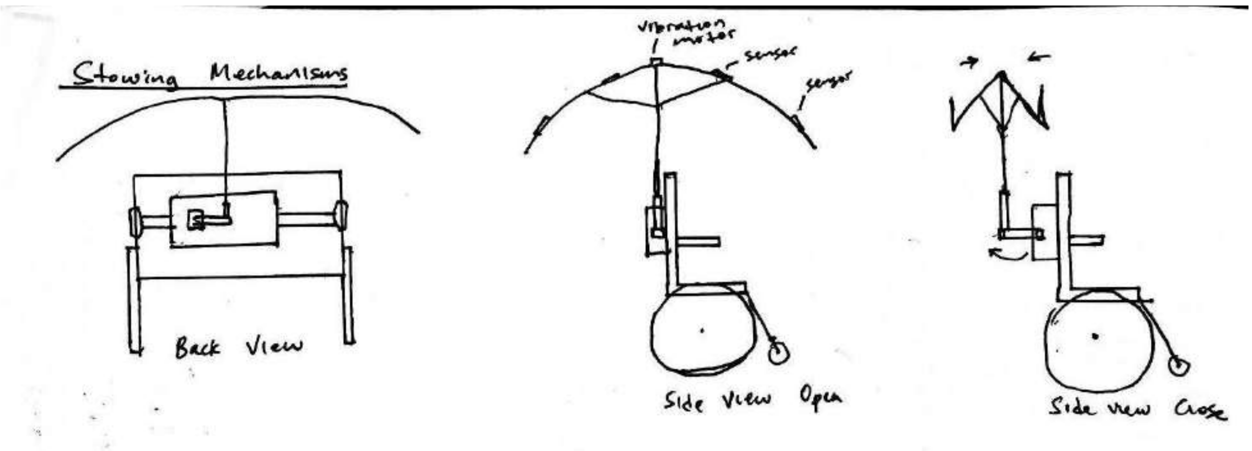


Figure I.11: Conception generation of stowing mechanism

1. **Overall CAD**

   The CAD below shows the attachment in its opened and closed position.

   a. <u>Closed position</u>

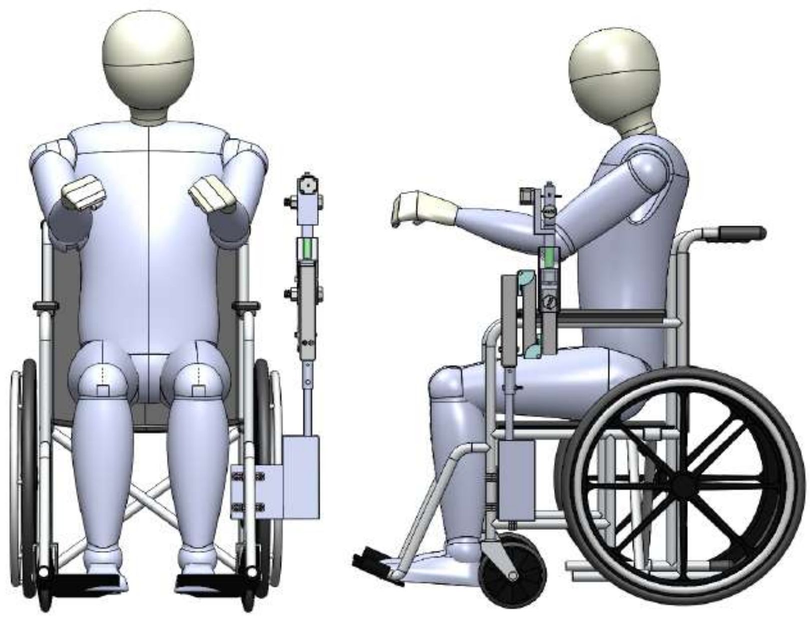


Figure I.12: When the stowing mechanism is in closed position

b. Opened position

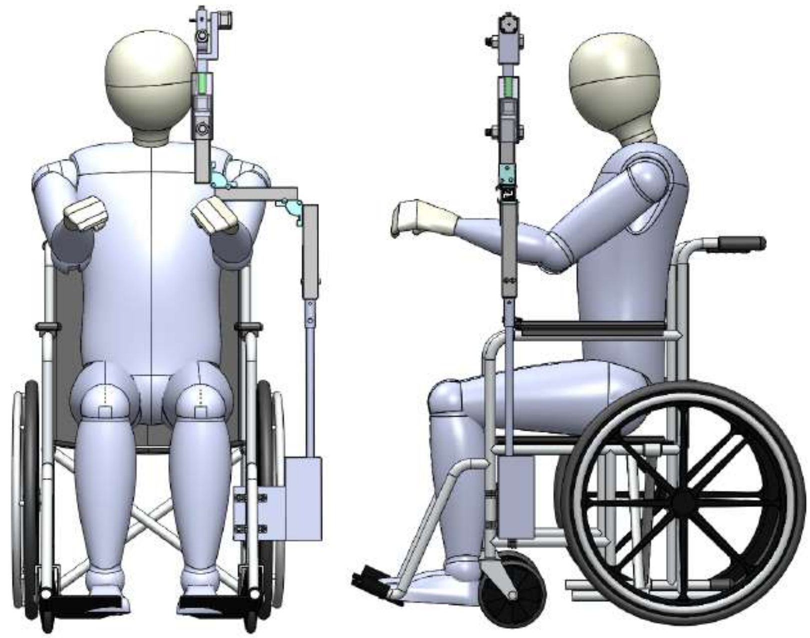


Figure I.13: When the stowing mechanism is in open position

Figure I.14: CAD of full assembly showing load cell sensor placement, tilting, and stowing mechanisms

2. **Stowing Mechanism**

The stowing mechanism was made with the main purpose of repositioning the umbrella from the side of the wheelchair to right in front of the user as that is the position where one would hold the umbrella normally in rainy conditions. The stowing mechanism utilised three different components in order to reposition from the initial stowed position to the final opened position. The first component is the linear actuator located at the bottom of the mechanism, which will actuate by 8''. The second component is the folding brackets located between the steel square tubes. The folding brackets would lock the stowing mechanism in our desired shape such that in windy conditions, the overall attachment would be steady. The final component is a lock button placed between the linear actuator and the rest upper half of the mechanism. The purpose of the lock button was to rotate the mechanism from the side of the wheelchair to in front of the user. The stowing mechanism is attached to the wheelchair through a housing which will be clamped to the wheelchair. The housing will be where the linear actuator will rest and all other necessary electronic components.

a. <u>Stowing Mechanism CAD</u>

(Red - linear actuator, Green - folding bracket, Blue - lock button)

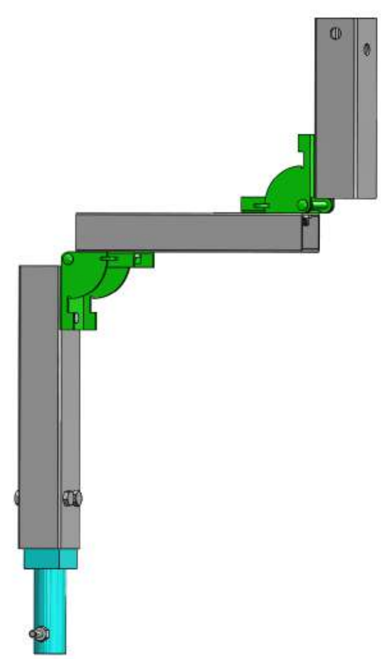


Figure I.15: Stowing mechanism

b. Stowing Mechanism Housing CAD

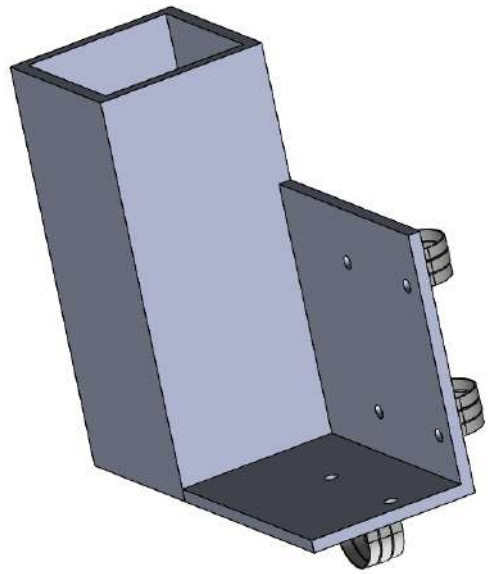


Figure I.16: Stowing mechanism housing

3. Tilting Mechanism

The tilting mechanism allows the canopy to pan and tilt to a certain direction in order to compensate for the wind/rain direction. This mechanism consist of two different components. The first component is a screw and coupler system that allow for a 30 degree ROM. The screw is attached to a motor in order to control the degree of tilt. The panning mechanism allows for 360 degree ROM. A motor is attached to the bottom of a well-lubricated shaft in order to allow for easy rotation.

a. Tilting Mechanism CAD

(Red - screw and coupler system, Green - Panning system)

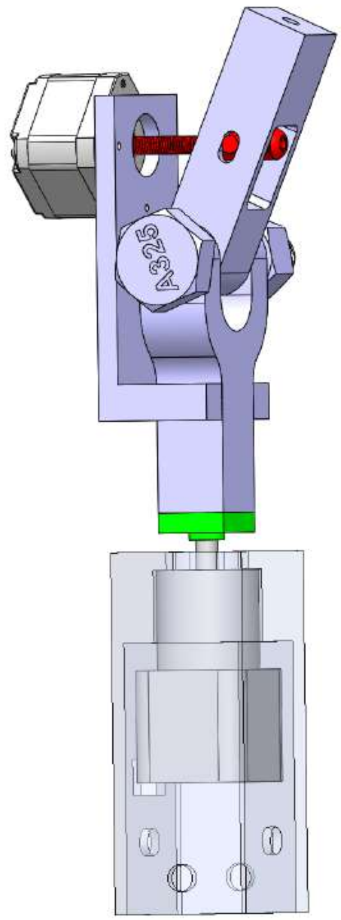


Figure I.17: Tilting mechanism with D-Hub

Figure I.17 displays the final tilting mechanism that was updated in the FDR phase to include the D-Hub connection to the geared motor shaft. Due to machining limitations, creating a D-shaped slot in the fork end for the motor shaft was not possible. The D-hub provided a secure connection between the tilting mechanism and the output of the yaw motor without impeding function.

Appendix J: Mechanical Assembly Manufacturing Drawings

Stowing Mechanism

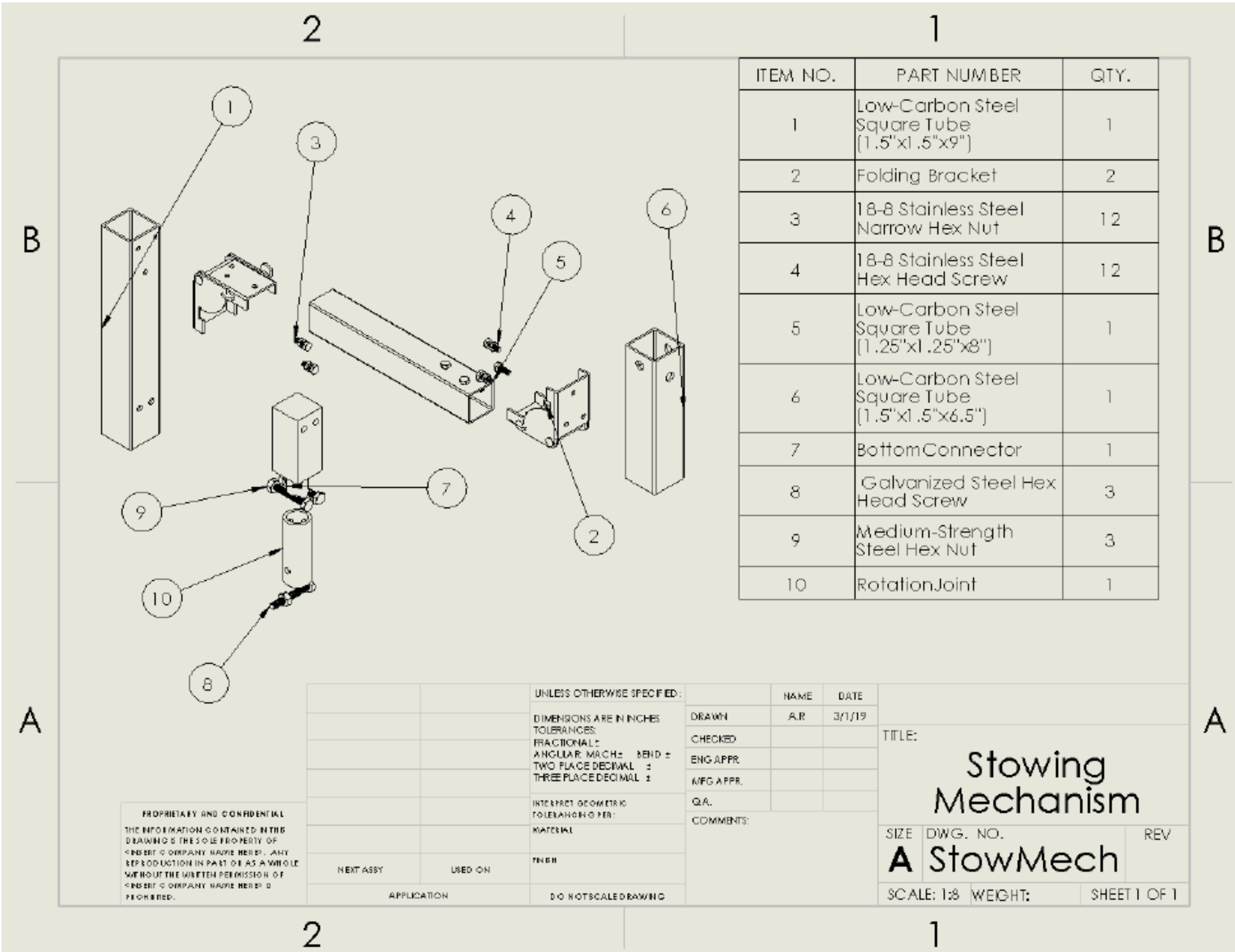


Figure J.1: Assembly drawing for the stowing mechanism

Figure J.1 shows the exploded view of the stowing mechanism with its bill of materials. Each part in the assembly is labeled and can be referenced in the table. The part drawings of the manufactured parts are listed below from Figure J.2 to Figure J.6.

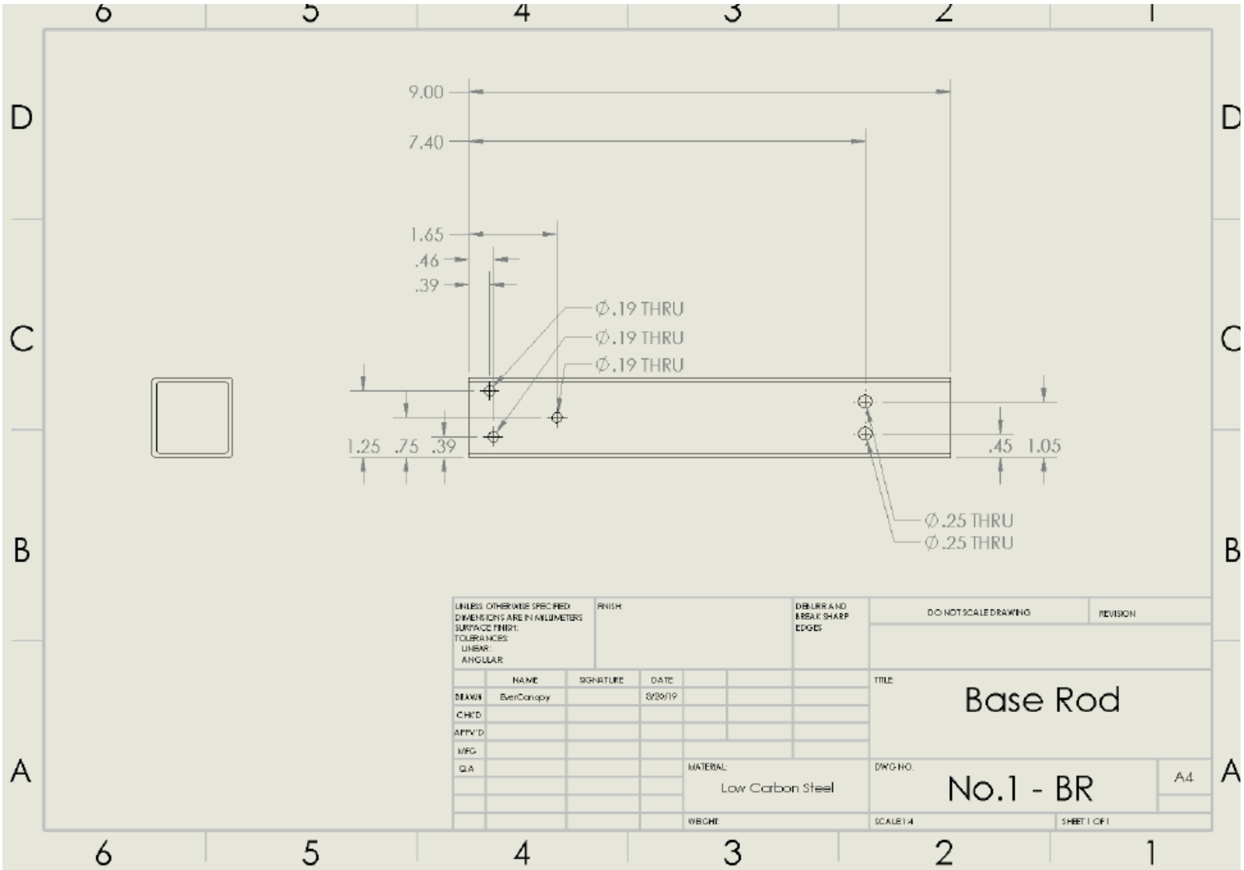


Figure J.2: Part drawing for the Base Rod of the stowing mechanism (Part 1)

