Team-9 Final Design Report

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1 Group Picture

Figure 1: Team 9

2 Abstract

The purpose of this project is to design, build, and program a food transport device that can maneuver around an obstacle course called "Mount Bruin." To this effect, three initial concepts were developed, screenshots of which are included in this report. Based on a pairwise comparison chart and an objectives tree, Design 2 with a scooping mechanism was chosen. A detailed CAD model of this design was then created in SolidWorks, with all electronic components included. Using the estimated weight of the device and properties of the device in SolidWorks, tractive force and power requirements are calculated and presented, as well as relevant calculations for the food retrieval motor and subsystem.

Contents

1 Group Picture 1

2 Abstract 2

3 List of Figures 8

4 List of Tables 13

5 List of Symbols 15

6 Introduction 16

6.1 Problem Statement 16

6.2 Literature Review 17

6.3 High-Level Design Requirements 18

6.4 Low-Level Design Requirements 19

7 Design Description 20

7.1 Design Concept Development 20

7.1.1 Design Concept 1 21

7.1.2 Design Concept 2 23

7.1.3 Design Concept 3 25

7.1.4 Objectives Tree and Pairwise Comparison Chart 26

7.2 Design Overview 27

7.3 System Specifications 31

7.4 Mechanical Systems 32

7.5 Control Systems 35

8 Subsystems Design Description 36

8.1 Structural . . . 36
8.1.1 Subsystem Description . . . 36
8.1.2 Design Requirements . . . 37
8.1.3 Subsystem CAD Models and Engineering Drawings . . . 38
8.2 Drive System . . . 41
8.2.1 Subsystem Description . . . 41
8.2.2 Design Requirements . . . 41
8.2.3 Subsystem CAD Models and Engineering Drawings . . . 42
8.3 Retrieval/Delivery Mechanism . . . 45
8.3.1 Subsystem Description . . . 45
8.3.2 Design Requirements . . . 45
8.3.3 Subsystem CAD Models and Engineering Drawings . . . 46
8.4 Sensors . . . 49
8.4.1 Subsystem Description . . . 49
8.4.2 Design Requirements . . . 49
8.4.3 Subsystem CAD Models and Engineering Drawings . . . 50
8.5 Electronics . . . 52
8.5.1 Subsystem Description . . . 52
8.5.2 Design Requirements . . . 52
8.5.3 Subsystem CAD Models and Engineering Drawings . . . 53
9 Design Analysis . . . 54
9.1 Analysis and Calculations . . . 54

9.1.1 Drive System Power Requirements 54

9.1.2 Move Profile 55

9.1.3 Motor Torque Requirements 56

9.1.4 Food Retrieval Calculations 57

10 Control System Design 58

10.1 Drive Motor Selection and Motor Specifications 58

10.1.1 Motor Selection 58

10.1.2 Motor Description 59

10.1.3 Circuit Diagram 60

10.2 Food Retrieval/Delivery Mechanism 61

10.2.1 Motor Selection 61

10.2.2 Motor Description 62

10.2.3 Circuit Diagram 64

10.3 Sensors and Theory of Operation 65

10.3.1 Sensors 65

10.3.2 Circuit Diagram 66

10.4 State Diagram 67

10.4.1 Stateflow Charts 67

10.4.2 Simulink Code 71

11 Product Fabrication 73

11.1 Chassis 73

11.2 Drive System 77

11.3 Food Retrieval/Delivery Mechanism 79

11.4 Final Product 80

12 Product Performance Testing and Evaluation 82

12.1 Run Times 82

12.1.1 Food Retrieval 82

12.1.2 Starting Area 82

12.1.3 Obstacle Area 82

12.1.4 Mt.Bruin Hill 82

12.1.5 Food Delivery 83

12.2 Overall Performance 84

13 Work Breakdown Schedule 86

13.1 Work Breakdown Schedule Diagram 86

13.2 Work Breakdown Schedule Dictionary 87

14 BOM and Cost Analysis 88

14.1 Assembly Drawings 88

14.1.1 Chassis Subassembly 88

14.1.2 Drive System Subassembly 91

14.1.3 Delivery Mechanism Subsystem 95

14.1.4 Sensor Subsystem 98

14.1.5 Electronics Subsystem 100

14.2 BOM 102

14.3 Final Cost Analysis 103

14.3.1 Material Costs 103

14.3.2 Labor Costs 105

15 Design Requirement Satisfaction 106

16 Conclusion 107

17 References 108

18 Appendix 109

18.1 Engineering Drawings 109

18.1.1 Exploded Views 109

18.1.2 Engineering Drawings of Parts 116

18.1.3 Stateflow Charts 123

18.1.4 Simulink Code 126

18.1.5 Work Breakdown Schedule 127

18.1.6 Packing Slips and Receipts 129

3 List of Figures

List of Figures

1 Team 9 1

2 Sketch of Concept 1-Front, Side, Top, and Isometric View 21

3 Sketch of Concept 2-Front, Side, Top, and Isometric View 23

4 Sketch of Concept 3-Front, Side, Top, and Isometric View 25

5 Objectives Tree utilizing the weights from the PCC 26

6 Pairwise Comparison Chart used to determine relative weights for design factors 26

7 Front Isometric View of the Device CAD 28

8 Rear Isometric View of the Device CAD 29

9 Isometric view of the device before the tune can is retrieved 30

10 Isometric view of the device after the tuna can is retrieved 30

11 Chassis with Electronics CAD Model 32

12 Drive System CAD Model 33

13 Food Retrieval System CAD Model 34

14 Structural Chassis CAD Model 38

15 Structural Chassis CAD Model with Top Plate Hidden 39

16 Structural Chassis Drawing 40

17 Drive System CAD Model 42

18 Rear Drive Assembly CAD Model 43

19 Drive System Drawing 44

20 Food Retrieval System CAD Model 46

21 Stepper Motor Assembly CAD Model 47

22 Food Retrieval System Drawing 48

23 Ultrasonic sensor and mounting bracket CAD model 50

24 Ultrasonic sensor positions in CAD model: Two are mounted on either side of the device, one is mounted on the front 51