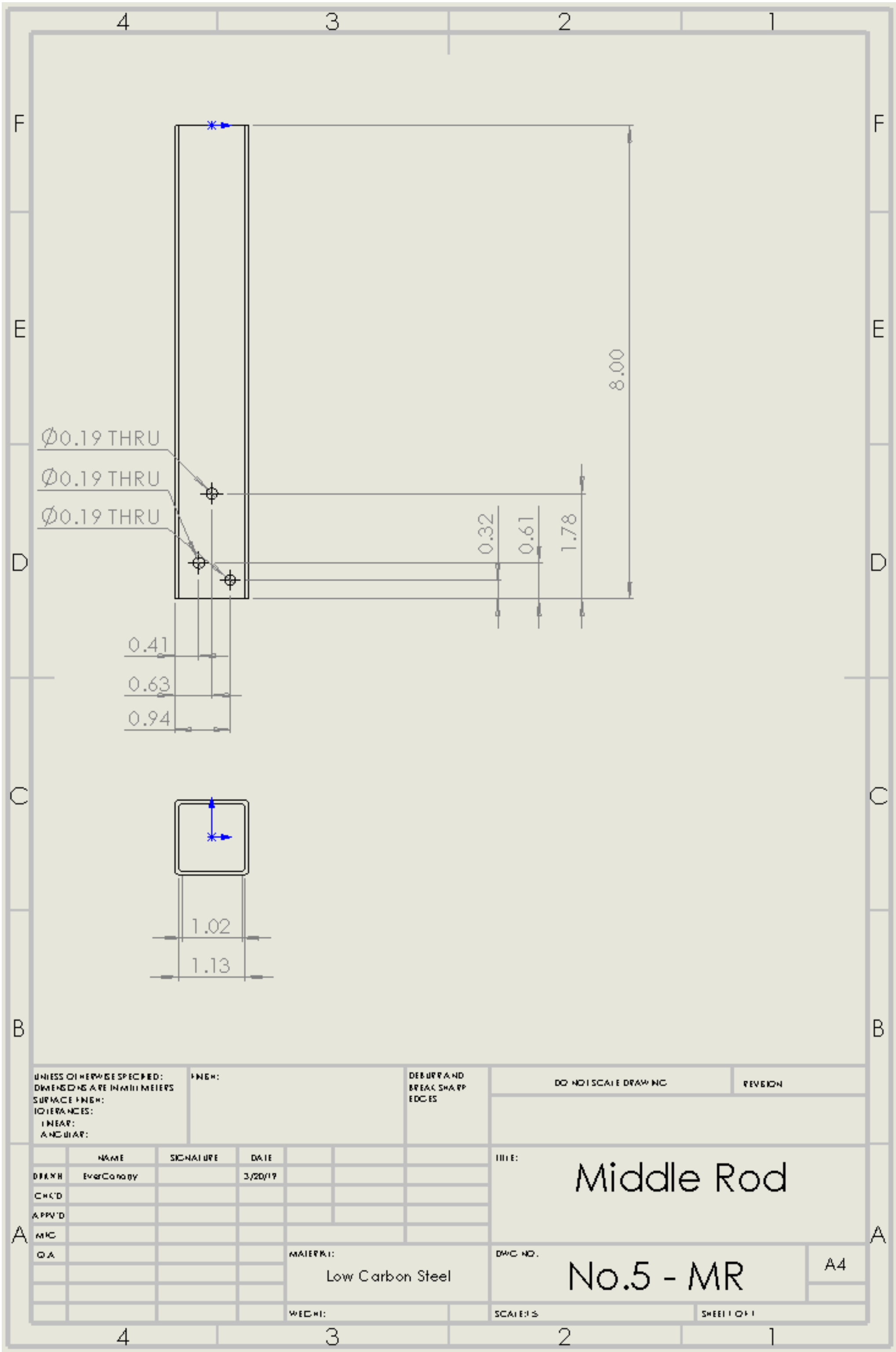


Figure J.3: Part drawing for the Middle Rod of the stowing mechanism (Part 5)

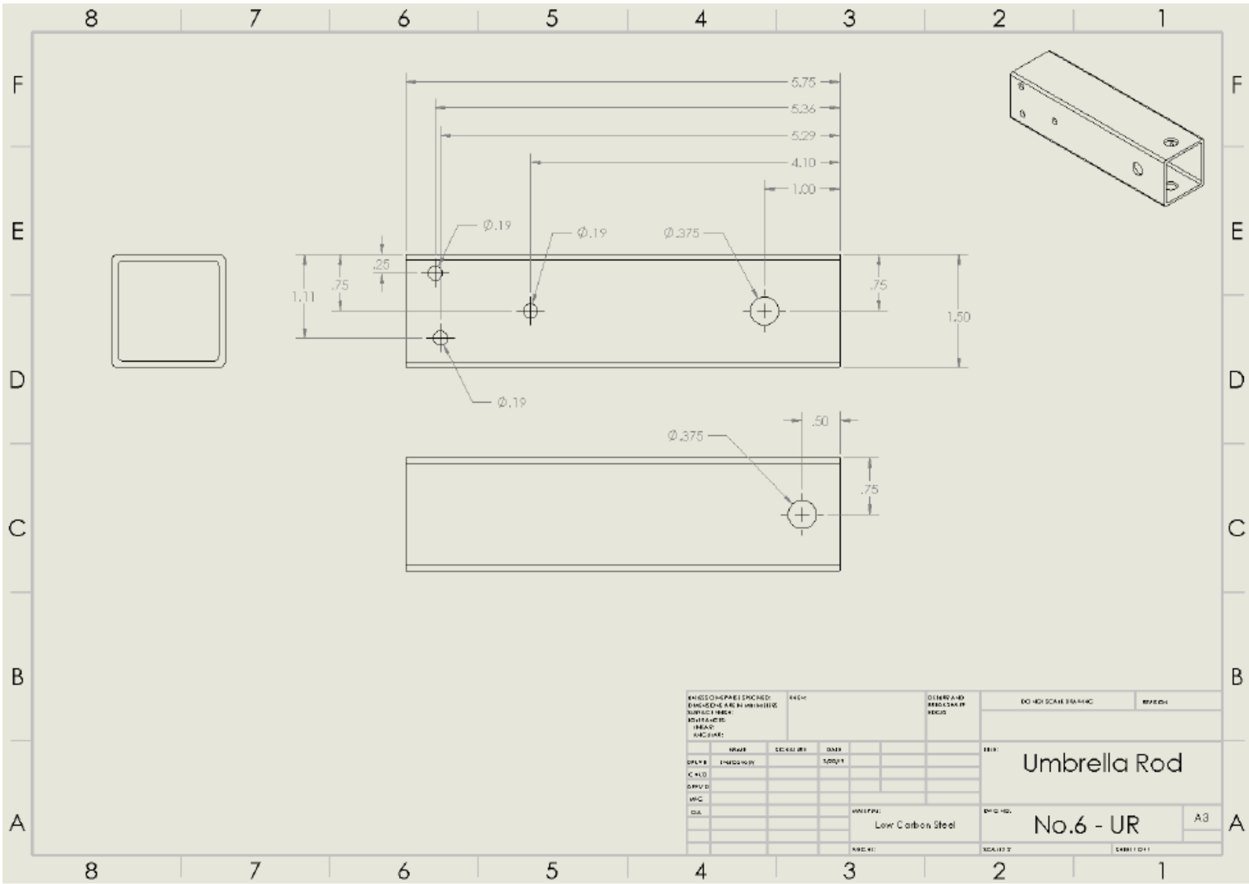


Figure J.4: Part drawing for the Umbrella Rod of the stowing mechanism (Part 6)

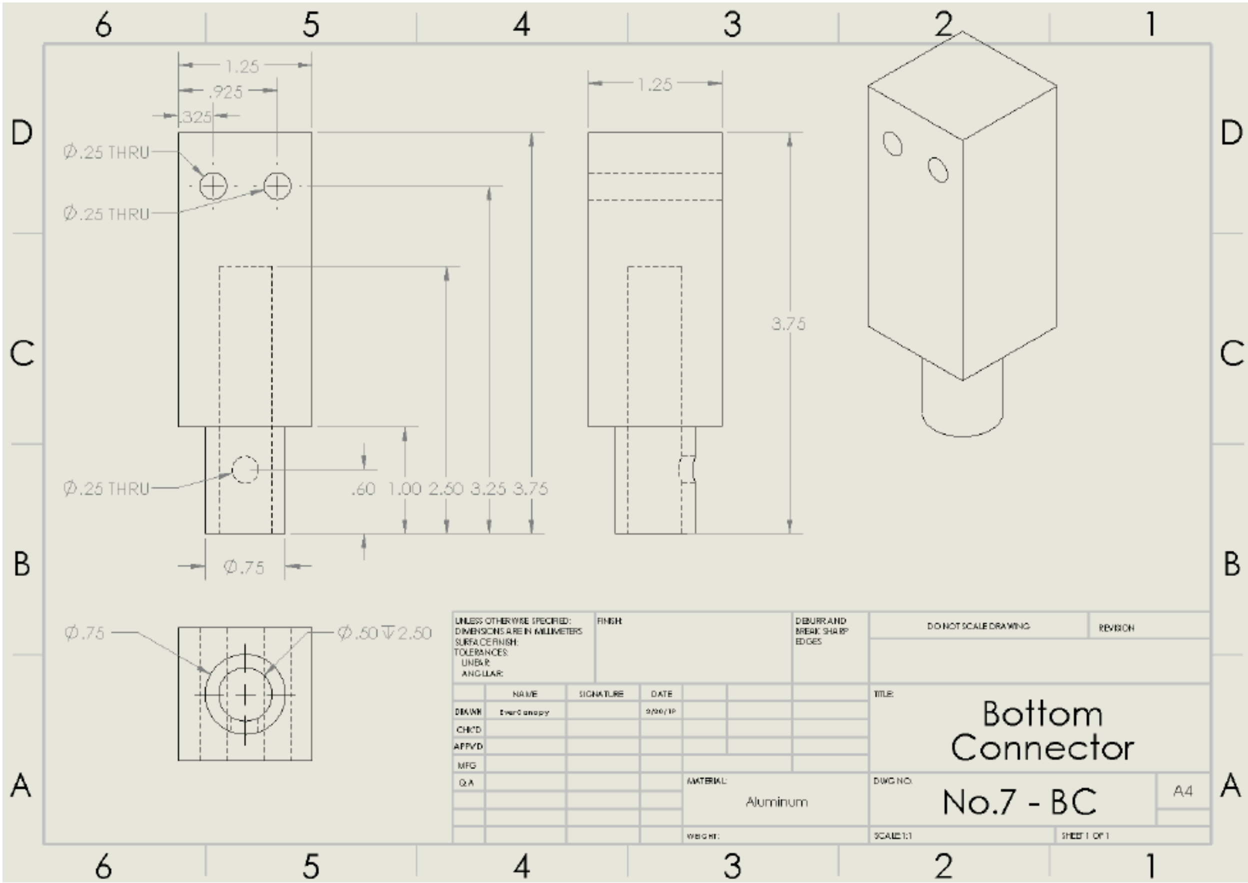


Figure J.5: Part drawing for the Bottom Connector of the stowing mechanism (Part 7)

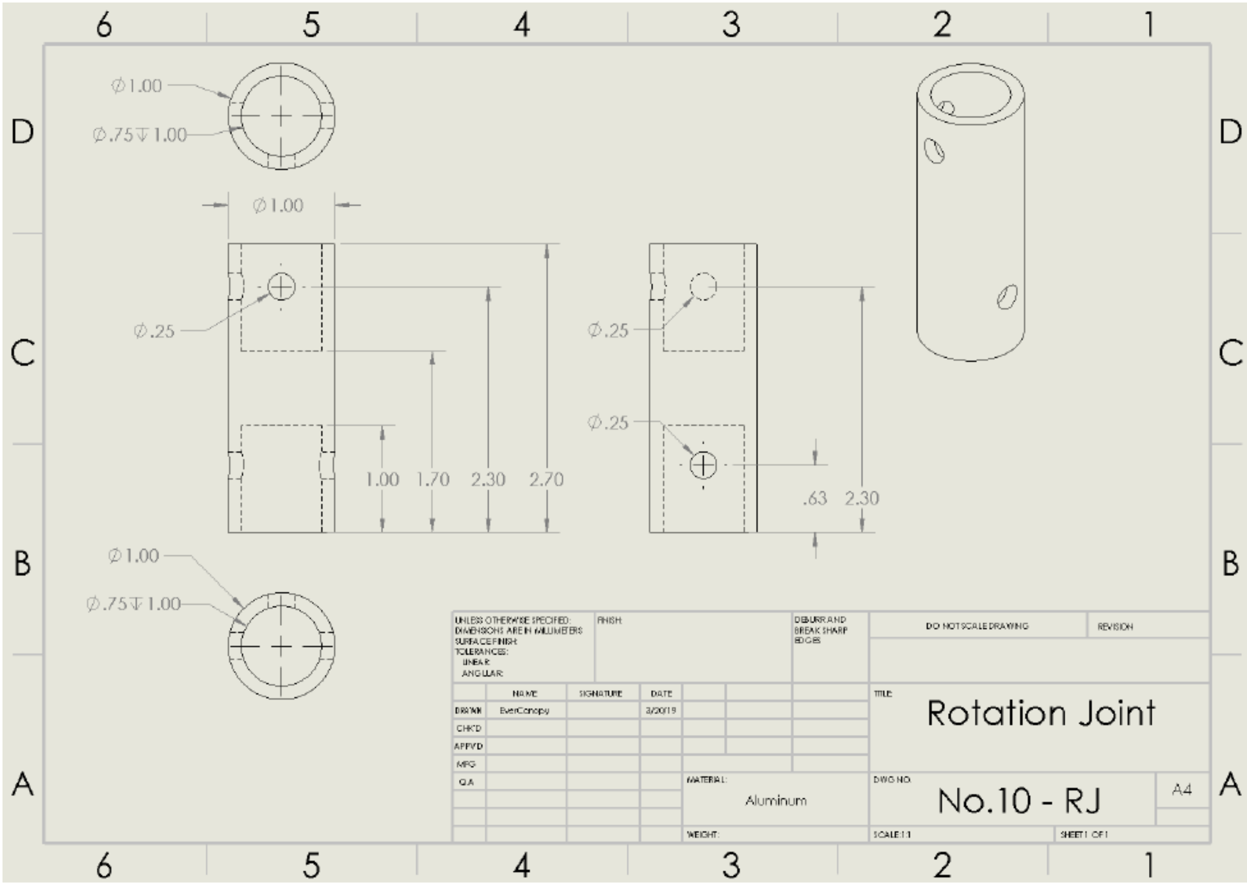


Figure J.6: Part drawing for the Rotation Joint of the stowing mechanism (Part 10)

Pan and Tilt Mechanism

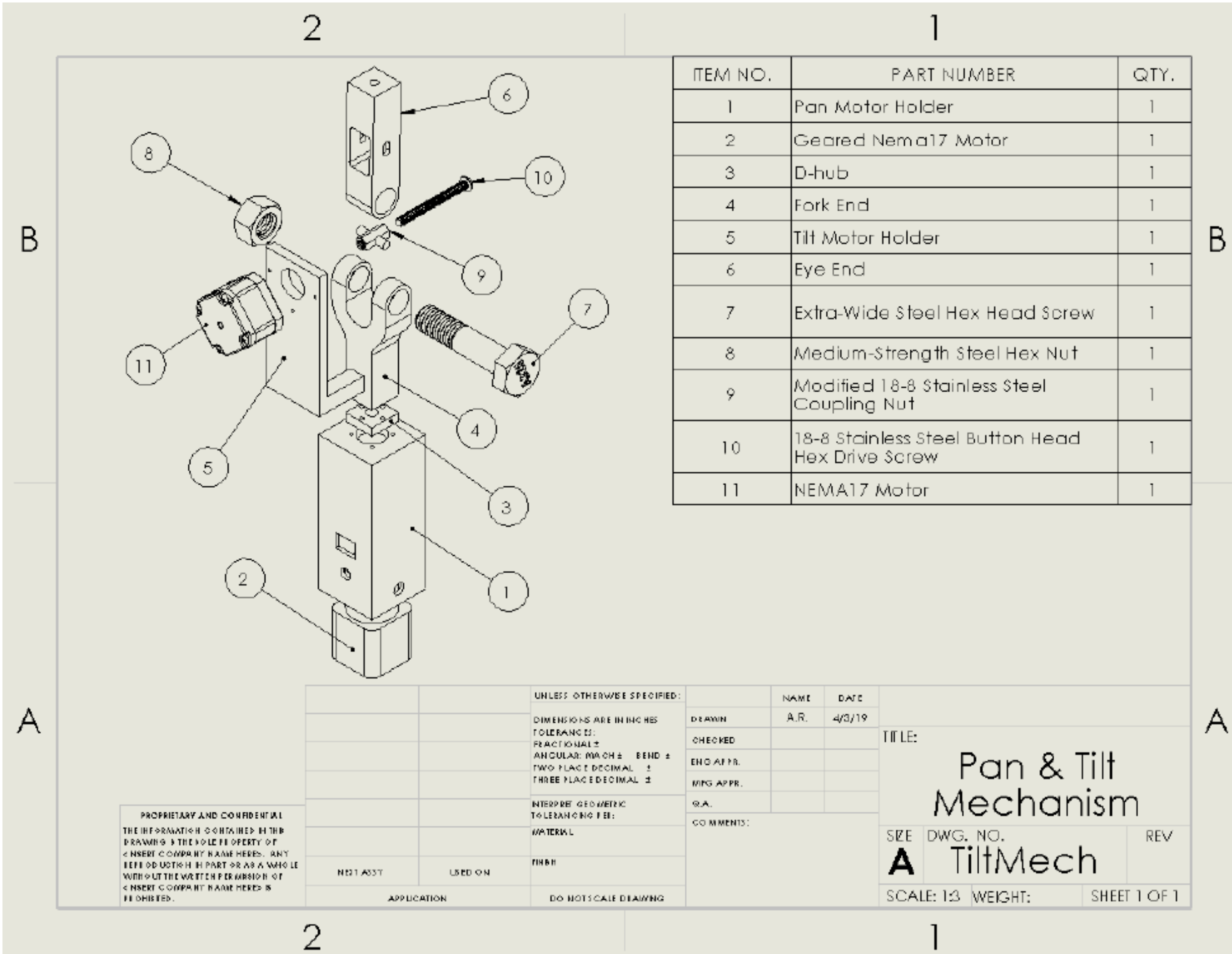


Figure J.7: Assembly drawing for the pan & tilt mechanism

Figure J.7 is an assembly drawing showing the parts required to make the pan and tilt mechanism. Each of the parts are labeled and referenced in the bill of materials table. The drawings for each of the manufactured parts are shown in Figure J.8 to Figure J.13