25 Ultrasonic sensor and mount drawing 51

26 Isolated Cad Model of main electronics 53

27 Required propulsion force and propulsion power for each path segment illustrated in Figure 28 54

28 Vehicle path through the Mount Bruin obstacle course, made up of 12 path segments 55

29 Move Profile Plot 55

30 Required propulsion torque calculated from propulsion power for each path segment illustrated in Figure 28 56

31 227:1 metal, medium power gearmotor from Pololu.com 58

32 Circuit Diagram for Drive Motors with Encoders 60

33 NEMA-17 Stepper Motor from Pololu.com 61

34 DRV8834 low-voltage stepper motor driver carriers with included header pins soldered 63

35 Wiring Diagram for connecting a microcontroller to a DRV8834 stepper motor driver carrier 64

36 Circuit Diagram for All Sensors 66

37 Overall Stateflow Chart 67

38 Left side of Stateflow Chart, zoomed in for increased legibility 68

39 Right side of Stateflow Chart, zoomed in for increased legibility 68

40 Overall Stateflow Chart with main sections labeled 69

41 Overall Simulink Code 71

42 First top and bottom plates printed for the robot. 73

43 Initial prototype of the press-fit standoffs. 74

44 Final CAD model of heat-set insert standoffs. 74

45 New square standoffs with brass heat set inserts. 75

46 New square standoffs with brass heat set inserts. 75

47 Final CAD model of top plate. 76

48 First time attaching the drive system to the bottom plate. 77

49 A CAD model of the motor mounts. 78

50 An exploded view of the front wheel subassembly. 78

51 CAD Model of the Food Retrieval Sub-assembly 79

52 Front and rear isometric views of the robot. 80

53 Bottom view of the robot. 80

54 Front and side views of the robot. 80

55 Overall Performance of 3 Runs 84

56 Work Breakdown Schedule Tree Structure View 86

57 89

58 90

59 91

60 92
61 93
62 94
63 95
64 96
65 97
66 98
67 99
68 100
69 101
70 Chassis Subassembly Exploded View 109
71 Front Wheel Subassembly Exploded View 110
72 Rear Wheel Subassembly Exploded View 111
73 Delivery Mechanism Exploded View 112
74 Scooper Exploded View 113
75 Sensor Subassembly Exploded View 114
76 Electronics Subassembly Exploded View 115
77 Bottom Plate Engineering Drawing 116
78 Top Plate Engineering Drawing 117
79 Rear Wheel Motor Mount Drawing 118
80 Front Wheel Mount Drawing 119
81 Standoff Drawing 120

82 Ultrasonic Sensor Mount Drawing 121

83 Scooping Mechanism Support Drawing 122

84 Overall Stateflow Chart 123

85 Left side of Stateflow Chart, zoomed in for increased legibility 124

86 Right side of Stateflow Chart, zoomed in for increased legibility 124

87 Overall Stateflow Chart with main sections labeled 125

88 Overall Simulink Code 126

89 Simulink code with the repeating sequence stair for the stepper motor shown 126

4 List of Tables

List of Tables

1 High Level Design Requirement 18

2 Low Level Design Requirement 19

3 Drive Motor Specifications 59

4 L298N Motor Driver Specifications 59

5 Stepper Motor Specifications 62

6 DRV8834 Specifications 62

7 Run Times for Food Retrieval 82

8 Run Times for Starting Area 82

9 Run Times for Obstacle Area 82

10 Run Times for Mt.Bruin Hill 82

11 Run Times for Food Delivery 83

12 Total Run Time 84

13 Standard Error Calculation 85

14 Work Breakdown Schedule Dictionary 87

15 Chassis Bill Of Materials 88

16 Drive System Bill Of Materials 91

17 Delivery Mechanism Bill Of Materials 95

18 Sensor Subsystem Bill Of Materials 98

19 Electronics Subsystem Bill Of Materials 100

20 Overall Bill of Materials 102

21 Material Costs 103

22 Design Requirement Satisfaction 106

5 List of Symbols

Symbol	Description	Units
μ_{FWD}	Coefficient of Friction for Forward-Wheel Drive Vehicles	unitless
μ_{RWD}	Coefficient of Friction for Rear-Wheel Drive Vehicles	unitless
μ_{AWD}	Coefficient of Friction for All-Wheel Drive Vehicles	unitless
F_{NR}	Normal Force Between Rear Wheels and the Ground	N
F_T	Total Tractive Force for the Device	N
F_{TR}	Tractive Force for the Rear Wheels	N
F_{TF}	Tractive Force for the Front Wheels	N
F_g	Force of Gravity	N
β_f	Fraction of Weight on the Front Wheels	unitless
β_r	Fraction of Weight on the Rear Wheels	unitless

6 Introduction

6.1 Problem Statement

This report outlines the development of a food delivery device that will autonomously navigate through an obstacle course called "Mount Bruin." More specifically, the device must adhere to thirteen high-level design requirements. Examples of these requirements include not exceeding 20x25x30 cm^3 in the starting position, being powered by electric batteries, and pressing a "push button" to begin the robot's motion. While remaining within these constraints, the device must pick the food item up, exit the starting area, avoid obstacles, drive up an incline, drop the food item off, and stop at the top of the hill. A combination of sensors (ultrasonic, line tracking, and more) and computer programming through MATLAB and Simulink will provide the robot with autonomous capabilities [2].

6.2 Literature Review

The concept of food delivery robots is not new. In fact, the COVID-19 pandemic has spurred the development and implementation of these robots due to the initial need for social distancing. Perhaps an example that will be immediately recognizable to members are the UCLA community are the Starship robots that populate sidewalks on campus, as well as those in cities such as "Milton Keynes, England; Modesto, California; and the company's hometown of Tallin, Estonia" [1]. Additionally, other robots such as drones or ones utilizing multi-axis arms have been developed as well. However, while these robots may have autonomous driving and/or food delivery in common with the food delivery device in this class, there are vast differences as well. For example, Starships don't mechanically pick-up or drop-off food, as people place and remove the food from insulated cabins instead. Thus, while there are similar devices on the market, this device has design requirements that are specific to this course at UCLA in order to better effectively enforce important aspects of mechanical engineering in an educational setting.

6.3 High-Level Design Requirements

Table 1: High Level Design Requirement

HLDR	Description	Comments
1	Device must be able to deliver a food item uphill to the loading area	Main objective of the device
2	Device must autonomously navigate the entire obstacle course	Remote control could be utilized as a backup option
3	Device dimensions at the beginning of its run must not exceed 20x25x30 cm^3 (HxWxL)	There are no weight limitations
4	Dimensions of device can change after start	Mechanisms can deploy after start
5	The device must use electric batteries; no other sources of power (e.g. muscle, hydraulics, chemical) are permitted	Cheapest option
6	Device may use torque or skid steering	A steering system is preferred
7	All sensors must be mounted on device	No sensors may be deployed on the course
8	No components may be left behind on the course during the device's travel	Device must be durable and structurally sound — cannot dump weight
9	Device must be able to navigate the course within 5 minutes	Long enough time for device to move slowly and securely
10	All mechanical actuators used must be designed and modeled in-house	No linear actuators may be purchased
11	Off-the shelf items that may be purchased are limited in terms of Hardware, Power Transmission, and Electronics	Economic limitations
12	350 USD total budget	Expenses must be documented in the Final Design Report, with vendors and prices listed
13	Disposable or rechargeable batteries may be used to power the vehicle	Battery types may not be mixed — either all disposable or all rechargeable must be used

6.4 Low-Level Design Requirements

Table 2: Low Level Design Requirement

LLDR	Description	Comments
1	Device arrives on top of hill within 2 min	Too long means auto driving or vision code is wrong
2	Device picks up food item with 30 seconds after start	Picking mechanism should be quick
3	Two motors for drivetrain	One per side for better control
4	The robot will use disposable electronic batteries to power the vehicle	Subject to change, depending on team's requirements
5	Utilize skid steering	Cheapest and easiest option
6	Most materials will be 3D printed	Cheap and high enough strength properties
7	The loading mechanism shall not shake unnecessarily, and shall not drop the object during the course run	The object must be dropped off at the end of the course

7 Design Description

7.1 Design Concept Development

We will first present preliminary sketches of the 3 concepts. In order to methodically select the best concept out of 3, we utilized a Pair-wise Comparison Chart and Objectives Tree in order to rank the concepts based on important criterion.

Concept 2 was chosen based on the Objectives Tree, as it achieved the most favorable score of 6.15 based on the weights assigned by the PCC. The main areas in which Concept 2 distinguished itself were complexity and cost; the front scooper mechanism of the second design was deemed the simplest and cheapest of the three options.

In Concept 1, the clamping mechanism would have to be actuated to clamp onto the water bottle, and the clamp would then have to raise or angle up in order to prevent the bottle from dragging on the ground. In Concept 3, a more complex holder would need to be designed that could lift the tuna can into the middle of the robot, and then lower back down and angle downwards in order to drop the tuna can off at the top of the hill. In both of these designs, more than one type of motion/actuation is necessary, whereas in Concept 2, the scooper simply has to be angled up to pick up the tuna can, and then angled back down to deliver it to the Bruin at the top of the hill.

In terms of cost, Concept 2 was deemed cheaper than Concept 1 for two main reasons. As discussed in the previous paragraph, it requires fewer actuators as it requires fewer types of motion of the food-holding mechanism. Additionally, due both to the fewer number of actuators included and the fact that Concept 1 was intended to carry the water bottle (which is heavier than the can of tuna), Concept 2 is lighter weight and is thus is likely to require less power, enabling the usage of cheaper motors. Concept 2 was deemed to be cheaper than Concept 3 for similar reasons; although Concept 3 is also intended to carry the tuna can, the more complex holding and tilting mechanism would likely result in higher weight and higher cost of materials/fabrication.

7.1.1 Design Concept 1

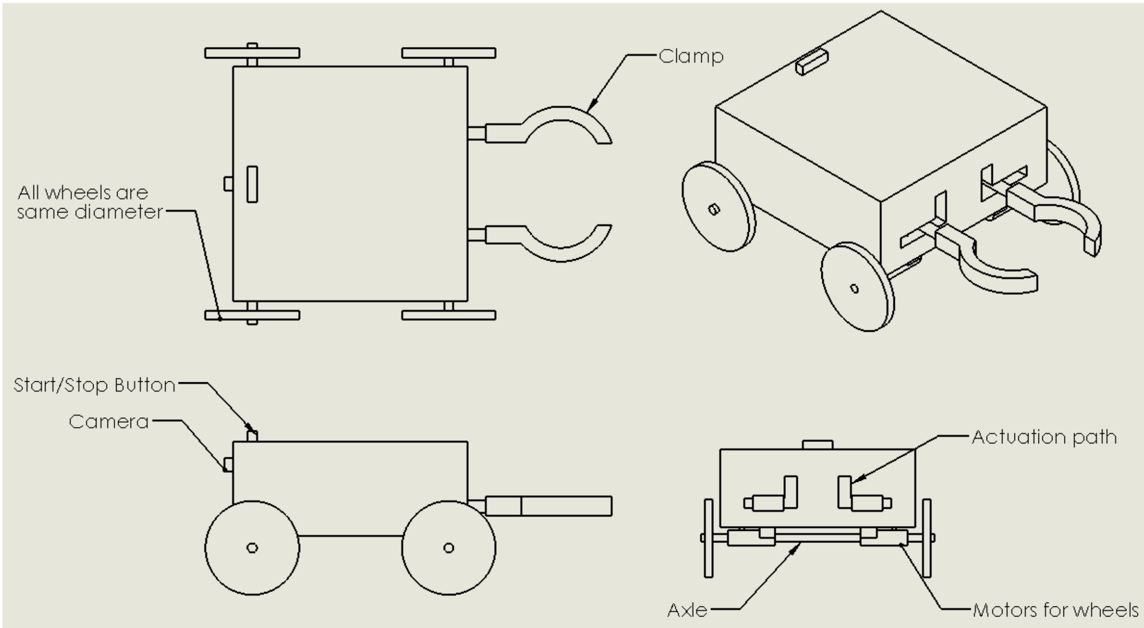


Figure 2: Sketch of Concept 1-Front, Side, Top, and Isometric View

Concept 1 utilizes a curved clamping mechanism to grip either sides of the object. The clamps are located in the back of the robot so that they will not interfere with any of the obstacles located throughout the course. First, the clamps will move inward horizontally at the same speed, will grip the object, and then rise vertically such that the bottom of the object does not drag against the ground. (This vertical rise is also necessary when considering that the device must climb up an incline.)

The ideal object for this concept is a water bottle due to it's material and relative height. The plastic material of the water bottle makes it easier to grip, as it is less slippery than metal of the tuna can and less stiff than the plastic of the bottle of honey. Additionally, the tuna can is too short to tightly grip.

A camera and related sensors will also be located in the front of the robot in order to accurately detect obstacles in a timely manner.

This device is likely to satisfy all high-level and low-level design requirements if implemented properly, as the clamps will securely grip into the water bottle and deliver it to the loading area. One potential issue is continuous grip on the water bottle throughout the navigation of the coarse. Continuous grip is paramount to because if grip is loosened on even one side, the bottle can slip out and roll down the ramp. Another potential issue is the size of the clamps, as the device must remain within specific dimensions prior to beginning the run. If the clamps were too large and had to extend in and out, this would require another degree of freedom and additional actuation. However, there are positives to this design as well. With the camera and corresponding sensors, the device will have the ability to navigate autonomously throughout the coarse. Because of the simplicity of the clamping and axle systems, the device may be powered with off-the-shelf motors and electric batteries that are compatible with the actuation systems that are designed. It is also reasonable that all components will be within the 350 USD budget.

Additionally, it is also possible to meet low-level design requirements listed previously. The food can possibly be picked up in 30 seconds, as the process is as simple as driving to the item, clamping it, and lifting it. (It is not necessary to move the bottle to a particular location or pin it against the wall prior to lifting.) Two motors will be used for the drivetrain, and are indicated in the drawing above. Most pieces of this design are low-impact and will not be sustaining any hits, which allows the use of 3D printed materials instead of hard metals. Again, continuous grip must be provided to the clamps in order to prevent malfunction of the loading system.

The positives to this design such as the use of cameras and sensors, axles, off-the-shelf motors and batteries are applicable to the following two designs as well. Lastly, the relatively low-impact nature of the robot chassis also holds true throughout the other two designs as well.