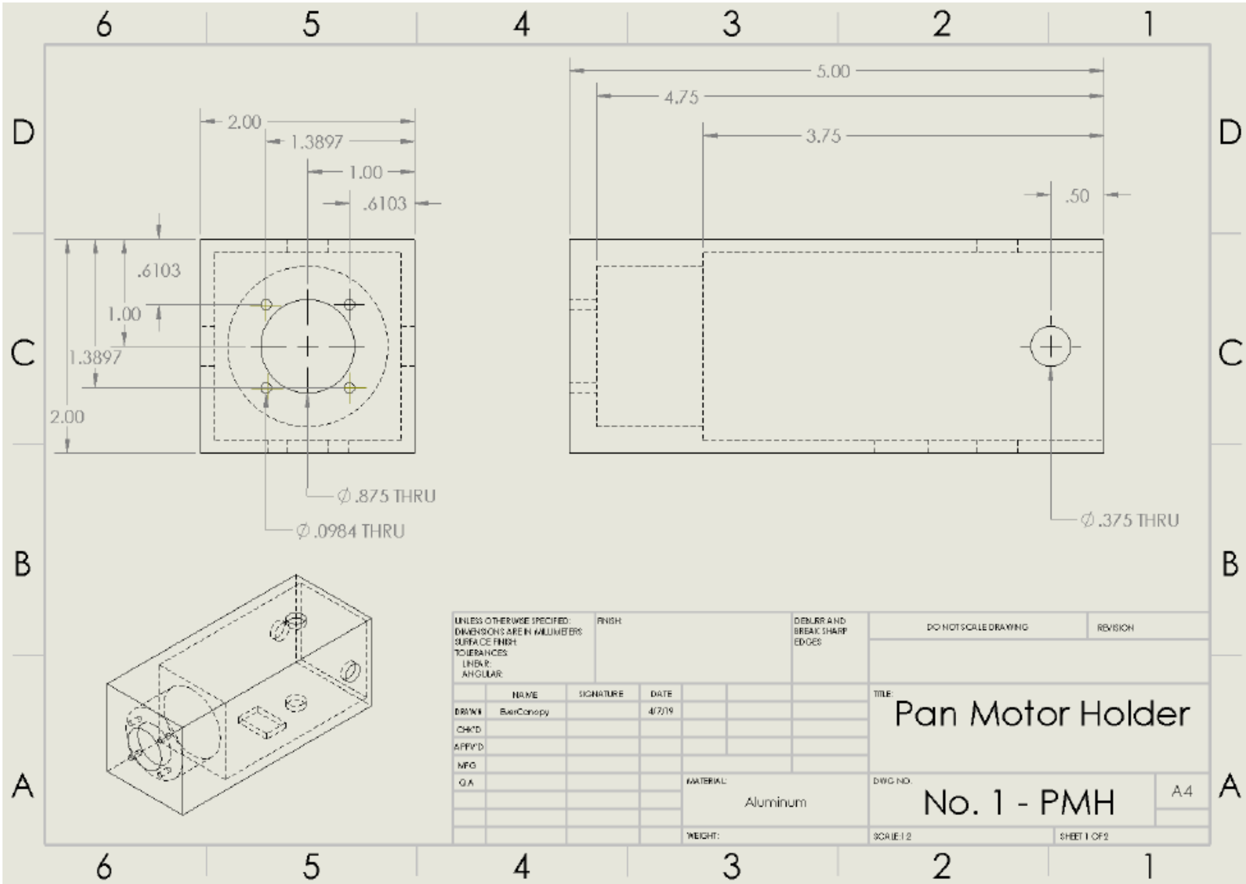


Figure J.8: Part drawing for the Pan Motor Holder of the pan & tilt Mechanism (Part 1)

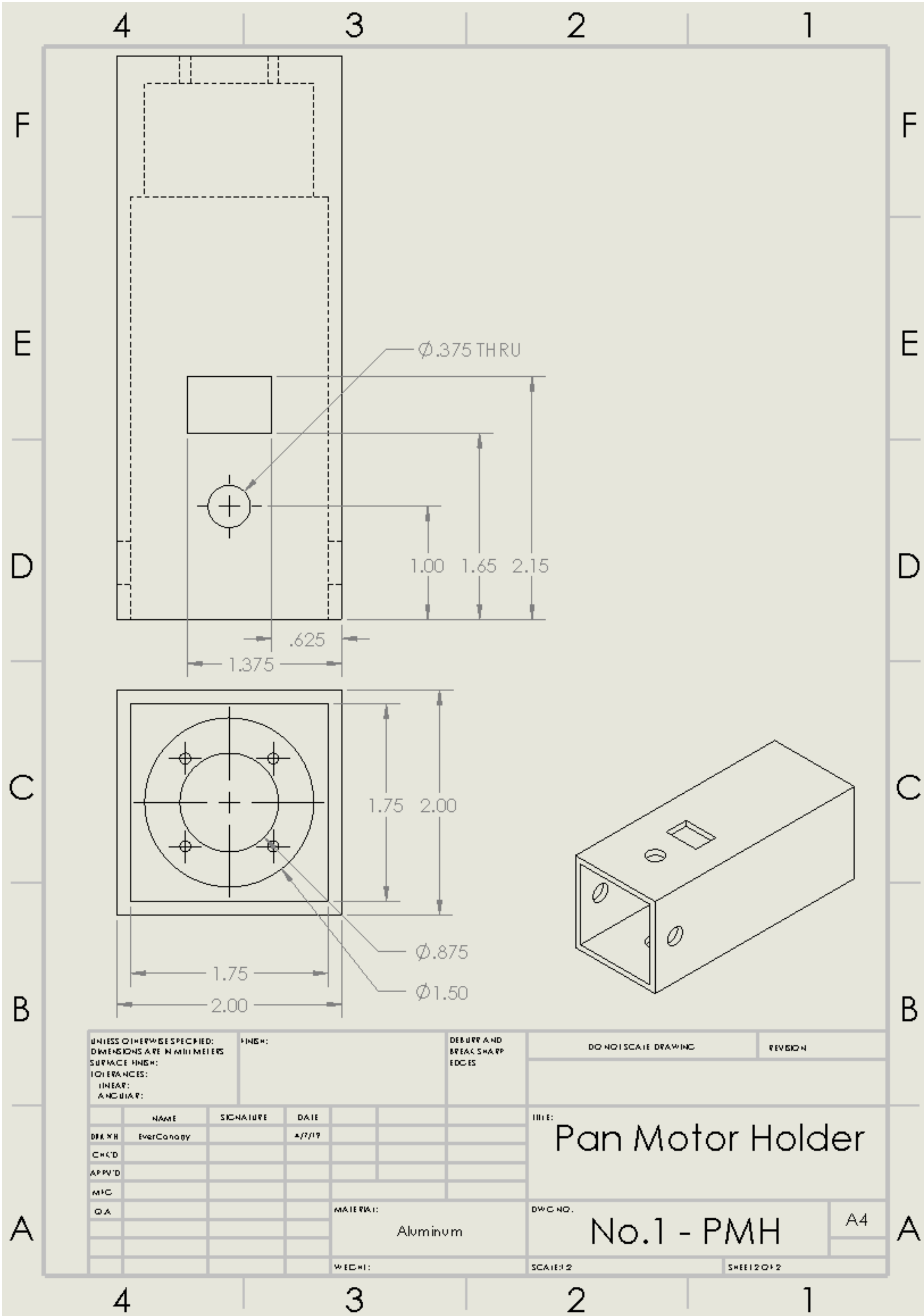


Figure J.9: Part drawing for the Pan Motor Holder of the pan & tilt mechanism (Part 1)

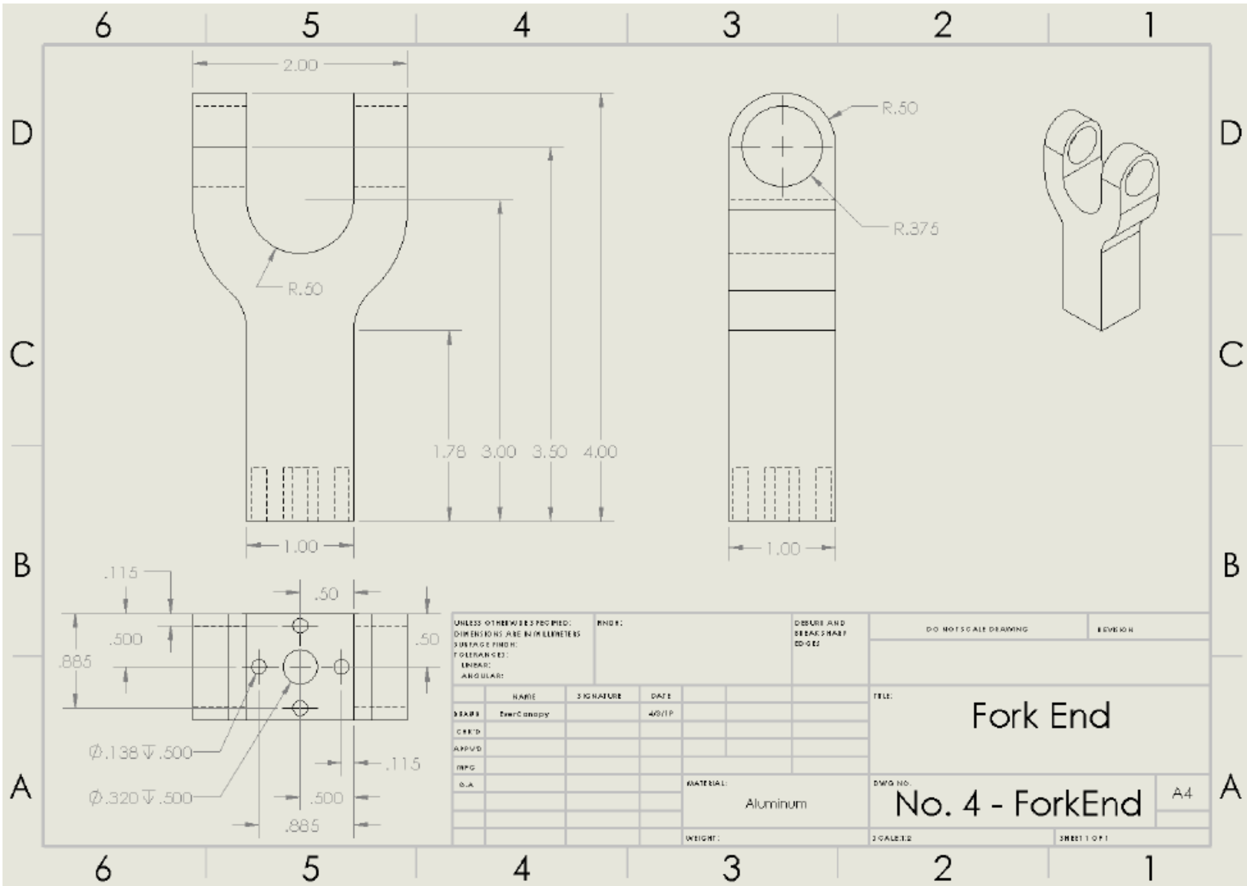


Figure J.10: Part drawing for the Fork End of the pan & tilt Mechanism (Part 4)

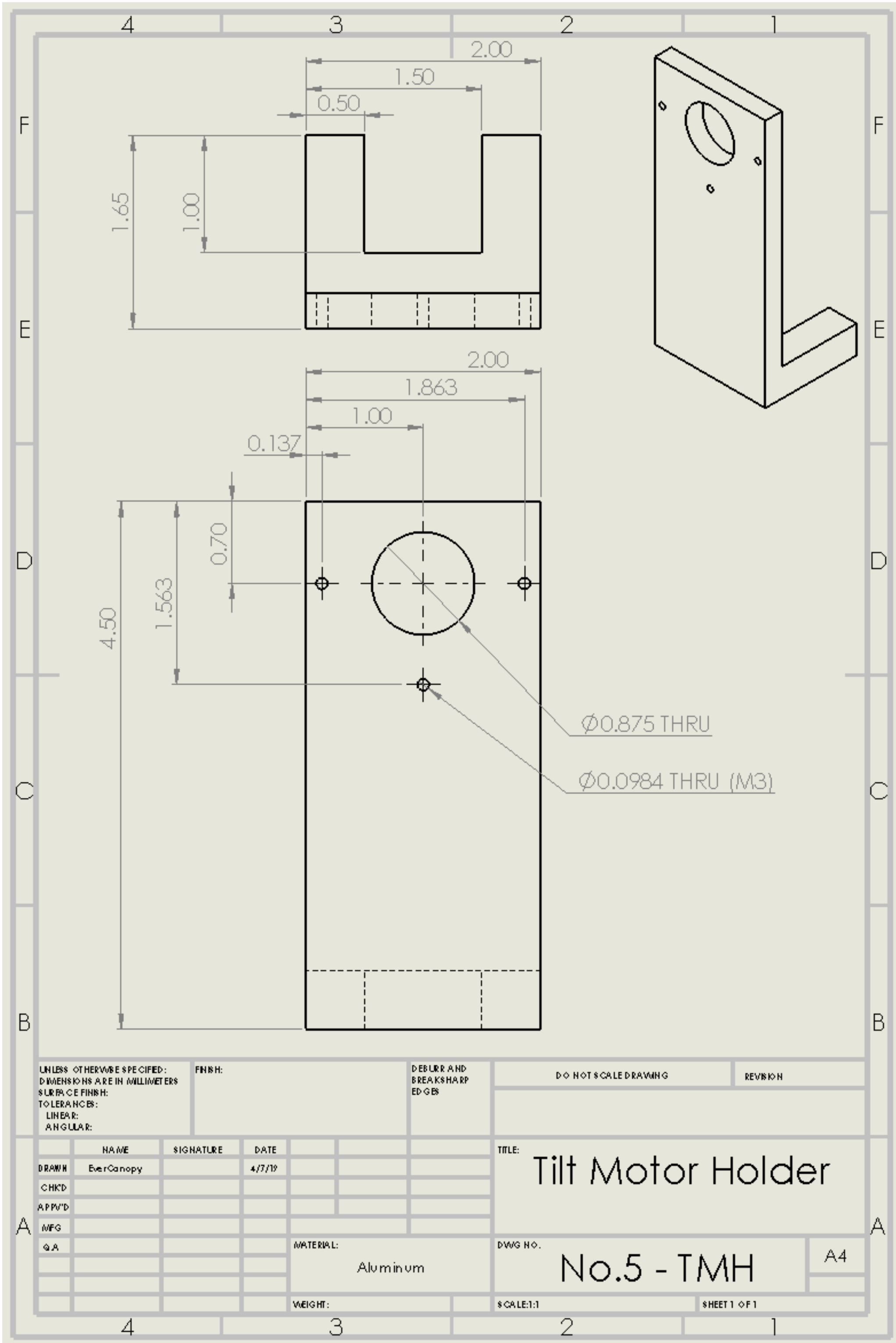


Figure J.11: Part drawing for the Tilt Motor Holder of the pan & tilt mechanism (Part 5)

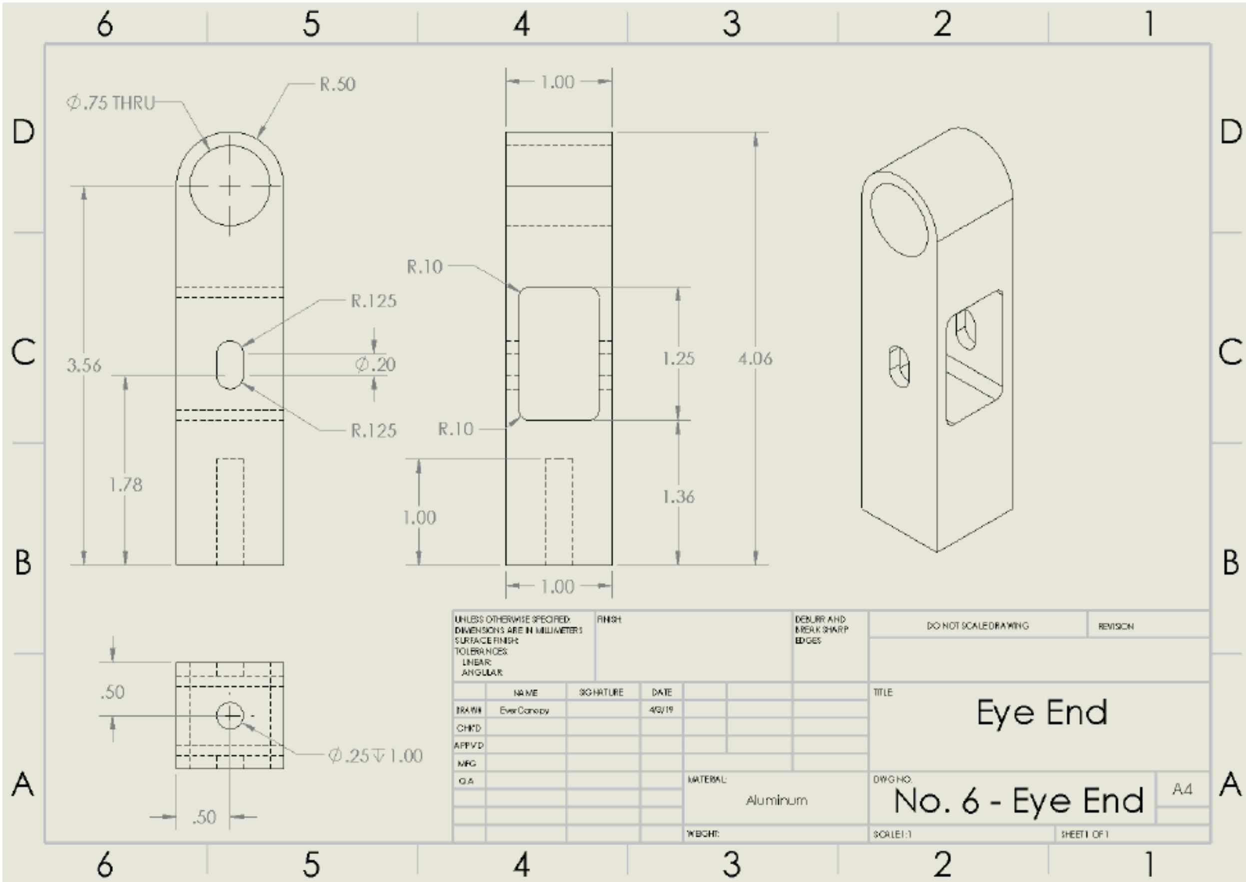


Figure J.12: Part drawing for the Eye End of the pan & tilt mechanism (Part 6)