7.1.2 Design Concept 2

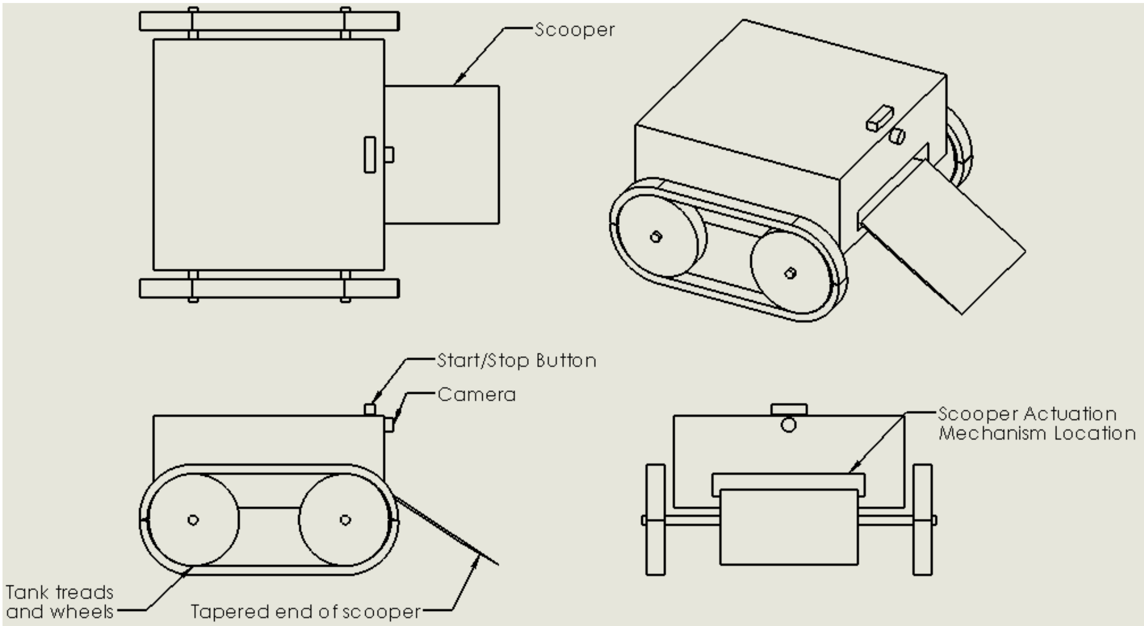


Figure 3: Sketch of Concept 2-Front, Side, Top, and Isometric View

Concept 2 will use a scooper mechanism in the middle, front of the device to avoid obstructing the sensors. The ideal object for this concept is a tuna can, as it will be easier to scoop due to its low center of gravity.

First, the scooper will tilt down to lift the tuna can. If needed, the robot will pin the tuna can against a wall and then lift. After loading the tuna can, the scooper will tilt up to keep the can from falling off during travel. Once the device reaches the top of the hill, the scooper will tilt back down to deposit the tuna can. The scooper is tapered at the end to assist with easier lifting.

Additionally, tank treads will be used for the wheels to support the device's stability as it travels over holes in the track. The wheels are a large diameter to accommodate for these holes as well.

This concept can also satisfy all design requirements but focus needs to be placed on the scooper mechanism in order to do so. The design need to keep in mind that device dimensions must not be breached prior to start so the scooper will have to be compact enough to not take up chassis and electronics space before deployment. The scooper also have a higher chance of losing items since it is not actively controlling the food item, either some small active mechanism or passive design will need to be implemented in order to ensure that transportation of food item is successful. The scooper and treads both may need to be bought or made of metal, potentially driving up costs and manufacturing time. Further examination of food items and prototyping should be done to ensure functionality of 3D printed designs.

7.1.3 Design Concept 3

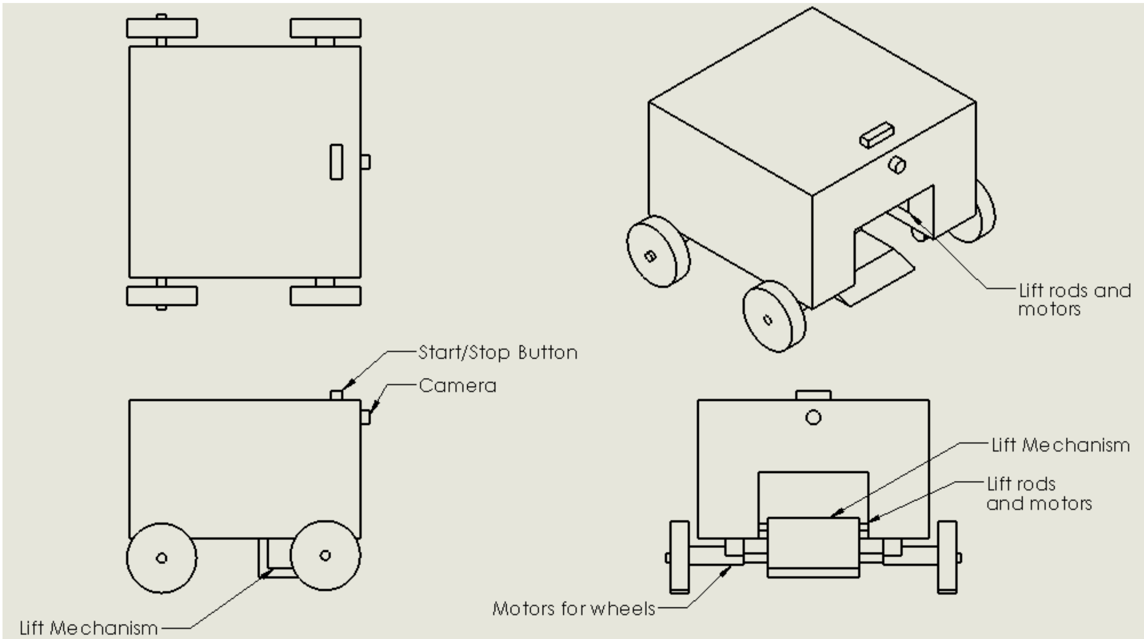


Figure 4: Sketch of Concept 3-Front, Side, Top, and Isometric View

Concept 3 will use a scooper/trap door mechanism to lift and drop the tuna can inside of the autonomous vehicle. The mechanism will deploy and drop closer to the ground. With its tapered end, it will lift the object. It will rise back up into the robot right before travel to other parts of the ramp, which will secure the can during travel and allow for drop-off the same way through the trap door at the top of the hill.

Because the tuna can is stored in the middle of the robot, this can help with ensuring that weight is equally distributed across the robot.

Concept 3 also will be able to satisfy all design requirements. Similar to concept 2, this concept faces the same issues when it comes to the scooper mechanism. However, there is a trade-off between a more complex design and a more secure food item environment since the scooper is located inside the robot in concept 3. With an internal scooper, the space available for electronic is much more limited compared to the other concepts, potentially limit the size of batteries or types of sensors that can be used.

7.1.4 Objectives Tree and Pairwise Comparison Chart

		Design Scores			Weighted Design Scores		
Design Objective Factors	PCC Weight	Design 1-Clamp	Design 2-Scooper	Design 3-Hold in Middle	Design 1	Design 2	Design 3
Cost	0.19	6	8	6	1.12	1.49	1.12
Weight	0.17	5	6	6	0.86	1.04	1.04
Safety	0.00				0.00	0.00	0.00
Durability	0.12	5	5	7	0.60	0.60	0.84
Aesthetics	0.00				0.00	0.00	0.00
Complexity	0.17	5	6.5	4	0.83	1.07	0.66
Power - how much we need	0.17	5	6	6	0.83	1.00	1.00
Maneuverability	0.19	6	5	4	1.14	0.95	0.76
	1			Total Score:	5.38	6.15	5.41

Figure 5: Objectives Tree utilizing the weights from the PCC

						# of Designers / Scale					
						10					
		Compared To									
Is this Factor Used? (1 = YES, 0 = NO)	Factors	Cost	Weight	Safety	Durability	Aesthetics	Complexity	Power	Maneuverability	Total	Weight
1	Cost	10	7	10	8.5	10	6	5	5	61.5	0.19
1	Weight	3	10	10	9	10	5	6	4	57	0.17
0	Safety	0	0	10	0	10	0	0	0	0	0.00
1	Durability	1.5	1	10	10	10	2	3	2	39.5	0.12
0	Aesthetics	0	0	0	0	10	0	0	0	0	0.00
1	Complexity	4	5	10	8	10	10	4	3.5	54.5	0.17
1	Power	5	4	10	7	10	6	10	3	55	0.17
1	Maneuverability	5	6	10	8	10	6.5	7	10	62.5	0.19
Aaron Aoyama, MAE-162B, UCLA, Fall 2010									Total Sum:	330	1

Asset

Figure 6: Pairwise Comparison Chart used to determine relative weights for design factors

7.2 Design Overview

Concept 2 will use a scooper mechanism located opposite end of the ultrasonic sensor to avoid obstructing the sensors. The ideal food object to transport for this concept is a tuna can, as it will be easier to scoop due to its low center of gravity. A counterweight is needed at the front of the device if the scooper mechanism is in the rear because the center of mass could result in tipping once the device drive up the hill.