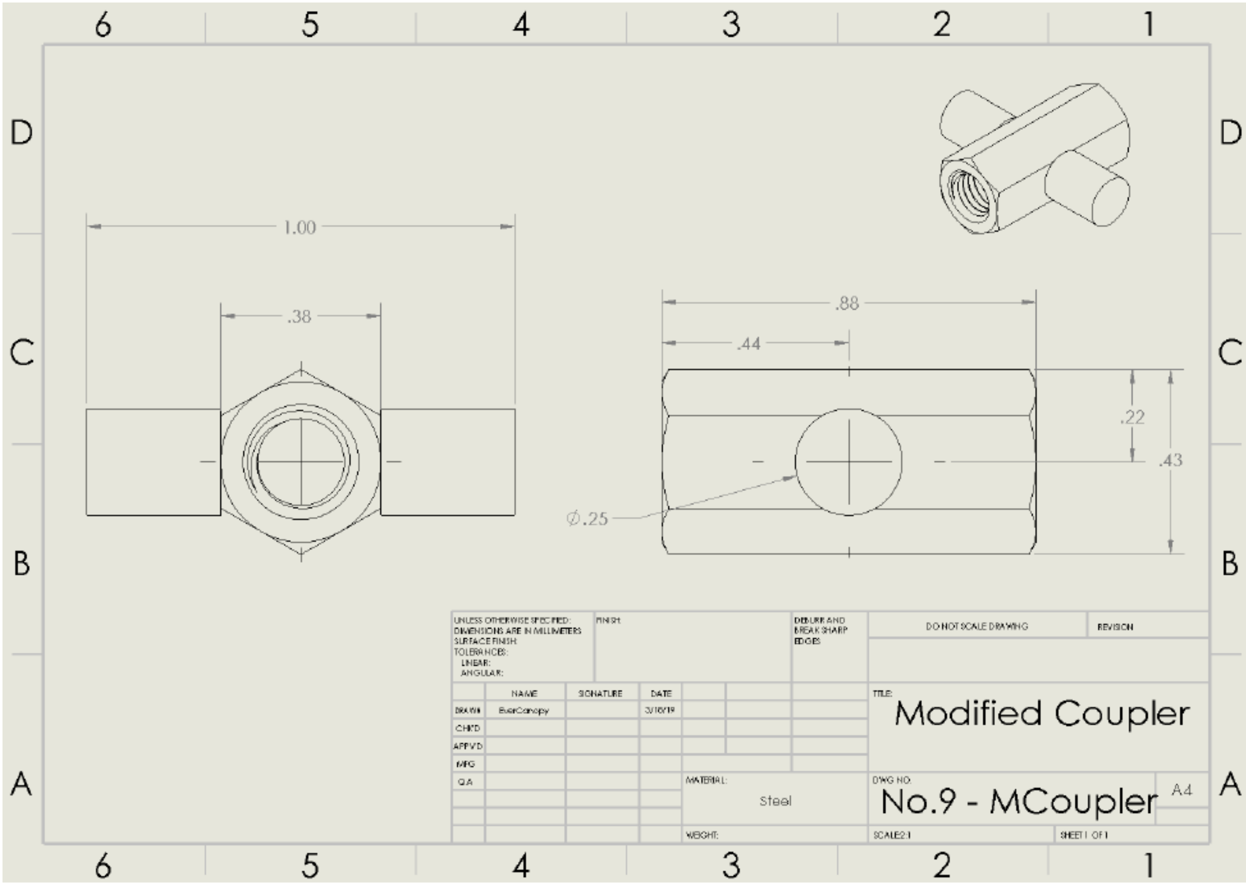


Figure J.13: Part drawing for the modified coupler of the pan & tilt mechanism (Part 9)

Appendix K: Mechanical CAE

FEA analysis was completed in Solidworks for the tilting mechanism, stowing mechanism, and load cell sensor.

1. Load Cell Sensor with Amplifier

As shown from the FEA results below, increasing the surface area of the load cell sensor with amplifier works to increase the total von mises stress (1.63e8 vs 6.708e6) on the sensor. This makes the sensor significantly more sensitive to the same wind load; as shown in the deflection plots, the sensor with an amplifier deflects 2.823 mm (max), while the sensor without an amplifier only deflects .01025 mm (max). Because the load cell sensors operate using a strain gage mechanism, the amount of deflection they undergo is directly proportional to the force reading they output.

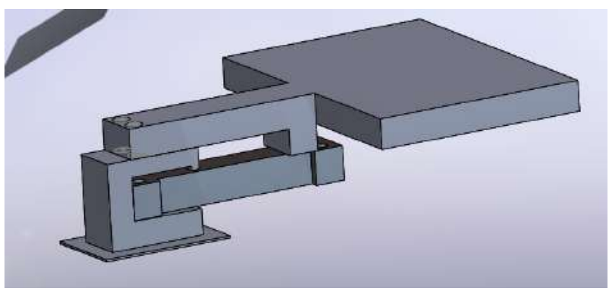


Figure K.1: Load cell sensor with paddle and holder attached

The figure shown above are the configurations when the load cell sensor holder and paddle are attached on the load cell sensor. The purpose of attaching the sensor holder is to fix one end of the load cell sensor so that it acts more effectively as a strain gage. The purpose of attaching the sensor paddle is to increase the surface area exposed to the wind load and to increase the possibility of force transmitted to the stand. This design was later modified to instead consist of only the paddle and a base plate to reduce manufacturing time. A base plate was also favored as opposed to the sensor holder due to stability.

a. *<u>Von Mises Stress including amplifier (wind speed = 25 mph)</u>*

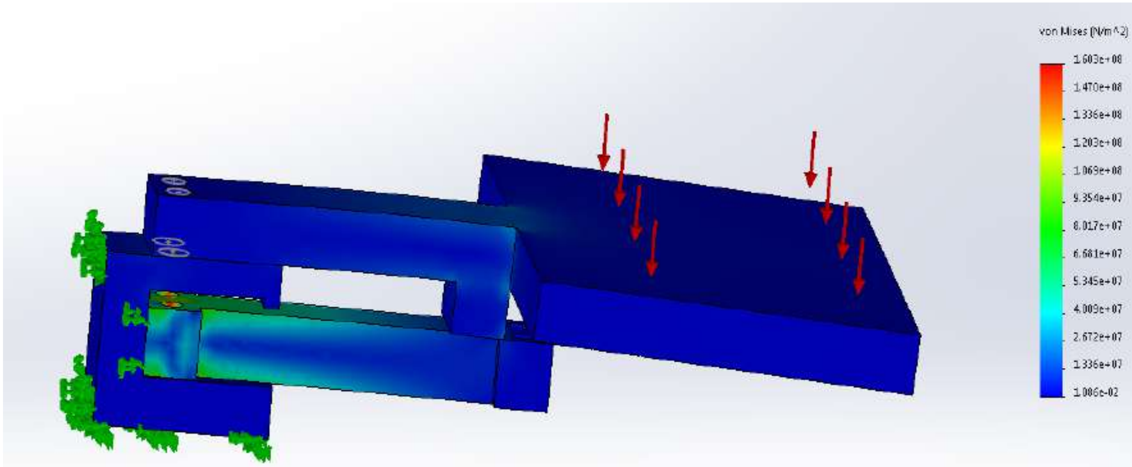


Figure K.2: load cell stress with amplifier

b. *<u>Von Mises Stress without amplifier (wind speed = 25 mph)</u>*

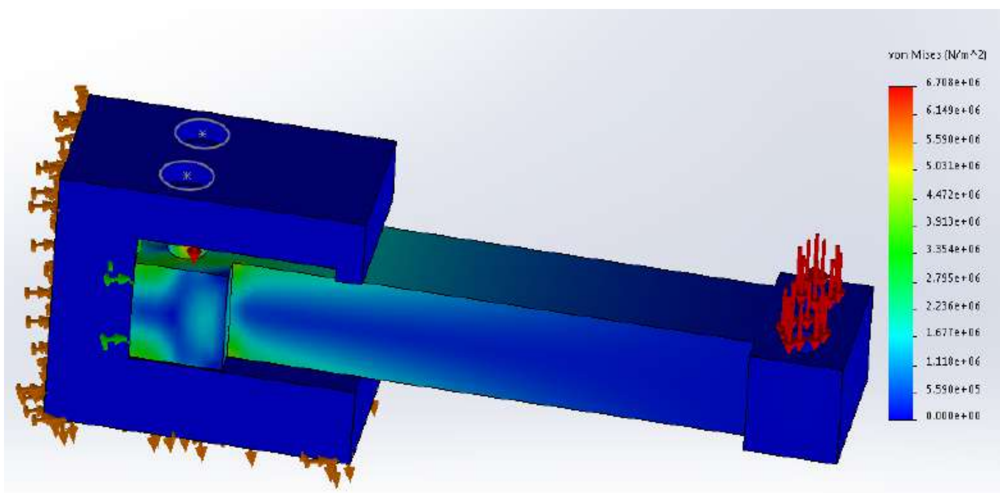


Figure K.3: Load cell stress without amplifier

The two figures above showcase the effectiveness of the setup with a paddle attached to the load cell sensor. The same force per unit area value were used to compare the von Mises experienced by both configurations. By comparing a with b, it can be seen that the paddle provides a greater surface area exposed to external force, increasing the overall force the load cell experiences underneath. This physical force amplification on a specific location on the load cell provides a more consistent change of resistance reading for our Arduino to use as input.

c. <u>Deflection including amplifier (wind speed = 25 mph)</u>

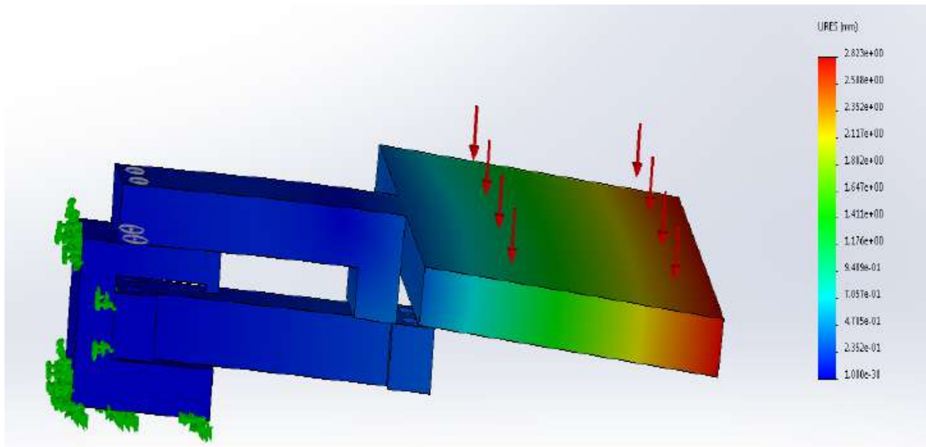


Figure K.4: Load cell sensor deflection with amplifier

d. <u>Deflection without amplifier (wind speed = 25 mph)</u>

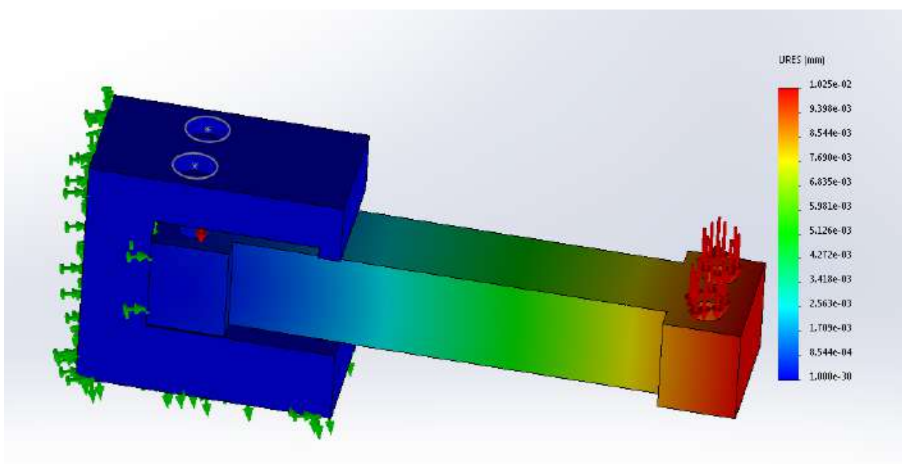


Figure K.5: Load cell sensor deflection without amplifier

Between the CDR and FDR phases, the load cell holder assembly was updated to only include the paddle and a base plate. Figures K.2-K.5 display the FEA stress analysis for the sensor assembly design using the sensor holder.

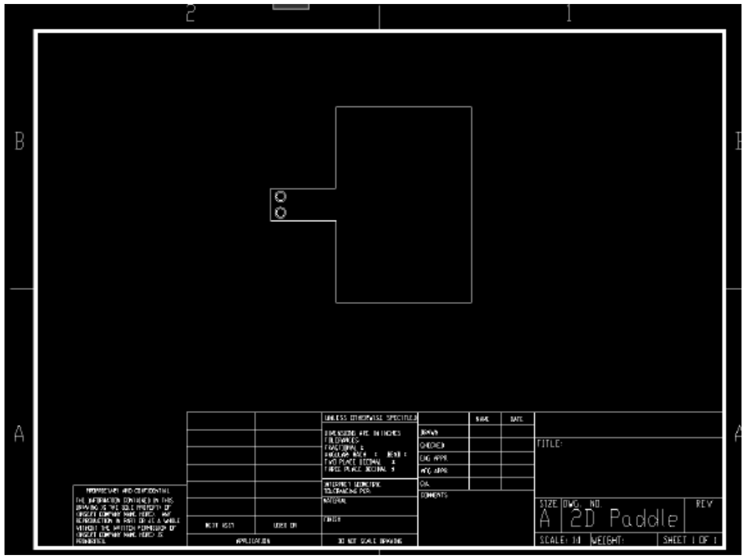


Figure K.6: Drawing of paddle

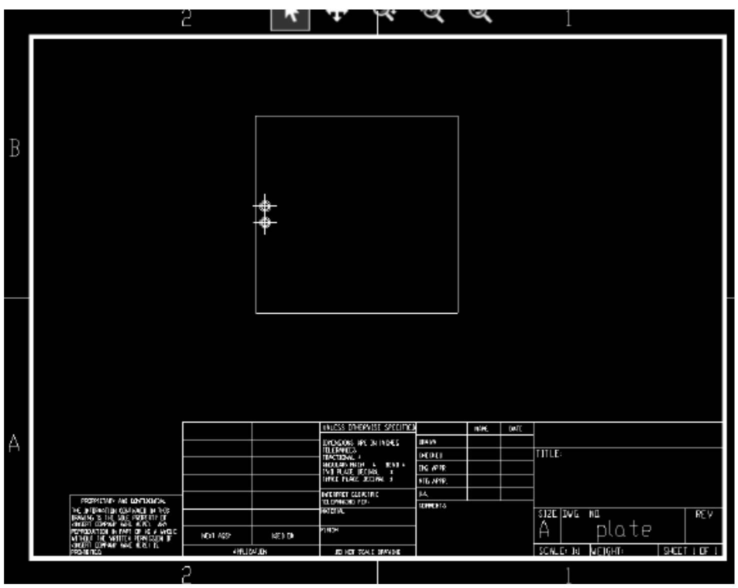


Figure K.7: Drawing of base plate

Figures K.6 and K.7 display the updated sensor holders. Instead of manufacturing the aluminum holder in figure 8, the paddle and base plate were lasercut from ⅛” acrylic and fastened together using 3mm diameter screws in the holes indicated on the drawings. This method of assembly for sensor holders was chosen because it reduced manufacturing time while still being effective at amplifying the wind load experienced by the load cell sensor.

2. Tilting Mechanism

The results below were used to determine the best material for manufacturing and the total stress experienced by the tilting mechanism. The concentrated load applied to the mechanism (143 N) corresponds to the device's maximum tilt of 30 degrees and a wind speed of 30 mph. As the strongest material, AISI 4130 (alloy steel containing chromium and molybdenum as strengthening agents) had the lowest von mises stress to material yield strength ratio. However, all materials tested are strong enough to endure the maximum loading that the tilting mechanism would experience. Therefore, we will be moving forward with 304 stainless steel due to its low cost.