First, the scooper will tilt down to lift the tuna can. If needed, the robot will pin the tuna can against a wall and then lift. After loading the tuna can, the scooper will tilt up to keep the can from falling off during travel. Then the device can begin navigating through the obstacle course. Once the device reaches the top of the hill, the scooper will tilt back down to deposit the tuna can. The scooper is tapered at the end to assist with easier lifting.

This concept can also satisfy all design requirements but focus needs to be placed on the scooper mechanism in order to do so. The design need to keep in mind that device dimensions must not be breached prior to start so the scooper will have to be compact enough to not take up chassis and electronics space before deployment. The scooper also have a higher chance of losing items since it is not actively controlling the food item, so side walls and some anti-slip mechanisms might be needed in order to ensure that transportation of food item is successful. The scooper may need to be bought or made of metal, potentially driving up costs and manufacturing time. Further examination of food items and prototyping of the scooper should be done to ensure functionality of 3D printed designs.

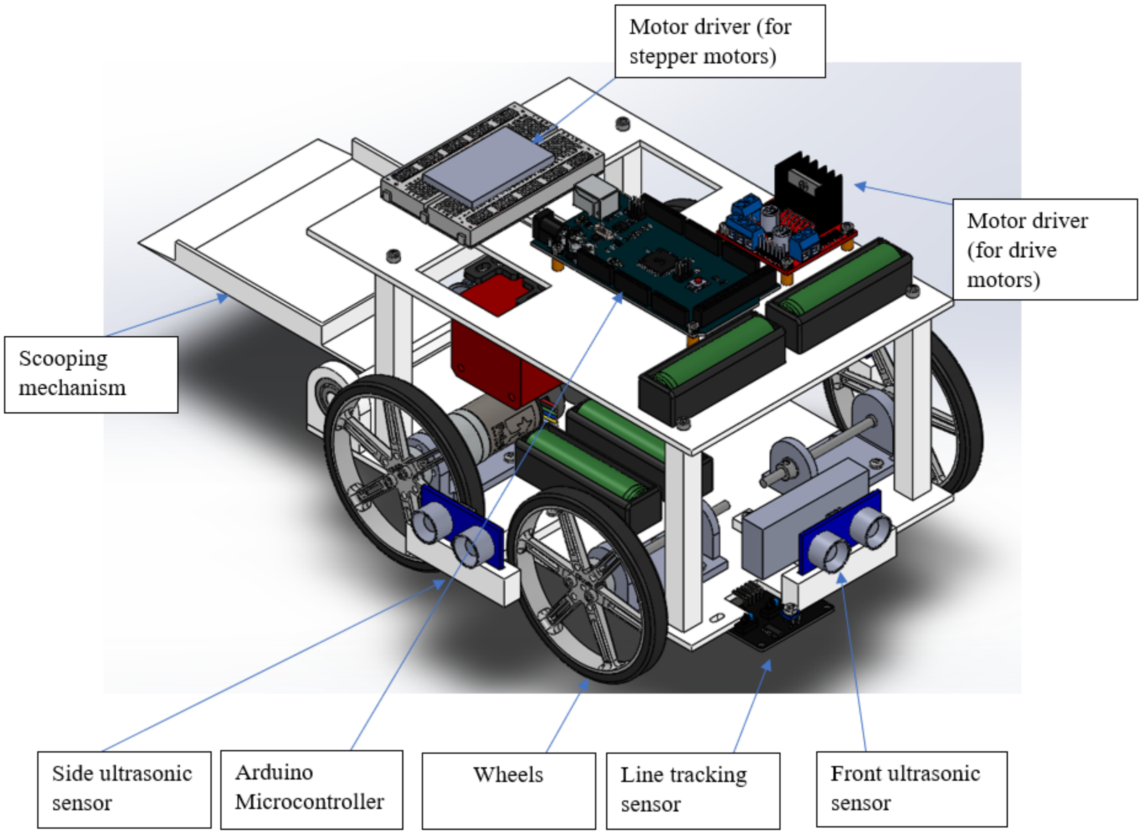


Figure 7: Front Isometric View of the Device CAD

The figure above is a screenshot of the front isometric view of the CAD model. In the front, there are two ultrasonic sensors on either side of the front plate to ensure that obstacles in front of the vehicle are accurately detected. If there was just one sensor in the middle, it is possible that it is not in the range of the sensor. Having two sensors increases the likelihood of the object being detected. There is also two ultrasonic sensors on the left and right side of the device that will help with wall following and object detection as well. There is also a line tracking sensor facing the ground on the front of the device that will help to detect the top of Mount Bruin.

More generally, there are four motors and four wheels. There is an additional motor that is used for moving the scooping mechanism up and down. Additionally, an Arduino microcontroller is located inside the device to control the sensors and the wheels.

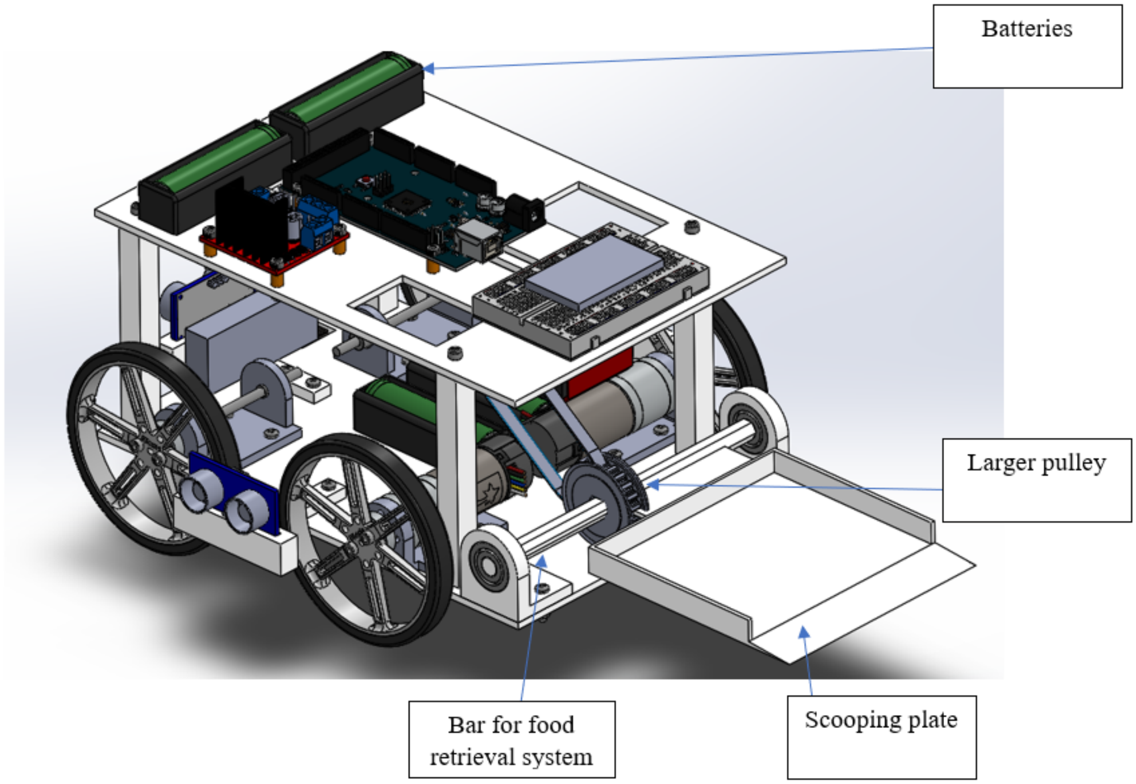


Figure 8: Rear Isometric View of the Device CAD

The rear isometric view of the device is shown in Figure ??. The battery pack is located inside the device to ensure that the center of gravity is located appropriately (i.e. closer to the ground), which will be helpful when driving forward and navigating around obstacles.