	Stainless Steel (AISI 304)	**Marine Grade Stainless Steel** (AISI 316)	**Cr/Mo Alloy Steel** (AISI 4130)	**Aluminum Alloy** (AISI 2219-T87)
Max. Screw Displacement (μm)	.02017	.005333	.0004170	.01067
Material Yield Strength (N/m^2)	206807000	137895145.9	460000000	395000000
Factor of Safety $\left(\frac{\sigma_{yield}}{\sigma_{VM}}\right)$	77	51	173	148
Cost Per Unit ($/lb)	0.48	0.66	17.34	1,800

Tilting Mechanism *(Wind speed of 30 mph = total force of 143 N on canopy, Max Von Mises Stress = 2.658e6 N/m^2)*

Table K.1: Summary of tilting mechanism FEA

a. *Von Mises Stress on Screw (exterior components hidden for viewing purposes) (AISI 304)*

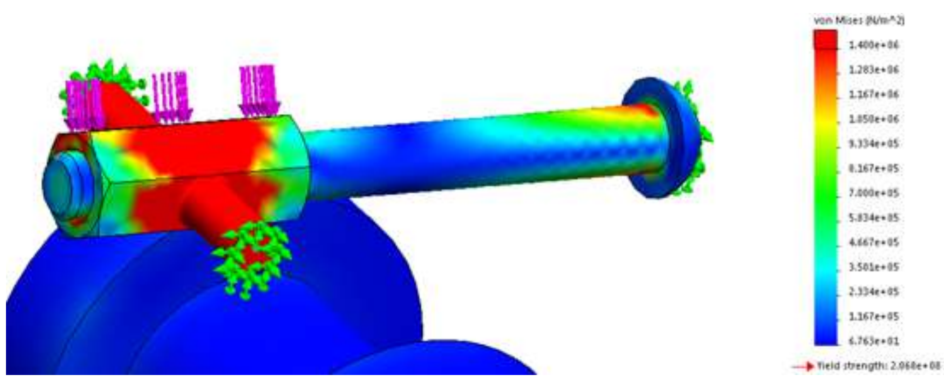


Figure K.8: Stress on tilting mechanism screw *b. <u>Deflection (AISI 304)</u>*

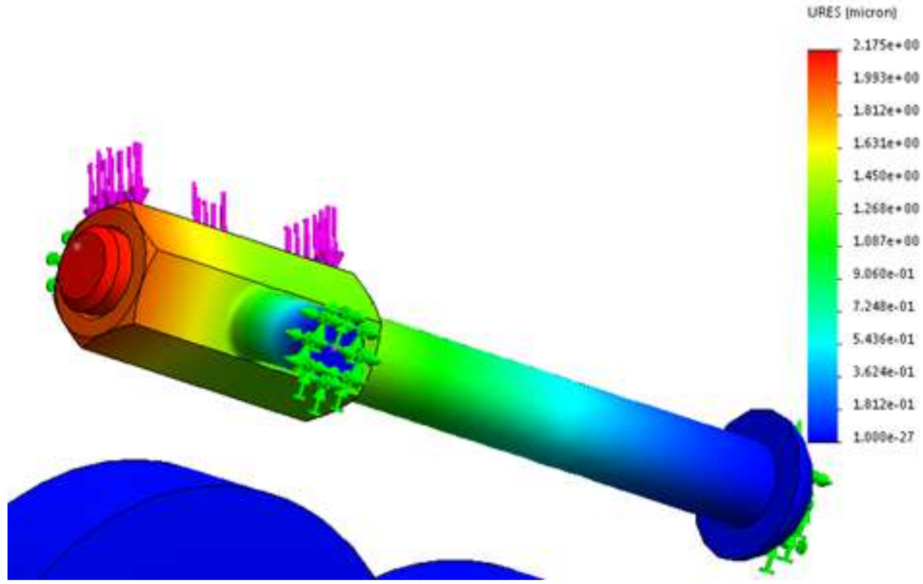


Figure K.9: Deflection on tilting mechanism screw

3. Stowing Mechanism

The stowing mechanism will be almost entirely purchased and made from low carbon steel. The factor of safety of this mechanism is 16, so no component failure is expected.

a. <u>Von mises stress</u>

<u>Stowing Mechanism:</u>

Max Von Mises Stress: 1.389e7 N/m^2

Material Yield Strength (Low Carbon Steel): 2.20 e8 N/m^2

Factor of Safety: 16

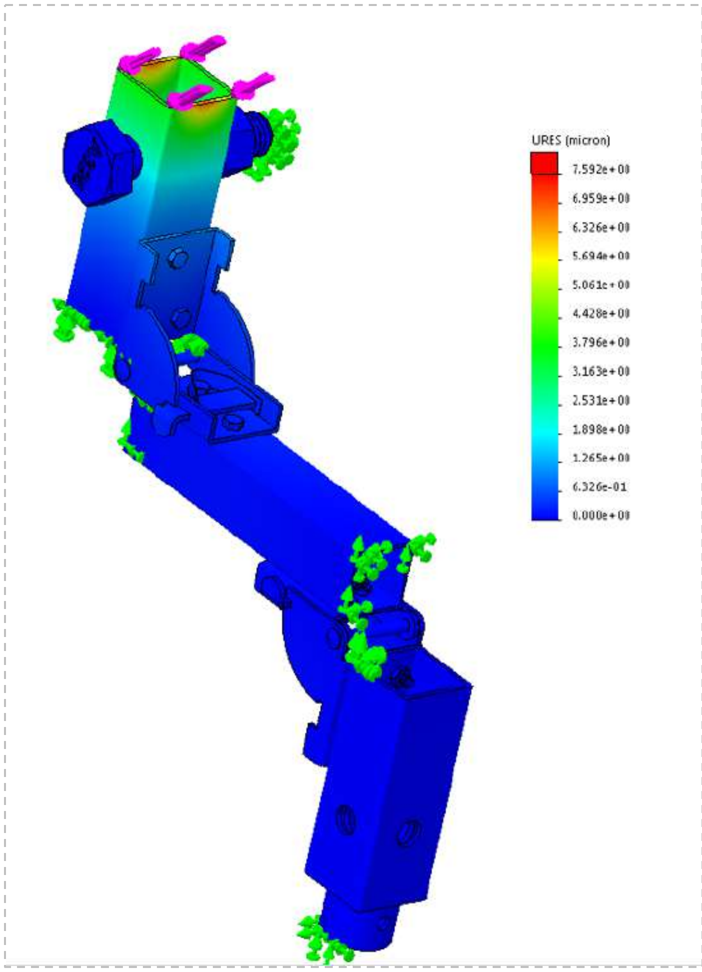


Figure K.10: Deflection of stowing mechanism

4. Stowing Mechanism Housing

This part is where the linear actuator and battery to power the linear actuator is housed. This is the support for the whole mechanism and it attaches to the bottom of the wheelchair

Force: 100N

Max Von Mises : 1.800 e +06

	AISI 4130 Steel	AISI 304 Steel	AISI 316 Annealed Stainless Steel Bar	Aluminum 2219-T87
Yield strength (N/m^2)	4.600 e +08	2.068 e +08	1.379 e +08	3.950 e +08
Max URES (mm)	5.167 e -03	5.563 e -03	5.451 e -03	1.439 e -02

Table K.2: FEA results summary of stowing mechanism housing

a. <u>Von Mises Stress</u>

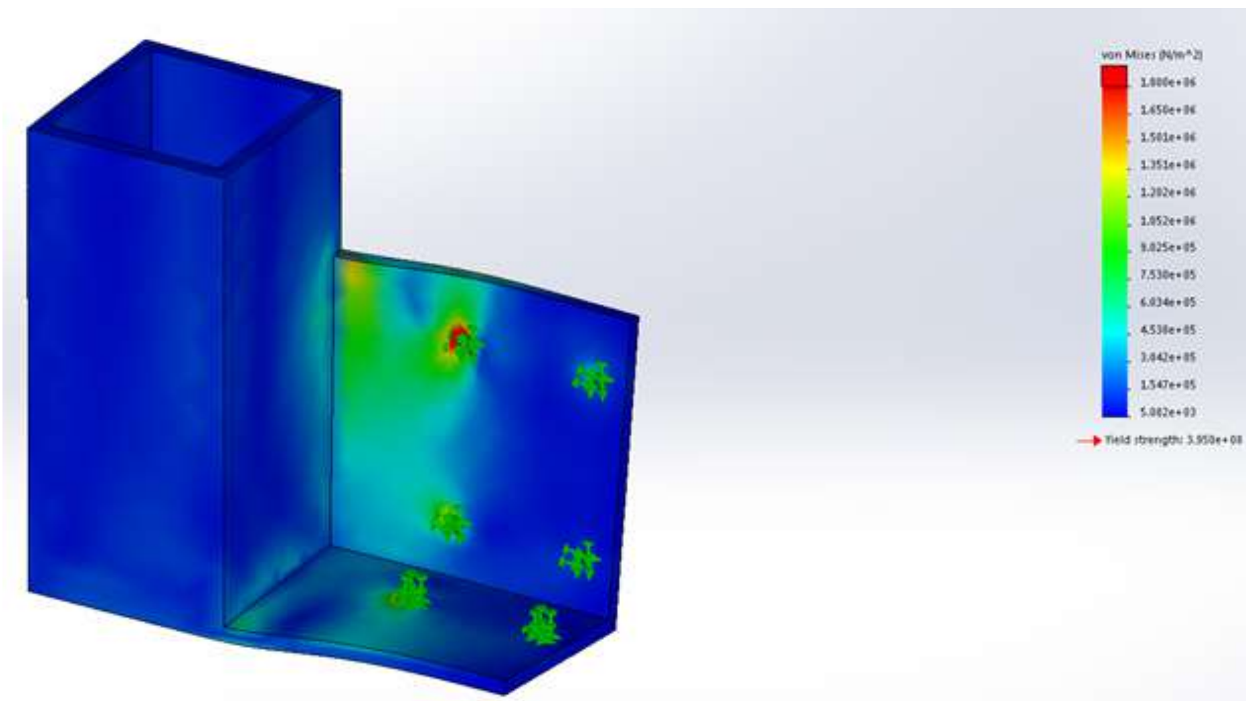


Figure K.11: Von Mises Stress on stowing mechanism housing

b. Displacement

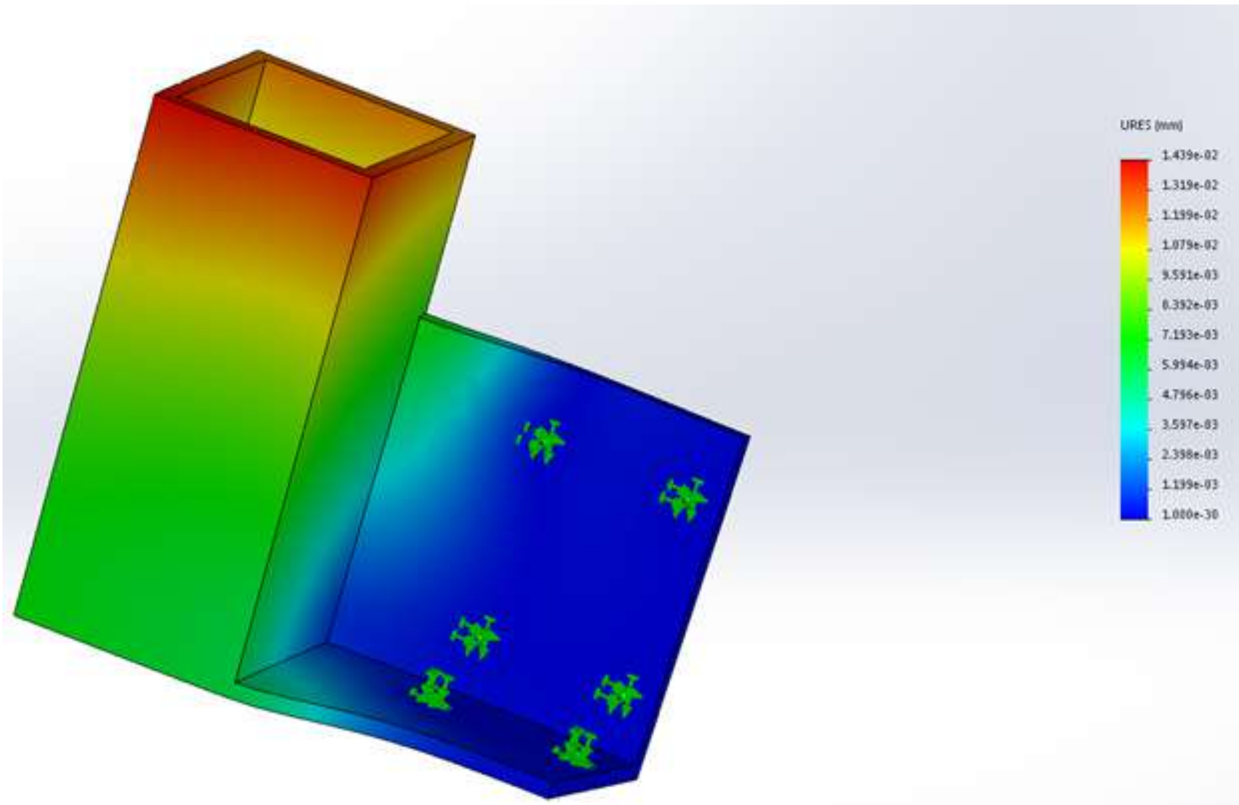


Figure K.12: Deflection of stowing mechanism housing

Appendix L: Slip Vs. Tip Calculation

The amount of wind force was calculated to see how much wind force was required to tip a wheelchair backwards with an average person sitting in the wheelchair. This was calculated for different pan and tilt angles.

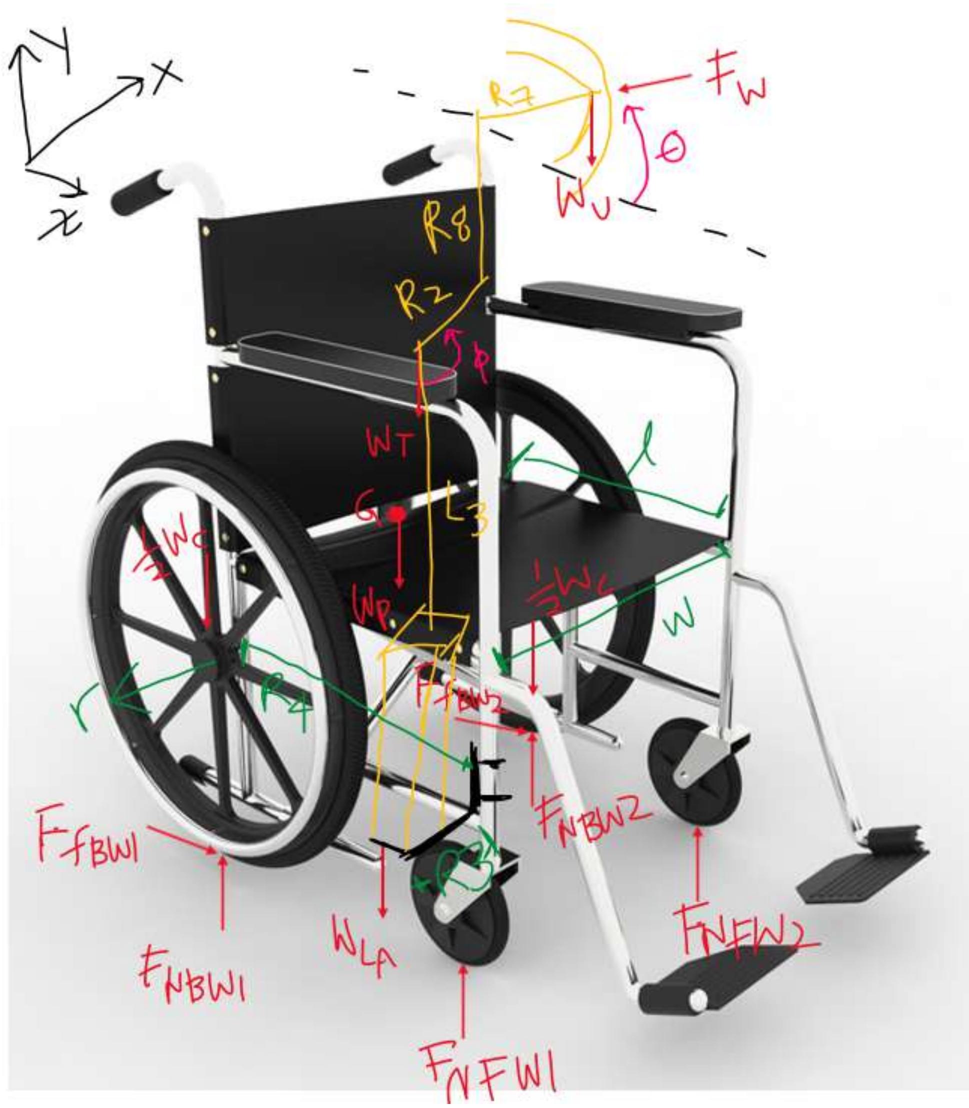


Figure L.1: Wheelchair Free Body Diagram

			TiltAngle (deg)	PanAngle (deg)	SlipForce (lbf)	TipForce (lbf)	TipOrSlip	WindSpeed (mph)
max wind speed	576.1004		1	243	9575.298432	17156.0374	Slip	576.1003537
min wind speed	79.27774		19	180	513.2934463	181.325364	Tip	79.2777401

Table L.1: Tipping and slipping calculation results

Appendix M: Percentage Increase of Effective Surface Area

This calculation shows the increase in surface area from our tilting device compared to a standard umbrella. This calculation shows that there is a 21% increase in surface area from our device.

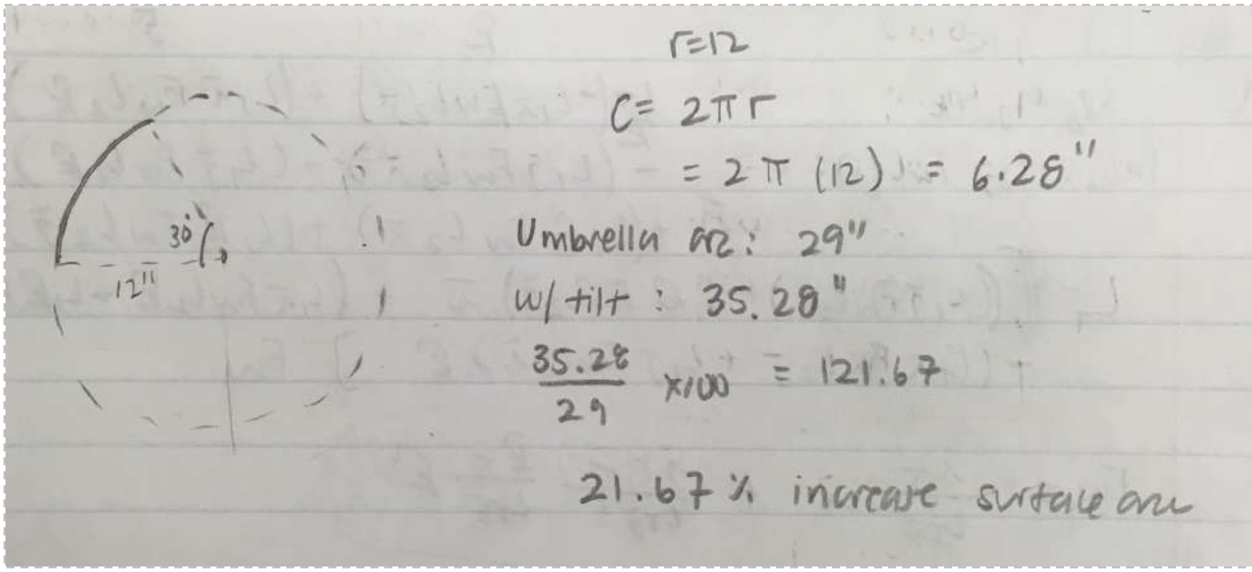


Figure M.1: Umbrella Coverage Calculations

Appendix N: Electrical Workflow

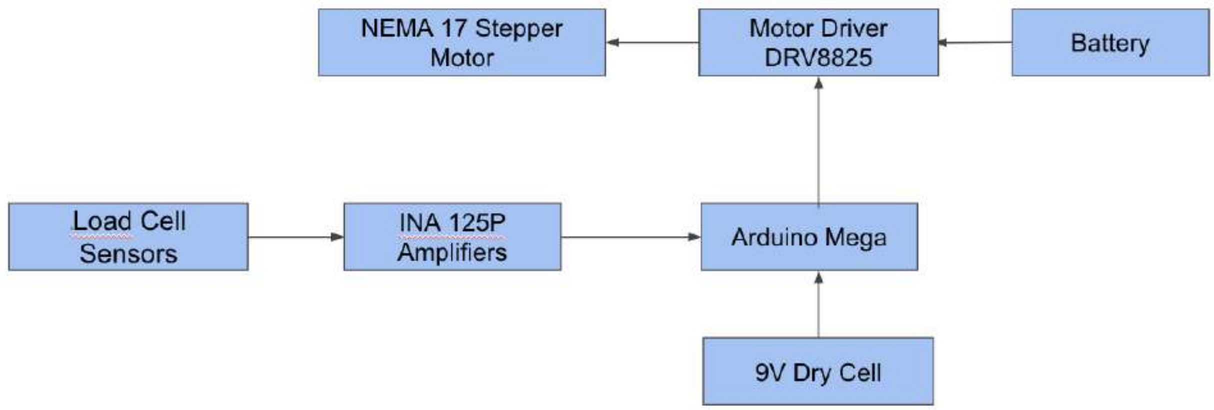


Figure N.1: Electrical Flow Diagram with each components included

As shown in the electrical workflow above, the project requires eight 100g load cell sensors and eight INA 125-125P amplifiers. The load cell sensors will measure and compare the forces exerted by the wind or rain on the canopy. Only the load cell sensor that registered the highest analog input force will be considered. In other words, other seven load cell sensors with lower analog input force will be ignored. The higher force input will be amplified, and the output of the amplifier is in term of electrical voltage. The amplified output voltage will be then sent to the Arduino Mega, which is powered by the 9V dry cell. The PWM output of the Arduino Mega will be sent to the DRV8825 motor driver, which is powered by the lithium battery. The motor driver will control the direction, speed and current flow to the stepper motor. The stepper motor will then tilt and rotate the umbrella towards the direction of the rain or wind.

Appendix O: Electrical Schematic

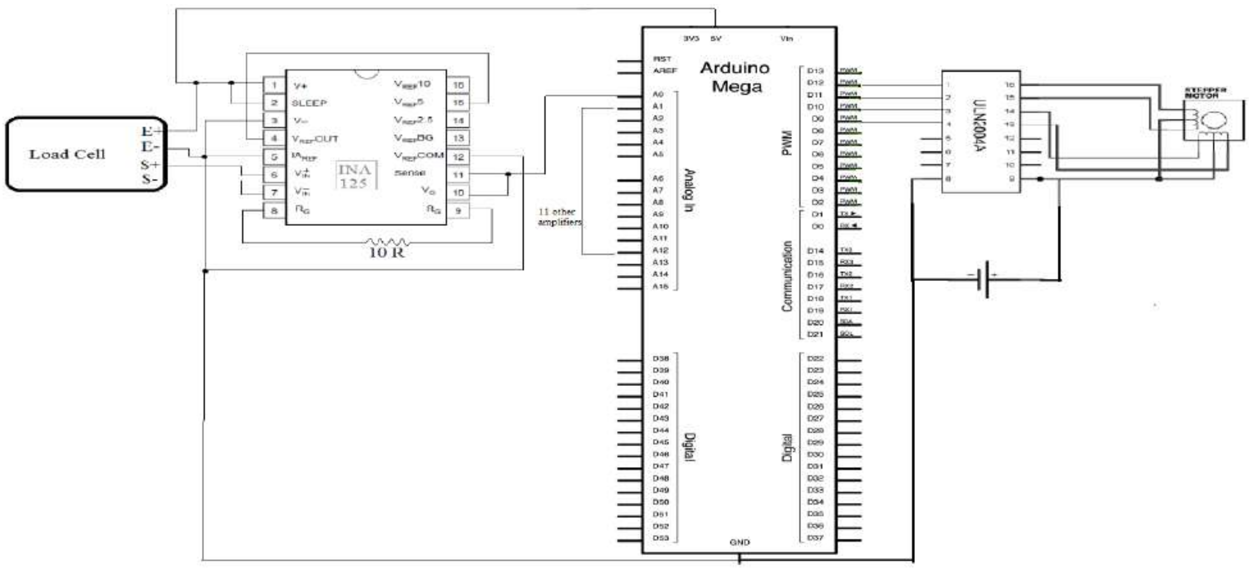


Figure O.1: Electrical Schematic

The figure shown above is the electrical schematic for our project, depicting the connections between the load cell sensors to the amplifier, Arduino Mega, motor driver and the stepper motor. To simplify the schematic, only the connection of 1 load cell sensor, 1 amplifier, 1 motor driver and stepper motor are shown. The connection for the other 11 load cell sensors, amplifiers, motor driver and stepper motor are the same as shown in the schematic shown above.

Appendix P: 100 grams Micro-Load Cell Sensor

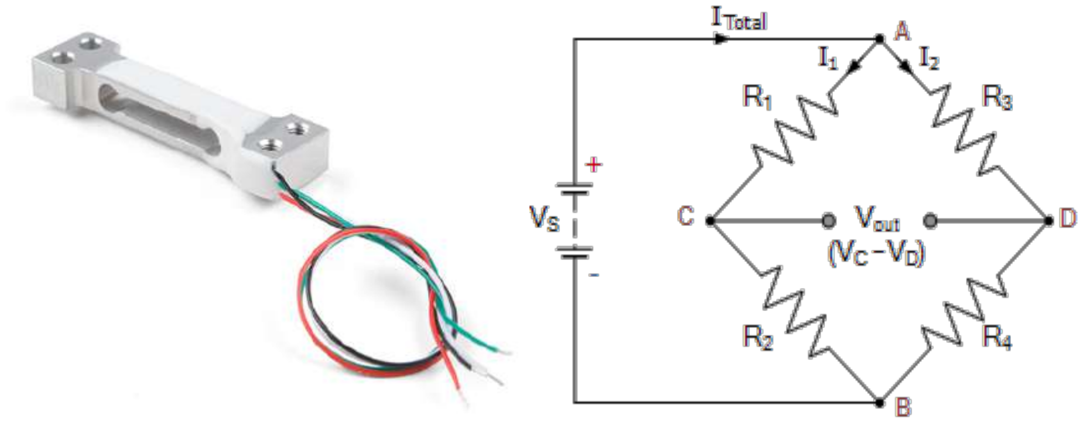


Figure P.1: 100g micro load cell sensor with whetstone bridge configuration

This 100g micro load cell sensor is a type of Wheatstone bridge sensor. The output voltage of the load cell sensor can be controlled by controlling the resistance of the resistor, R_3. For this load cell sensor, the output voltage of the load cell sensor is fixed at 600 micro V/V. The main reason of choosing this load cell sensor is because this sensor has an accuracy of 0.1% of the full-scale measurement. Furthermore, it is small and readily available compared to other types of sensors such as anemometer and force sensor.

Properties	Load Cell Sensor
Surface Area	0.00042 m^2
Weight	3.2 g
Sensor resolution	+/- 50 mg (+/- 50 mN)
Rated Output	+/- 600 µV/V
Supply Voltage	3- 10 DC V

Table P.1: Specification of the load cell sensor

Appendix Q: Placement of Sensor Assembly

Three 100g test weights were used to test the physical appearance of the umbrella with the weights.

Approximated total weight for one complete assembly (load cell, sensor holder, sensor paddle) ≅ 20g.

Side View

Bottom View

Figure Q.1: Physical Side and Bottom View of the umbrella with sensors' approximated relative positions

From bottom view, there is no sign of canopy indentation or failure due to weight. Strengthening the claim that the canopy could withstand the force of all the load cells

Appendix R: INA 125P Amplifiers

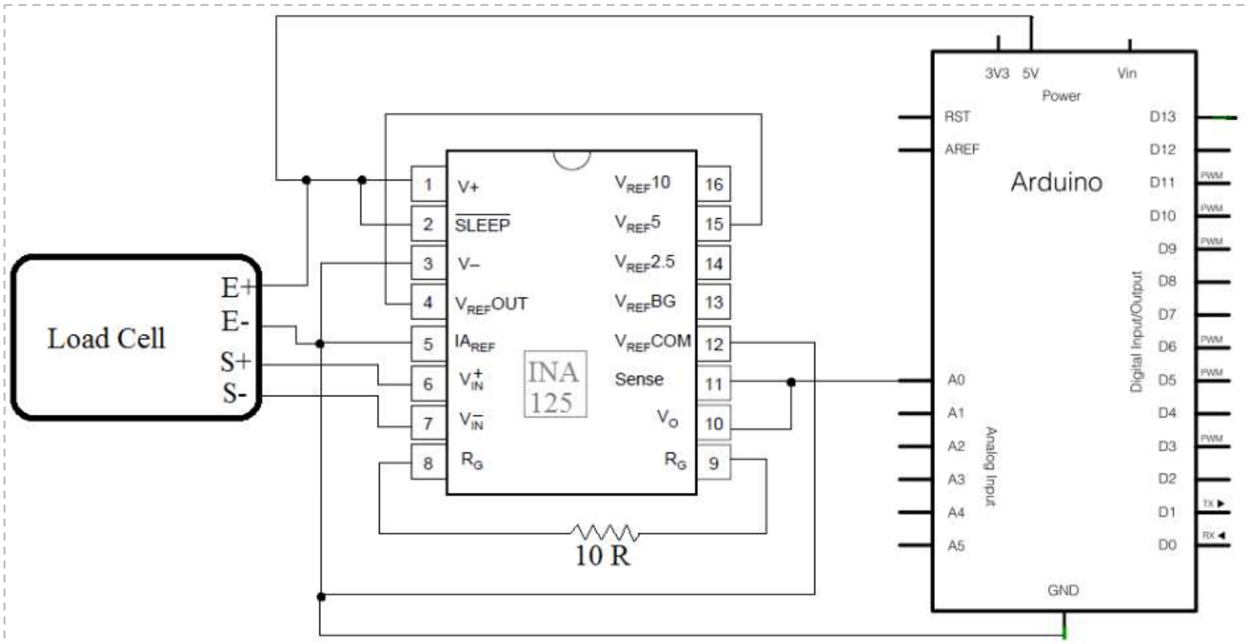


Figure R.1: Load Cell Amplifier to Arduino UNO Connections

The resistor 10Ω connected between pin 8 & 9 is responsible for Gain of INA125P amplifier, the output is taken combined from V_o and Sense (Pin 10 & 11) and it is fed into Arduino analog pin A0. The E+ shown on the load cell sensor is the excitation + (red wire) , E- is the excitation - (black wire), S+ is the signal + (white wire) and S- is the signal - (green wire).

Appendix S: Output Voltage Amplification - Integrated Chip Amplifier

From 100g load cell sensor datasheet,

- Wheatstone bridge sensor
- Rated output: 600 µV/V
- Supply voltage: 3 -10 V DC
- RoHS compliant

Figure S.1: Load Cell Sensor Specifications

Raw sensor output voltage,

$$Raw\ Sensor\ Output\ Voltage\ =\ (600\ micro - V/V)(5V)\ = 0.003\ V$$

Since the raw sensor output voltage calculated is small,

$$Gain\ =\ (49499/R_{gain})\ +1$$

$$R_{gain} = 100\ ohm$$

$$Gain\ =\ (49499/100ohm)\ + 1 = 495$$

The theoretical output voltage is thus

$$Theoretical\ Output\ Voltage\ =\ (0.003\ V)(495)\ =\ 1.485\ V$$

The output voltage of the integrated chip amplifier measured using multimeter,

$$Experimental\ Output\ Voltage\ =\ 1.4748\ V$$

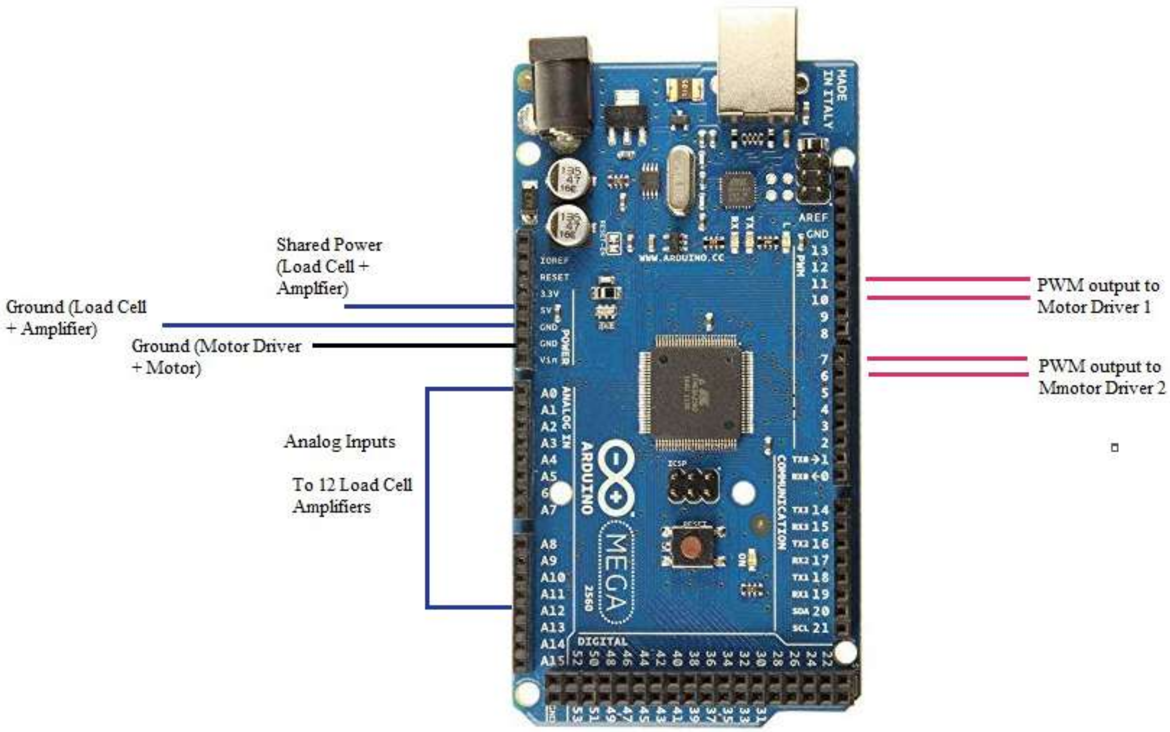
The percentage error (% Error) is thus,

$$\%\ Error\ =\ (|\ 1.4748\ V\ - 1.485\ V|\ /\ 1.485\ V) * (100\%)\ = 0.687\%$$

Specification	Values
Theoretical Output Voltage	1.485V
Experimental Output Voltage	1.4748V
% Error	0.687%

Table S.1: Theoretical and experimental output voltage values for the amplifier

Appendix T: The Arduino MEGA



Components	Required Pins	Available Pins on Mega
Load Cell Amplifier	32	16
Motor Driver (PWM)	4	15

Table T.1: Comparison of pins available on the Arduino Mega and pins required

The Arduino Mega contains 54 input output pins. Of those, the 12 load cell amplifiers require 12 to use as analog inputs, and the motor drivers require 4 as PWM outputs to drive the stepper motors.

Appendix U: Motor Driver DRV8825

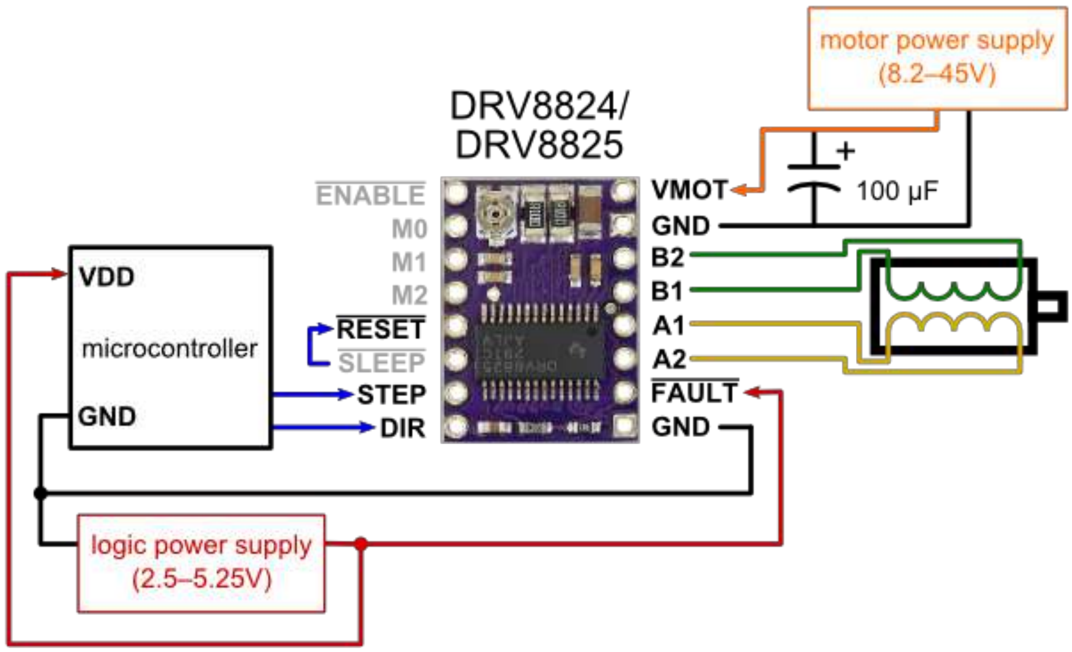


Figure U.1: Connection schematic for DRV8825 motor driver

The figure shown above is the electrical schematic for the motor driver. The purpose of connecting the motor driver is to interface the Arduino Uno with the stepper motor. To ensure that everything works well, the motor driver current rating must be greater than the stepper motor current rating. Since the stepper motor has a current rating of 2.1 Amp per phase, DRV8825 motor driver will be used because it has a current rating of 2.2 Amp per phase. A potentiometer will be used to control the current flow.

Appendix V: Stepper Motor Calculations

Tilting Motor

The stepper motor selected is the NEMA 17 Bipolar Stepper motor. The Following are relevant motor specifications:

- Peak Torque: 55 N-cm
- Current Draw: 2.1 Ampere per phase
- 200 steps per revolution
- 1.8 degree per step

Based on the wind load equation $F = 0.5\rho AV^2 C_d$, where A = 1.07 m^2 , V = wind velocity in m/s, and $C_d = 1.21$for a curved surface.

The wind loads experienced normal to the tilting mechanism were calculated for different wind speeds. The forces were resolved in the x (axial) direction assuming a full tilt of 30° and are displayed in the following table.