The food retrieval system is also more easily viewed in this figure. There is a motor connected to a gear. This gear is connected to another gear that is attached to the food retrieval bar and scooping plate. The gear, bar, and plate will be 3-D printed and manufactured together as one piece. Thus, when the motor turns, the scooping plate will move up or down. It is also important to note that there are bearings attached to the food retrieval bar to aid in smooth turning during operation. Lastly, there are small side walls on the scooping plate to protect the tuna can from falling off of the plate in the event that it slides around during the obstacle course.

In the figures below, there is an older version of the CAD model from Winter Quarter 2022 for reference and to compare to Figures 7 and 8. Additionally, these images are provided to portray how the tuna can is picked up and held by the robot. Figure 9 depicts the vehicle before the tuna can is retrieved. The scooper is angled downward and the tapered end touches the ground to pick the tuna can up. Figure 10 depicts the vehicle after the tuna can is retrieved, as the scooper is angled slightly upward to ensure that the tuna can does not fall down.

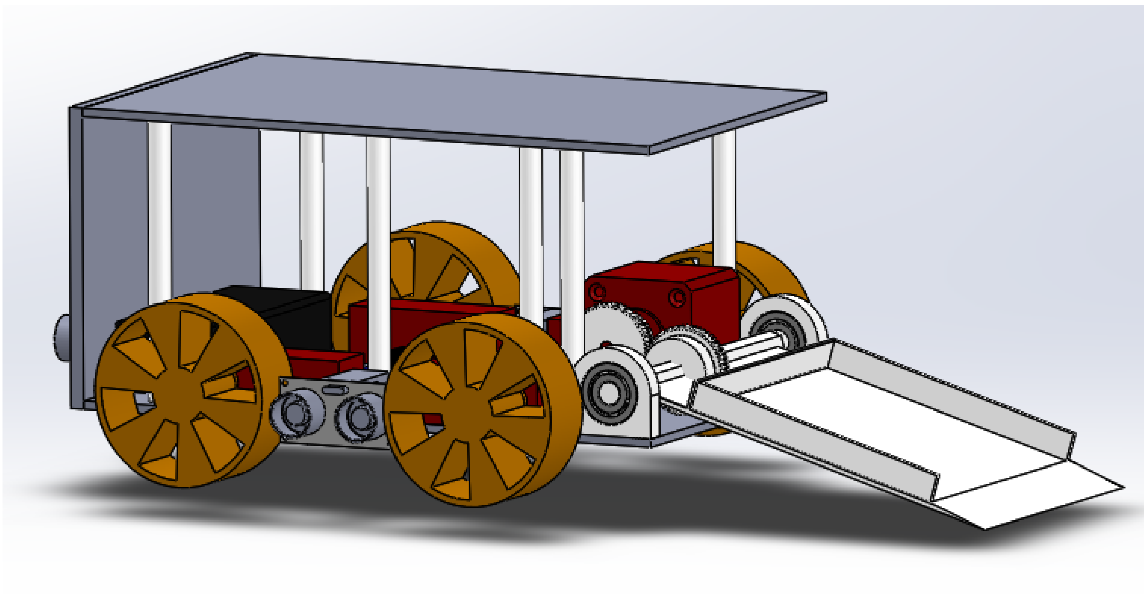


Figure 9: Isometric view of the device before the tune can is retrieved

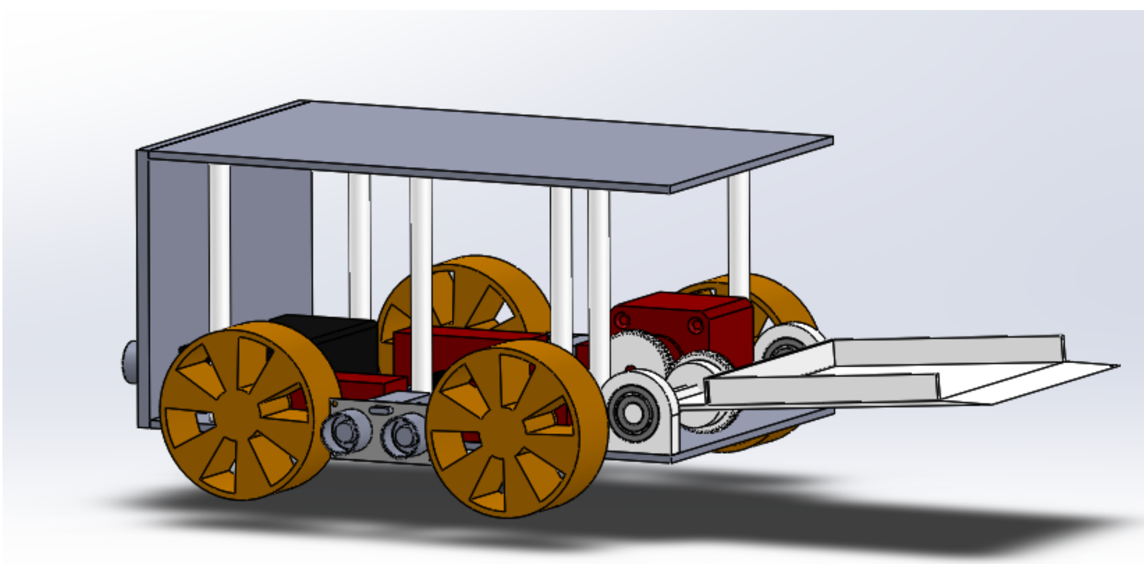


Figure 10: Isometric view of the device after the tuna can is retrieved

7.3 System Specifications

Only purchasing what's not possible to create in-house, the team spent less than $300 dollars in acquiring electric motors and mechanical hardware such as bearings and bolts. The final device dimension stands at 15x25x30 cm^3 and weighs around 1.4 kg. With 2 drive motors, the device can operate smoothly at a speed of 0.17 m/s. To ensure long operating time and consistent performance, 3 batteries are used to power the drive system while the food retrieval system has it own dedicated battery. The device also housed 3 ultrasonic sensors to help it autonomously navigate through the course, as well as 1 infrared line sensor to detect that the device has reached the top of the hill.