Wind speed (m/s)	Axial Wind Load (N)
5	8.025
10	32.01
15	72.23
20	128.4
25	200.63

Table V.1: Wind speed and corresponding axial load on threaded rod

The following stepper motor effort equation was used to determine the motor effort in N-cm required to turn the threaded rod against these wind loads. The following table summarizes the efforts required.

$$Effort\ (Ncm) = \frac{Load}{2\pi(\frac{R}{p})S_e}$$

Where R = Radius of screw, P = pitch of screw, and S_e = screw efficiency = 0.3

Wind speed (m/s)	Stepper Motor Effort (N*cm)
5	.39
10	1.52
15	3.45
20	6.13
25	9.57

Table V.2: Stepper motor effort required under various wind loads

The stepper motor efforts are relatively low compared to the output torque of the motor. However, a safety margin is necessary because the effort equation does not consider friction between the rod and the coupler. Also, a strong motor is desired to move the mechanism quickly and smoothly.

Rotation Motor

The motor for rotation is the same motor as the one used for the tilting mechanism. Below is a torque output curve for this specific motor:

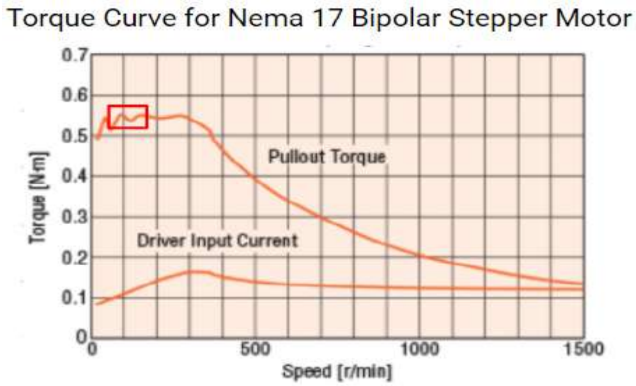


Figure V.1: Torque curve for NEMA 17 55 Ncm stepper motor

According to Figure V.1, the peak torque of the motor is not achieved until a motor speed of approximately 80 rotations per minute is reached. A reasonable speed to run the motor at is 100 RPM, as this provides a peak torque. However, at 100 RPM, the rotation mechanism cannot be directly connected to the output shaft of the motor because this is too fast. Instead, a 1:8 gear train will be used to step down the speed of the motor such that the final output shaft of the rotation mechanism will be rotating at 12.5 RPM.

Because there are 200 steps/ revolution of the motor, the following equation was used to calculate the time in seconds needed to rotate the umbrella 180°. This angle was chosen because at a given moment, the greatest angular rotation that would be required from the motor is 180°**.**

$$12.5\,\frac{revolutions}{minute} * 200\,\frac{steps}{revolution} = 2500\,\frac{steps}{minute}$$

$$180\,° = 100\,steps$$

$$\frac{100\,steps}{2500\,\frac{steps}{minute}} = 0.04\,minute = \boldsymbol{2.4\,seconds}$$

The following table shows the reaction time for a 180° rotation of the umbrella canopy.

Stepper Motor RPM	Output Gear RPM	Reaction Time (seconds)
80	10	3
90	11.25	2.67
100	12.5	2.4
150	18.75	1.6
200	25	1.2

Table V.3: Yaw stepper motor reaction time

Since the CDR phase, the pan motor selection has been changed. The closest gear ratio stepper motor that was available was a 1:19 high torque stepper motor.

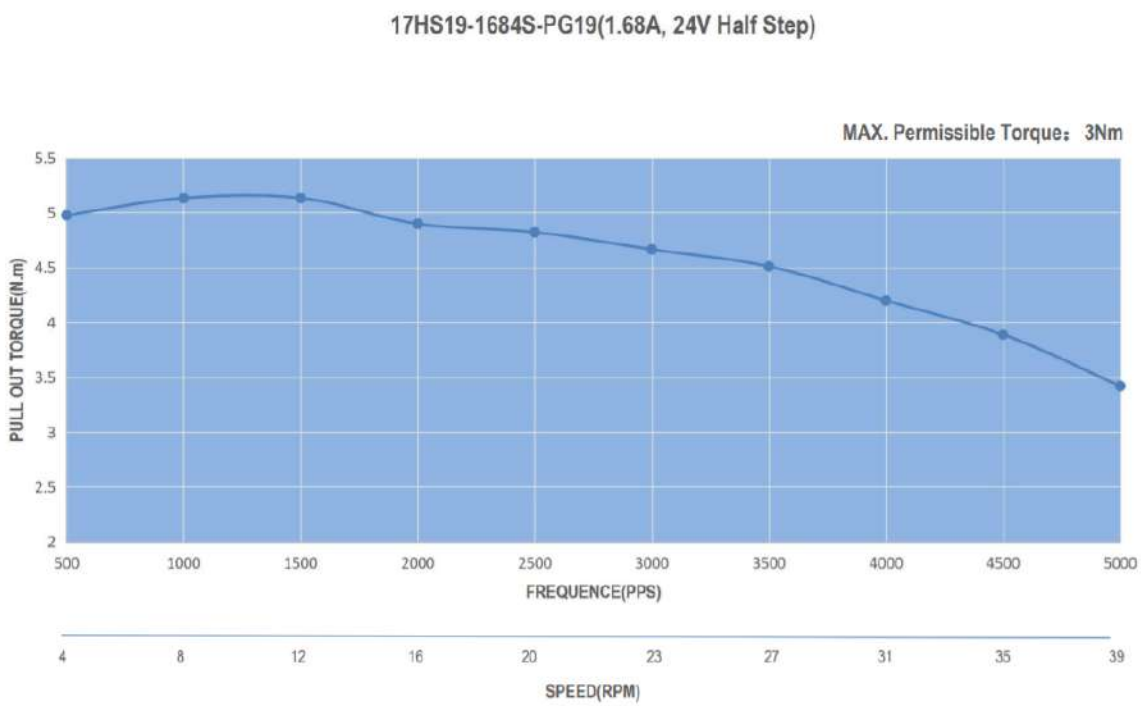


Figure V.2: Torque curve for geared stepper motor

Based on the above figure, the 1:19 motor provides a peak torque at an output rotation speed of about 12 RPM. This is ideal for our application as it would result in a worst case 180 degree rotation of around 2.4 seconds, which satisfies the design requirement of being under 3 seconds.

Appendix W: Battery Life Calculations

1. Lithium battery for stepper motor

The lithium battery usually have 10 hour discharge rate (2AH)

$$Capacity, C \ = \ (current\ drawn)(hours) \ \ [amp - hours]$$

$$Capacity, C \ = (10\ Amps)(1\ hour) \ = 10\ Ah$$

Assume that the lithium battery uses 80% of its charge, with 20% remaining,

$$C' = 10\ Ah/0.80 \ = \ 12.5\ Ah$$

Then take into account the possibilities that the lithium battery is discharging at high rate,

$$C' = 12.5\ Ah/0.50 \ = \ 25\ Ah$$

The stepper motor requires a current of 2.1 Amp per phase to operate,

a. Assume that the lead acid battery discharge slowly

$$Time = 12.5\ Ah/\ 2.1A \ = 5.92\ hours$$

b. Assume that the lead acid battery discharge quickly

$$Time = 25\ Ah/\ 2.1A \ = \ 11.90\ hours$$

2. Lead acid battery for linear actuator

Lead acid batteries usually have 20 hour discharge rate (20AH)

$$Capacity, C \ = \ (current\ drawn)(hours) \ \ [amp - hours]$$

$$Capacity, C \ = (20\ Amps)(1\ hour) \ = 20\ Ah$$

Assume that the 12V lead acid battery uses 80% of its charge, with 20% remaining,

$$C' = 20\ Ah/0.80 \ = \ 25\ Ah$$

Then take into account the possibilities that the lead acid battery is discharging at high rate,

$$C' = 25\ Ah/0.50 \ = \ 50\ Ah$$

Meaning, a 50 AH battery will be need to power the linear actuator for 1 hour at 20 amps average.

The linear actuator requires a current of 5 Amp per phase to operate,

a. Assume that the lead acid battery discharge slowly

$$Time = 25\ Ah/\ 2.1A\ =\ 11.9\ hours$$

b. Assume that the lead acid battery discharge quickly

$$Time = 50\ Ah/\ 2.1A\ =\ 23.8\ hours$$

	12V Lithium Battery (Stepper Motors)	12V Lead Acid Battery (Linear Actuator)
Capacity, C [amp - hours]	10	20
Capacity, C (Assume only 80% of the charge is used)	12.5	25
Capacity, C (Assume that the battery is discharging at a high rate)	25	50
Current required [A]	5	2.1
Lifetime of the battery [Hours]	**11.90**	**23.8**

Table W.1: Battery life for the 12V lithium battery for stepper motor and 12V lead acid battery for the linear actuator

Appendix X: Solder Board

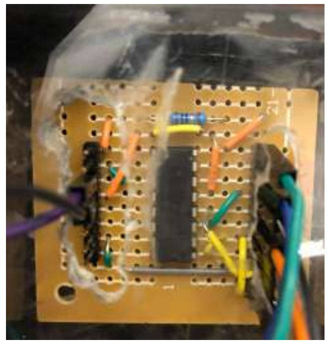


Figure X.1: Solder board connections

The solder board is the alternative solution to the printed circuit board (PCB). The solder board can be deemed as an external type of PCB. The purpose of using the solder board is to eliminate the use of breadboard. The solder board solves the short circuit problem and also makes the circuit a lot easier to debug. The solder board holds the circuit for the amplifier chip circuit. The connections displayed to the right are inputs from the load cell sensors, while the connections on the left are to the Arduino analog in, and Arduino ground.

Appendix Y: Functional Flow Diagram of Arduino Algorithm

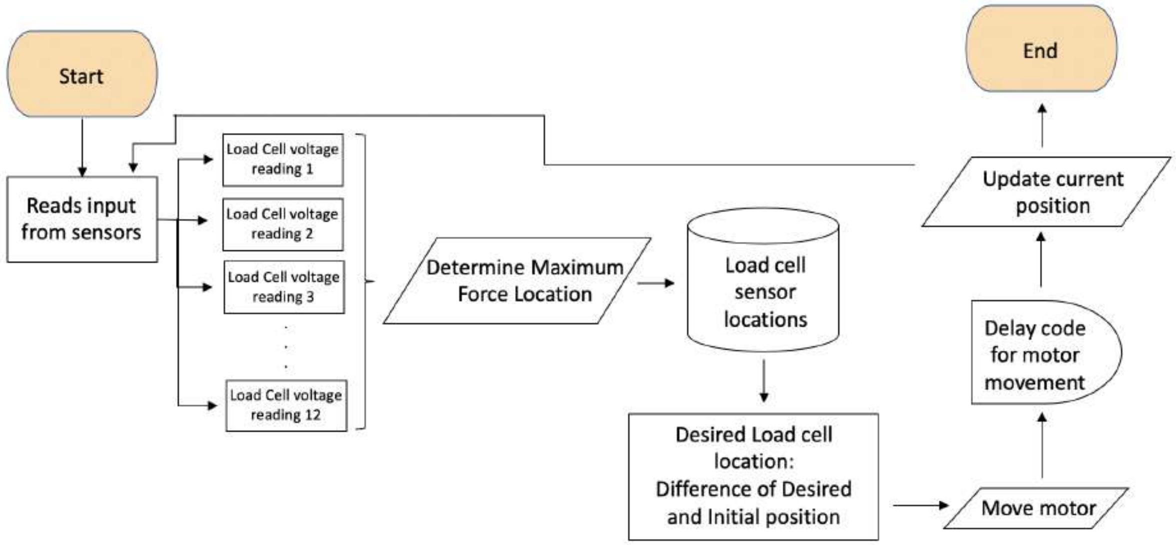


Figure Y.1: Functional flow diagram of Arduino algorithm

Appendix Z: Arduino Code

Declare pin functions for both motor drivers

```
#define dir2 10

#define stp2 11


#define dir 8

#define stp 9


#define MS1 25

#define MS2 26

#define EN  27


#define MS12 4

#define MS22 6

#define EN2  5
```

Declare variables for motor functions

```
char user_input;

int x;

int y;

int state;

int posYaw;

int posPitch;

int desYaw;

int desPitch;

int button = 7;

int spstVal;
```

```
// Declare iteration location variable

int numLoop;


// Initialize arrays of test weights and corresponding analog values

float loadA[12];

float analogValA[12];

float loadB[12];

float analogValB[12];


// static const uint8_t analogPins[] =
{A0,A1,A2,A3,A4,A5,A6,A7,A8,A9,A10,A11}; // for MEGA

static const uint8_t analogPins[] = {A0,A1,A2,A3,A4,A5}; // for UNO


float analogValAvg[12] = {};

float analogVal[12] = {};

float load[12] = {};


// How often do we do readings?

int timeBetweenReadings = 3000; // We want a reading every 3000 ms;
```

Load cell calibrated weights

```
void setup() {

  pinMode(7, INPUT);

  numLoop=0;


  spstVal = digitalRead(7); // Single Pole Single Throw switch

  posYaw = 0;
```

```
  posPitch = 0;

  // Enter you own analog values here for 0
  loadA[0] = 7.5; // g
  analogValA[0] = 90; // analog reading taken with load A on the load cell

  loadB[0] = 10; // g
  analogValB[0] = 65; // analog reading taken with load B on the load cell
/////////////////////////////////////////////////////////////////////////////

  // Enter you own analog values here for 1
  loadA[1] = 7.5; // g
  analogValA[1] = 120; // analog reading taken with load A on the load cell

  loadB[1] = 2.5; // g
  analogValB[1] = 98; // analog reading taken with load B on the load cell


/////////////////////////////////////////////////////////////////////////////

  // Enter you own analog values here for 2
  loadA[2] = 7.5; // g
  analogValA[2] = 122; // analog reading taken with load A on the load cell

  loadB[2] = 2.5; // g
  analogValB[2] = 100; // analog reading taken with load B on the load cell
```

```
////////////////////////////////////////////////////////////////////////////

  // Enter you own analog values here for 3
  loadA[3] = 7.5; // g
  analogValA[3] = 100; // analog reading taken with load A on the load cell

  loadB[3] = 2.5; // g
  analogValB[3] = 86; // analog reading taken with load B on the load cell
////////////////////////////////////////////////////////////////////////////

  // Enter you own analog values here for 4
  loadA[4] = 7.5; // g
  analogValA[4] = 110; // analog reading taken with load A on the load cell

  loadB[4] = 2.5; // g
  analogValB[4] = 101; // analog reading taken with load B on the load cell
////////////////////////////////////////////////////////////////////////////

  // Enter you own analog values here for 5
  loadA[5] = 7.5; // g
  analogValA[5] = 22; // analog reading taken with load A on the load cell

  loadB[5] = 2.5; // g
  analogValB[5] = 18; // analog reading taken with load B on the load cell

  pinMode(stp, OUTPUT);
```

```
  pinMode(dir, OUTPUT);

  pinMode(MS1, OUTPUT);

  pinMode(MS2, OUTPUT);

  pinMode(EN, OUTPUT);

  resetEDPins(); //Set step, direction, microstep and enable pins to default 
states

  pinMode(stp2, OUTPUT);

  pinMode(dir2, OUTPUT);

  pinMode(MS12, OUTPUT);

  pinMode(MS22, OUTPUT);

  pinMode(EN2, OUTPUT);

  resetEDPins2();

  Serial.begin(9600); //Open Serial connection for debugging

}
```

Load cell weight comparison code

```
void loop() {

    //spstVal = 0;


    for (int i = 0; i < 6; i++) {

      analogVal[i] = analogRead(analogPins[i]);

    }


    // running average - We smooth the readings a little bit for all 12 
inputs (in this case 5)

    for (int i = 0; i < 6; i++) {

      analogValAvg[i] = analogValAvg[i] * 0.99 + analogVal[i] * 0.01;

    }


    if(millis() > time + timeBetweenReadings){
```

```
      for (int i = 0; i < 8; i++) {

        load[i] = abs(analogToLoad(analogValAvg[i], analogValA[i],
analogValB[i], loadA[i], loadB[i]));

      }



      for (int i = 0; i < 6; i++) {

        Serial.print("analogValue"); Serial.print(i); Serial.print(": ");
Serial.println(analogValAvg[i]);

        Serial.print("             load"); Serial.print(i); Serial.print(":
"); Serial.println(load[i],5);

      }



      float maxVal = max(max(max(max(max(load[0], load[1]),load[2]),
load[3]), load[4]), load[5]);

      Serial.print("Max: "); Serial.println(maxVal);



      spstVal = 0;

      //spstVal = digitalRead(7); // Single Pole Single Throw switch

      spstVal = 1;



      int countStop = 0;

      Serial.println("Test0: ");

      if (countStop == 1) {

        // Stop

      }



      else if(numLoop == 4) {



      }

      else if (numLoop == 5) {
```

```
}
else if (maxVal < 20) {


}

// yaw: +ve forward
// pitch: -ve forward

else if (maxVal == load[0]) {

  if (spstVal == 1) {
    moveConvert(0, -3600-posPitch);

    posYaw = 0;
    posPitch = -3600;

    numLoop+=1;
  }
  else{
    // Stay stationary.
  }
}

else if (maxVal == load[1]) {

  if (spstVal == 1) {
```

```
    moveConvert(0, -1800-posPitch);

    posYaw = 0;
    posPitch = -1800;

    numLoop+=1;
  }
  else{
    // Stay stationary.
  }
}
else if (maxVal == load[2]) {
  spstVal = 1;
  if (spstVal == 1) {
    moveConvert(1200, -1800-posPitch);
  }
  else{
    // Stay stationary.
  }
}
else if (maxVal == load[3]) {

  if (spstVal == 1) {
    moveConvert(-1200, -3600-posPitch);

    posYaw = -1200;
    posPitch = -3600;
    numLoop+=1;
```

```
    }
    else{
      // Stay stationary.
    }
  }
  else if (maxVal == load[4]) {

    if (spstVal == 1) {
      moveConvert(2400, -1800-posPitch);
      posYaw = 2400;
      posPitch = -1800;
    }
    else{
      // Stay stationary.
    }
  }
  else if (maxVal == load[5]) {

    if (spstVal == 1) {
      moveConvert(1200, -3600-posPitch);

      posYaw = 1200;
      posPitch = -3600;

      numLoop+=1;
    }
    else{
      // Stay stationary.
```

```
        }
      }
      Serial.print("\n");
      time = millis();
    }
}
```

Load cell weight calibration method

```
float analogToLoad(float analogval, float analogvalA, float analogvalB, float loadA, float loadB){

  // using a custom map-function, because the standard arduino map function only uses int
  float load = mapfloat(analogval, analogvalA, analogvalB, loadA, loadB);
  return load;
}

float mapfloat(float x, float in_min, float in_max, float out_min, float out_max)
{
  return (x - in_min) * (out_max - out_min) / (in_max - in_min) + out_min;
}
```

Motor movements method

```
// to move the motors
void moveConvert(float yawDist, float pitchDist)
{
  // for the first stepper motor for yaw
  digitalWrite(EN, LOW); //Pull enable pin low to allow motor control
```

```
  digitalWrite(MS1, LOW);
  digitalWrite(MS2, LOW);

  digitalWrite(EN2, LOW); //Pull enable pin low to allow motor control
  digitalWrite(MS12, LOW);
  digitalWrite(MS22, LOW);

  Serial.print("YawDist: "); Serial.println(yawDist);
  Serial.print("pitchDist: "); Serial.println(pitchDist);

  if (yawDist > 0) {
    digitalWrite(dir, LOW); //Pull direction pin low to move "forward"
    Serial.println("Moving FORWARDS at default step mode.");

    for(int x= 1; x<yawDist; x++)  //Loop the forward stepping enough times
for motion to be visible
    {
      spstVal = 1;

      if (spstVal == 1) {
        digitalWrite(stp, HIGH); //Trigger one step forward
        delay(1);
        digitalWrite(stp, LOW); //Pull step pin low so it can be triggered
again
        delay(1);
      }
      else if (spstVal == 0) {
        Serial.println("Stopping Pan Motor.");
        break;
```

```
        spstVal = 0;
      }
    }
  }
  else if (yawDist < 0) {
    digitalWrite(dir, HIGH); //Pull direction pin high to move in "reverse"
    Serial.println("Moving BACKWARDS at default step mode.");
    for(int x= 1; x<(-1*yawDist); x++)  //Loop the sw
      {
        spstVal = 1;

        if (spstVal == 1) {
          digitalWrite(stp,HIGH); //Trigger one step
          delay(1);
          digitalWrite(stp,LOW); //Pull step pin low so it can be triggered
again
          delay(1);
        }
      else if (spstVal == 0) {
        Serial.println("Stopping Pan Motor.");
        break;
        spstVal = 0;
      }
    }
  }

  // Move Pitch Motor
  Serial.println("Pitch movement");
```

```
  if (pitchDist > 0) {


    digitalWrite(dir2, LOW); //Pull direction pin low to move "forward"

    Serial.println("PITCH: Moving FORWARDS at default step mode.");

    for(int x= 1; x<pitchDist; x++)  //Loop the forward stepping enough times 
for motion to be visible

      {



       spstVal = 1;

        if (spstVal == 1) {

          digitalWrite(stp2, HIGH); //Trigger one step forward

          delay(1);

          digitalWrite(stp2, LOW); //Pull step pin low so it can be triggered 
again

          delay(1);

        }

        else if (spstVal == 0) {

          Serial.println("ZERO");

          break;

          spstVal = 0;

        }

      }

  }

  else if (pitchDist < 0) {

    spstVal = 1;


    Serial.print("spstValFINALFINAL: "); Serial.println(spstVal);

    digitalWrite(dir2, HIGH); //Pull direction pin high to move in "reverse"

    Serial.println("PITCH: Moving BACKWARDS at default step mode.");
```

```
    for(int x= 1; x<(-1*pitchDist); x++)  //Loop the stepping enough times
for motion to be visible
    {

      if (spstVal == 1) {
        digitalWrite(stp2,HIGH); //Trigger one step
        delay(1);
        digitalWrite(stp2,LOW); //Pull step pin low so it can be triggered
again
        delay(1);
      }
      else if (spstVal == 0) {
        Serial.println("ZERO");
        break;
        spstVal = 0;
      }
      spstVal = 1;

    }
  }
}


//Reset Driver pins to default states
void resetEDPins()
{
  digitalWrite(stp, LOW);
  digitalWrite(dir, LOW);
```

```
  digitalWrite(MS1, LOW);
  digitalWrite(MS2, LOW);
  digitalWrite(EN, HIGH);
}

void resetEDPins2()
{
  digitalWrite(stp2, LOW);
  digitalWrite(dir2, LOW);
  digitalWrite(MS12, LOW);
  digitalWrite(MS22, LOW);
  digitalWrite(EN2, HIGH);
}
```

Appendix AA: Test and Validation Plan

There were three main tests conducted to validate the prototype:

Test 1: Load cell/Motor Subsystem Assembly

To test the sensitivity of the load cell, and the validity of the Arduino comparison code, a dynamic subsystem test was conducted. This involved placing small weights on the load cell paddles at different locations, moving them to the other paddles continuously, and observing how the stepper motor reacts. An example test of this subsystem would be to place weight on one specific paddle, and note the specific reaction of both motors. Then, move the weight to a paddle on the opposite side of the umbrella canopy from the previous paddle and observe the motor reaction. In this scenario, the pan motor should rotate the shaft 180 degrees, while the pitch should move either forward or backward, depending on whether the new paddle is at a higher or lower position than the previous paddle.

Test 2: Stowing Mechanism

The force needed to stow and assemble the stowing device was measured using a push pull force (strain) gauge. From the stowed position, the gage was used to pull out each of the mechanism bars and lock in position. For the hinge release buttons, the force gauge was used to push on the buttons until they release. The data from this test determined whether the functional requirement of required forces less than 50 N is met. The test was low-risk; the biggest concern was ensuring that fingers cannot get pinched anywhere in the mechanism. An additional test was to ensure that the front wheel clears the attachment in order to allow for normal movements of the wheelchair.

Test 3: Full Assembly Test

To simulate wind loading conditions, three large box fans were placed equidistant at 0, 90, adn 180 degrees relative to the wheelchair umbrella position. The elevation of the fans was controlled to determine whether a tilt of 15 or 30 degrees was expected. Once a fan was started, a stopwatch was used to determine the time taken between each movement of the canopy. The fans were single-speed (12m/s), but varying the distance relative to the umbrella position allowed for variation in wind velocity. The time required to complete movements will be compared to the desired reaction times to determine whether the functional requirements have been met.

Appendix AB: Validation and Testing

Test 1: Load Cell/Motor Subsystem Test

Methodology

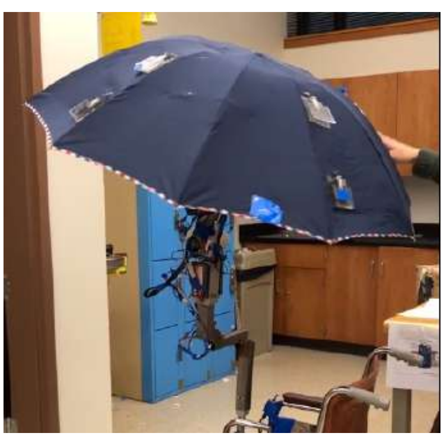
From Appendix AA, the purpose of this test was to ensure that the comparison code, the load cell sensors and the mechanism works in tandem. The load cell sensors would be physically pressed one at a time and it would be observed if the umbrella would pan and tilt to the location at which it was pressed. A certain sequence of load cell sensors would be pressed and the movement would be recorded.

Results/Discussion

a)

b)

c)



d)

Figure AB.1: Subsystem test results showing response to physical input

Figure AB.1 displays the results of preliminary subsystem testing of the umbrella responding to load cell input and driving the motors. a) demonstrates a light touch (load applied) to the load cell sensor near the bottom of the canopy, and b) shows the corresponding movement or a 30 degree tilt. Similarly, c) demonstrates that while the umbrella is in a given position and a load cell in another location experiences a force, the umbrella will tilt and rotate to point the canopy in that direction. This final position is shown in d).

Recommendations/Actions

The results of this subsystem test demonstrate that the load cells are capable of detecting forces, the comparison code works, and the interface between the arduino and motor drivers is working. The speed of the motors can be increased if necessary, the canopy could have excess weight removed, and the tilting mechanism can be smoothened by lubricant to reduce turbulence, but overall this test validates the first two functional requirements.

Test 2: Stowing Mechanism

Methodology

As mentioned in Appendix AA, the stowing mechanism was tested to meet the functional requirements by use of a push pull force gauge.

1. While the entire umbrella assembly is attached, the force gauge is pressed against the release button on the hinge until the hinge is released. The force was recorded and this was repeated for five trials.
2. While the entire umbrella assembly is attached and the mechanism is in its stowed position, the force gauge is hooked onto a stowing mechanism and pulled until the stowing mechanism is in its desired open position. The force required was recorded and the process was repeated for five trials.

Results/Discussion

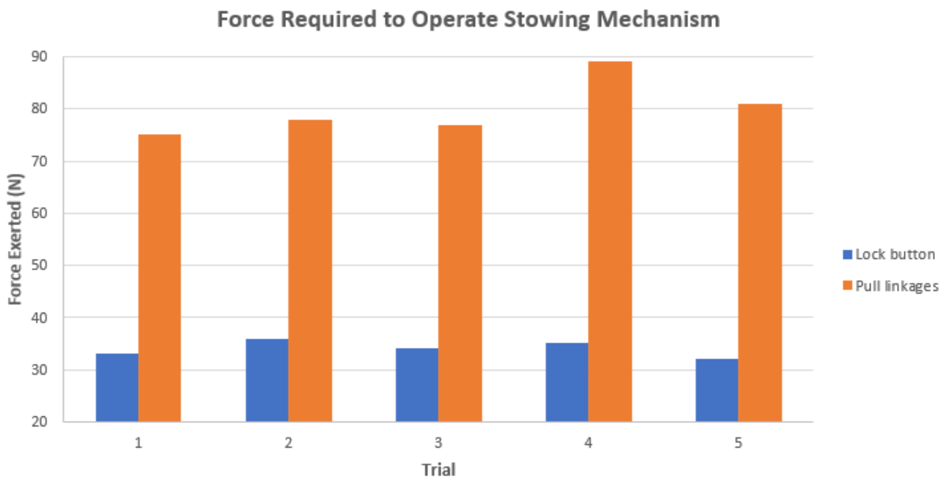


Figure AB.2: Stowing mechanism test results

Figure AB.2 displays the results of the push/pull force gauge readings take from raising the stowing mechanism. Pushing the release buttons on the hinges required much less force than the raise the stowing mechanism itself. Though the release buttons required less than 50 N to operate, the actual raising of the stowing mechanism did not. Therefore, the stowing mechanism did not meet the functional requirement. However, this is most likely due to the additional weight of the stowing and tilting mechanisms. The stowing was made of steel instead of aluminum, and the electrical components and multiple batteries made the tilting mechanism heavy as well.

Figure AB.3: Wheel clearance demonstration

Lastly, one of the main customer concerns with the attachment was whether it will impede in of the normal movements that can be done with a normal wheelchair. The figure above shows that the front wheels of the wheelchair were able to swivel under the attachment, therefore it does not impede on the motion of the wheelchair.

Recommendations and Actions

From the test results, the main improvements that could be done in future iteration would be to make the whole assembly lighter by using lighter materials. The functional requirement was not met due to the weight of the umbrella, therefore targeting this problem would benefit the overall functionality of the umbrella. In addition, adding lubrication between the joints and re-evaluating the tolerances between hinges and joints could make motion smoother.

Test 3: Full Assembly Test

Methodology

In order to determine the efficiency and accuracy of the prototype when subjected to real-world wind loading conditions, box fans were used at varying speeds and distances to observe system response.

Three box fans (Heat Buster SPL4213) were set up 90 degrees apart from each other and turned on and off at varying times as shown below in Figure AB.4. Each box fan provided a wind speed of 12 m/s. For each trial, the distances between the umbrella canopy and fans were altered to simulate different wind speeds which were verified with a handheld anemometer. The time taken for the umbrella to perform certain patterns of motion were recorded for each trial with a stopwatch, and a total of five trials were conducted. The movements tested (see results) were chosen to consider the most difficult or time-consuming shifts in position that could be observed.

Figure AB.4: Test 3 setup

Results/Discussion

Results are tabulated in Table AB.1. Canopy reaction times were slower than desired for certain movements. Response times were satisfactory for yawing motion, but were slightly slower than anticipated for pitching and pitching/yawing motion. This is likely due to a higher than expected frictional coefficient between the screw and coupler in the tilting mechanism. In addition, pitching upward took over 2.5 times longer than pitching downward, likely due to the gravitational force from the umbrella and electronics.

Overall, the umbrella reaction time was 9% slower than desired, though it reacted appropriately to sensor inputs

	Yaw 90° at 30° pitch [sec]	Yaw 90° at 15° pitch [sec]	Pitch Down 15° [sec]	Pitch Up 15° [sec]	Yaw 180 at 30° pitch [sec]
Average Response Time	2.1	1.3	1.6	4.2	4.8
Desired Response Time	2.1	1.5	1.5	3.6	4.4

Table AB.1: Movement test of the final assembly

Recommendations and Actions

To increase the response rate of the canopy, the tilting mechanism components can be made smoother to reduce friction, particularly between the screw and coupler. More powerful motors can be used to increase the rate of tilt and yaw. In addition, the weight of all components can be reduced significantly by manufacturing with lighter materials. The current materials used provide a higher than necessary factor of safety, and replacing them with cheaper and less dense alternatives would take a significant load off the motor.

Appendix AC: Manufacturing Appendices – Process and Operation Planning

a. Tilting Mechanism - Eye End

1. Horizontal Bandsaw to cut the raw aluminum to 4.25"
2. Vertical Bandsaw used to cut the 4.25" block to correct dimensions
3. Use Mill to face the sides and reduce the block to the desired dimensions of 1x1x4"
4. Use a ¾" drill bit on the Mill machine to drill the hole for the ¾" bolt.
5. Use ¼" end mill on Mill machine to mill out the opening for the threaded rod and coupler to pass through.
6. Use ¼" end mill to mill out the slot for the coupler arms.
7. Use a ¼" drill bit to create .5 inch deep hole in the bottom of the eye end for the umbrella stem to fit.

b. Tilting Mechanism - Fork End

1. Bandsaw to the correct dimension.
2. Use a Mill to face the sides and reduce the size of the block to the desired dimensions of 1x2x4".
3. Use ¾" drill bit to drill the hole for the ¾" bolt.
4. Use a ½" end mill on the Mill machine to remove the material in the center of the fork and on the sides.
5. Finally, drill the 4 holes for the d-hub screw connections as well as the motor shaft.

c. Tilting Mechanism - Tilt Motor Holder

1. Bandsaw aluminum square tube to 4.7"x2"x2" (tube has 2"x2" cross section, so only one cut is needed)
2. Face lengthwise side of square tube to exact dimensions (4.5"x2"x2")
3. Remove specified cross section of square tube using end mill
4. Drill center thru hole (.875" diameter) at specified location
5. Drill 2 thru holes (.0984" diameter) at specified location for screw positioning
6. Tap M3 holes for both .0984" diameter holes

d. Tilting Mechanism - Pan Motor Holder

1. Bandsaw the hollow square tube to the correct dimension (2"x2"x5")
2. Face the hollow square tube to the correct dimension (2"x2"x4.75")
3. Drill 0.375" holes thru the square tube at the specified location
4. Drill a 0.75" hole thru the square tube at the specified location

5. Bandsaw the solid square block to the correct dimension (2”x2”x0.5”)
6. Face the solid square block to the correct dimension (2”x2”x0.25”)
7. Drill a 0.875” thru hole at the center of the solid square block
8. Drill and tap 4 M3 holes at the specified locations
9. Weld the solid square block to the top of the hollow square tube

e. Tilting Mechanism - Modified Coupler

1. Weld 1” dowel pins at the specified locations on the coupler
2. Bandsaw the dowel pins to reduce its length to the appropriate size

f. Stowing Mechanism - Hollow Tube

1. Bandsaw and face the hollow tubes to the specified dimensions
2. Drill 0.2” holes at the specified location
3. Drill 0.375” holes at the specified location

g. Stowing Mechanism - Lock Button Housing

1. Bandsaw the solid square block to the appropriate dimension (1.5”x1.5”x4”)
2. Face the square block to the specific dimension (1.25”x1.25”x3.75”)
3. Lathe a 0.75” shaft at the bottom of the square block 1” in length
4. Mill a 0.5” hole inside the 0.75” shaft 2.5” into the shaft
5. Drill 0.25” thru holes at the specified locations

h. Stowing Mechanism - Linear Actuator Connector

1. Bandsaw 1’’ circular rod to correct length of 2.7’’
2. Face rod to exactly 2.7’’ in length
3. Lathe a 0.75’’ into shaft from both top and bottom
4. Mill 0.25" hole thru, center should be 0.63" from the bottom of the piece
5. Mill 0.25" hole 0.5" deep, same plane as the 0.25" hole, 0.4" from the top of the piece
6. Mill 0.25" hole 0.5" deep, 90 degrees to the left of the 0.25" hole at top of the piece, 0.4" from the top of the piece

i. Stowing Mechanism - Linear Actuator Housing

1. 4 face 3D steel open faced cube was bandsaw to the correct length (8’’x3’’x5’’)
2. Mill a .66’’x.72’’ hole on the bottom face to fit the bottom of the linear actuator
3. Mill 6 17/64’’ holes, 4 on the back face and 2 on the bottom face

j. Load Amplifier

1. Using the CAD drawings from Figure 26 and 27, convert the drawings to a .dxf file for the laser cutter.
2. Cut 8 pieces of each from ⅛” acrylic
3. Place load cell sensor between the base plate and paddle and secure the assembly using two 3M screws.

k. Electronics’ Housing

1. Square, 6-sided box was made from acrylic and laser-cut into the proper dimensions
2. Epoxy used to construct boxes and place PCB inside each box
3. Hand drills used to cut two holes into top of the box for wiring

Appendix AD: Inspection and Quality Assurance Operation Sheet

Proof of Safety Approval by Mechanical Engineering Lab Manager at all three phases of the project

Mike Sherwood <msherwoo@purdue.edu>
Thu 2/7, 11:44 AM
Yovan Justin Chu

Approved to proceed.

Mike Sherwood
Purdue Mechanical Engineering
Pearl Lab Manager
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Mike Sherwood <msherwoo@purdue.edu>
Mon 3/4, 2:44 PM
Yovan Justin Chu

Approved to proceed.

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Re: Test Plan - Team EverCanopy

Mike Sherwood <msherwoo@purdue.edu>
Mon 4/15, 10:47 AM
Yovan Justin Chu

Inbox

SR3 approved with testing with caution.

Mike Sherwood
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Pearl Lab Manager
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Figure AD.1: Email approval from Mike Sherwood