7.4 Mechanical Systems

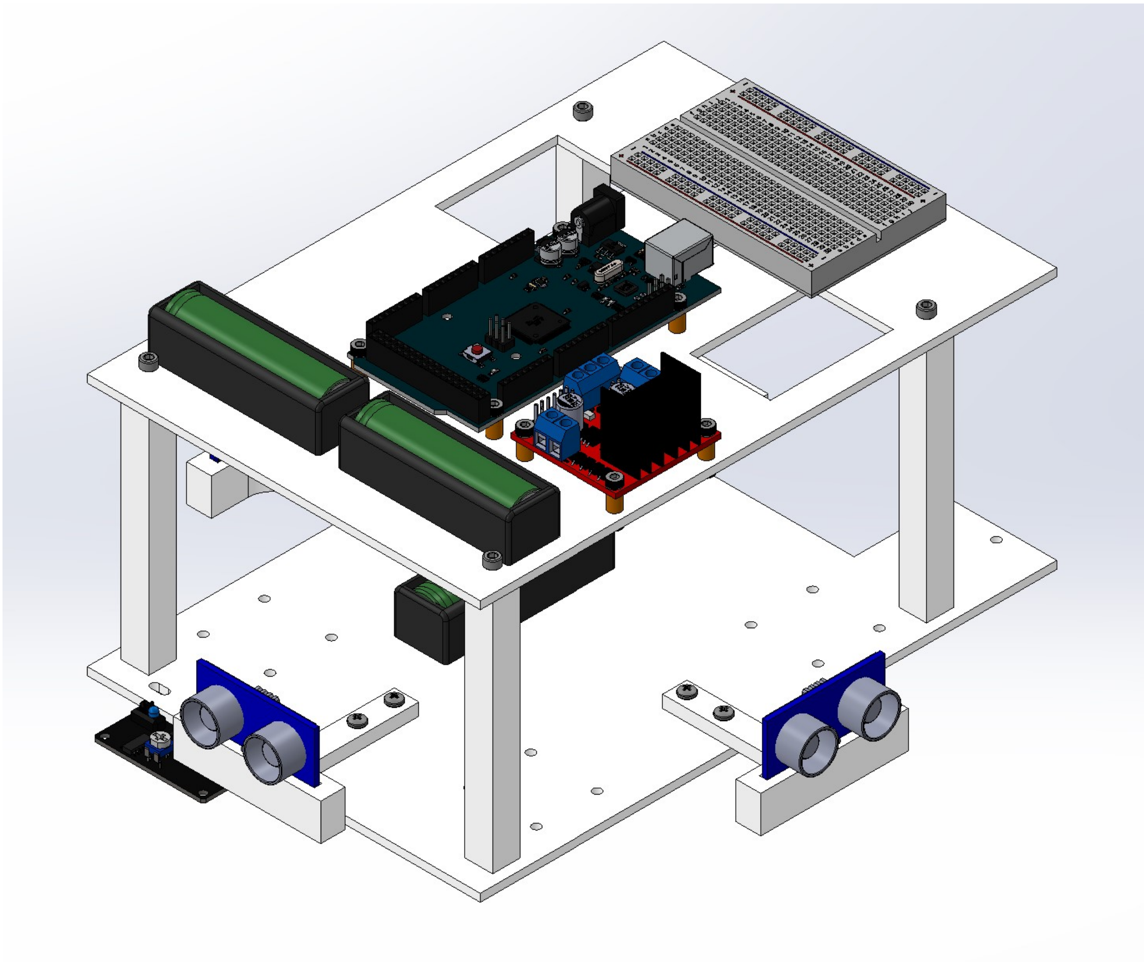


Figure 11: Chassis with Electronics CAD Model

The chassis holds all mounting and electrical components compactly with cutout for wire path and easy access.

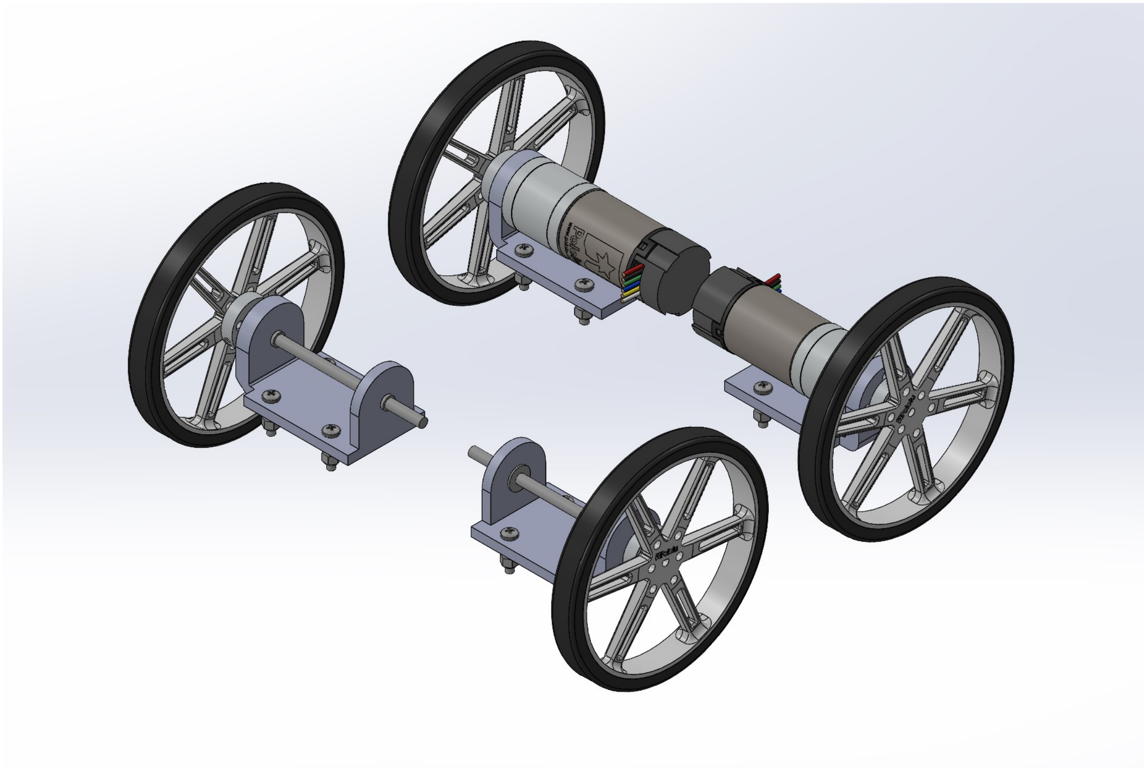


Figure 12: Drive System CAD Model

Rear-wheel drive with one motor on each side that can be controlled separately.

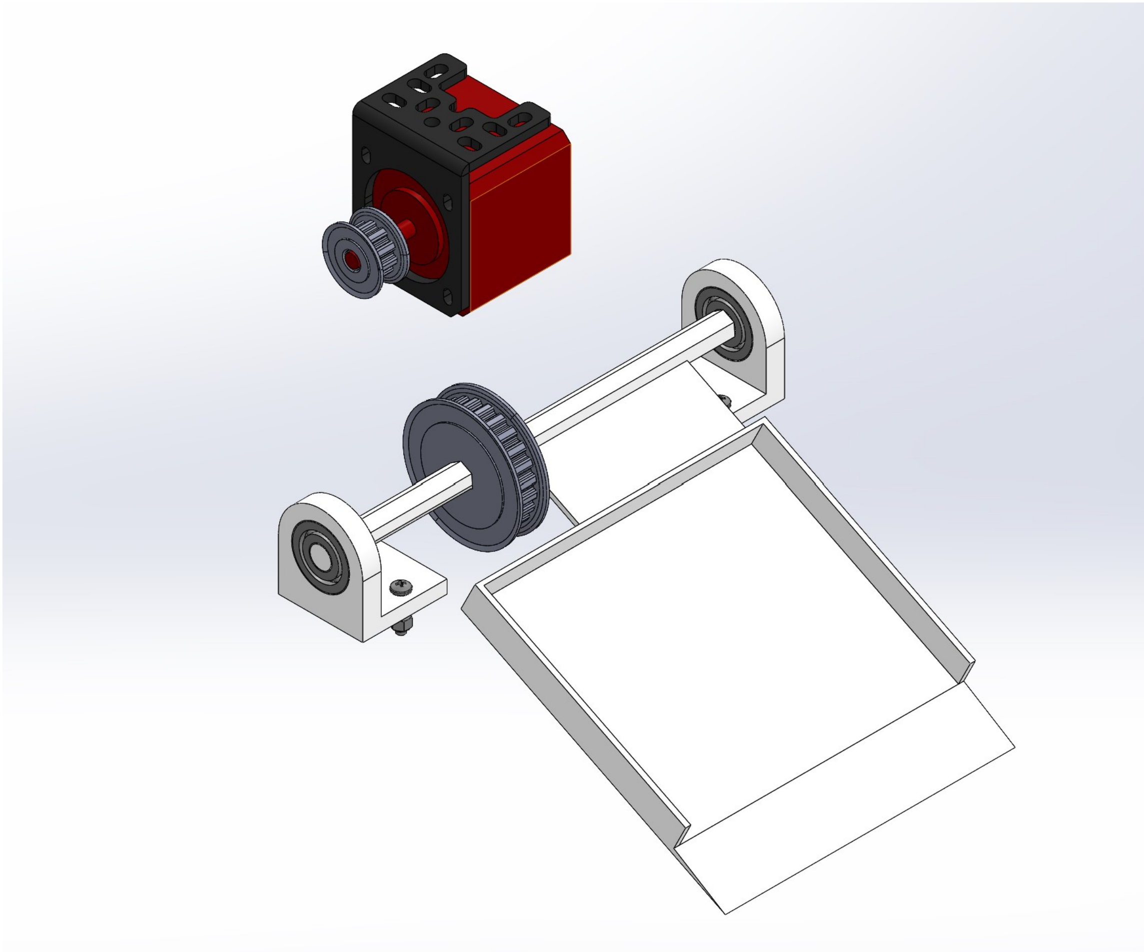


Figure 13: Food Retrieval System CAD Model

Stepper motor powering a belt and pulley system to rotate the scooper down when acquiring the food item, up when traversing through the obstacle course, and down again when dropping off the food item.

7.5 Control Systems

The device houses 3 ultrasonic sensors facing the front, right, and left, as well as an infrared line tracking sensor. The device moves based on the information received from these sensors. During the obstacle course, the device try to maintain a good distance from the side walls based on distance detected by the ultrasonic sensor on the side, increasing the right motor rpm if too far from the left wall or decreasing the rpm if too close, and vice verse for the left motor. The robot will also complete a 90 degree turn in one direction if one ultrasonic sensor on that side cannot detect a wall at all.

After traversing through the obstacle course and climbing up the hill, the infrared sensor will detect the black tape at the top of the hill and trigger the device to lower the scooper, dropping off the food item, and stopping the drive motors. The initial food item pickup is simply set timer for the drive motor to move the forward and the stepper motor to raise the scooper to pick up the food item.

8 Subsystems Design Description

8.1 Structural

8.1.1 Subsystem Description

The structural chassis for the device consisted of 2 plates. The drive system as well as all the sensors are mounted on the bottom plate. To make use of the empty space, some batteries are also placed on the bottom. On the top plate, most electronics are mounted there including the Arduino board, motor driver, bread board, etc. There are also holes cut out on the top plate for wires to pass through without having to route outside of the chassis or risk getting tangled by moving parts. There are four spacers which connect the two plates, hold them firmly together without the top plate shifting.

8.1.2 Design Requirements

The structural chassis must be be able to house all other components as well as minimizing empty spaces to ensure the smallest overall device size. It must have sensible mounting points to secure the components and enough access points to conduct maintenance and repair on any components. It must be able to withstand all impact the device might make with the walls and obstacles during the course with no damage.

8.1.3 Subsystem CAD Models and Engineering Drawings

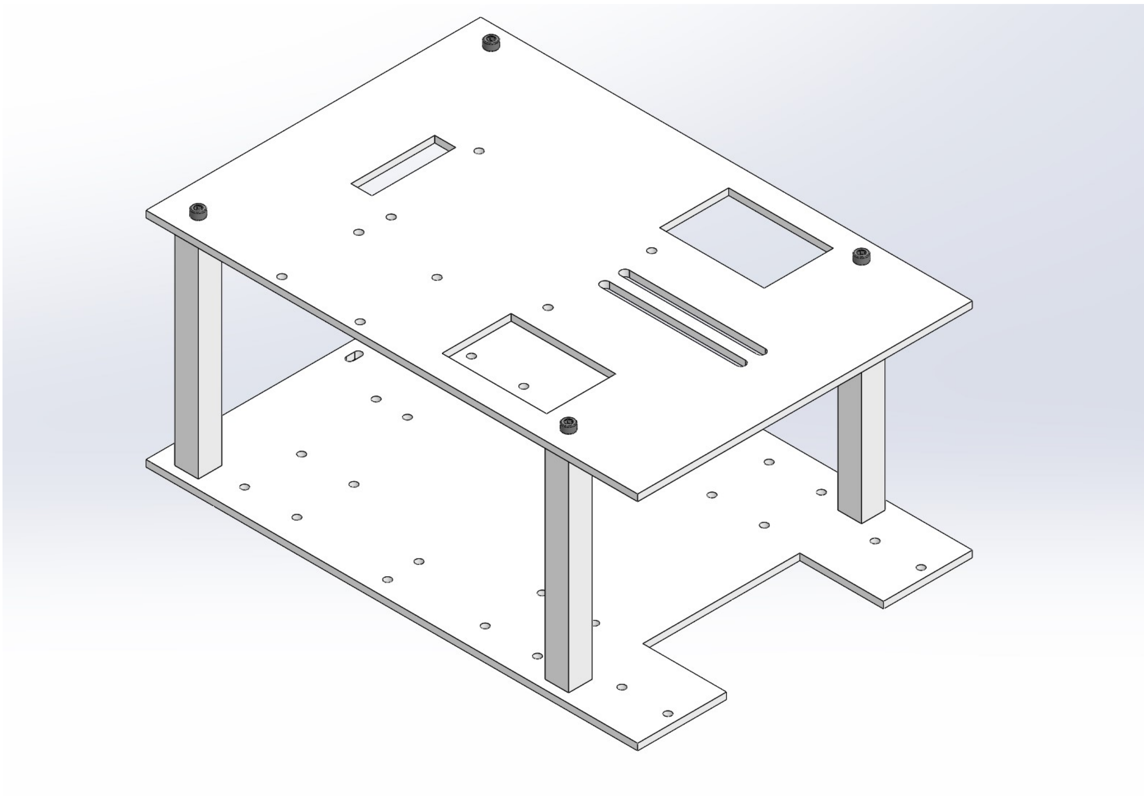


Figure 14: Structural Chassis CAD Model

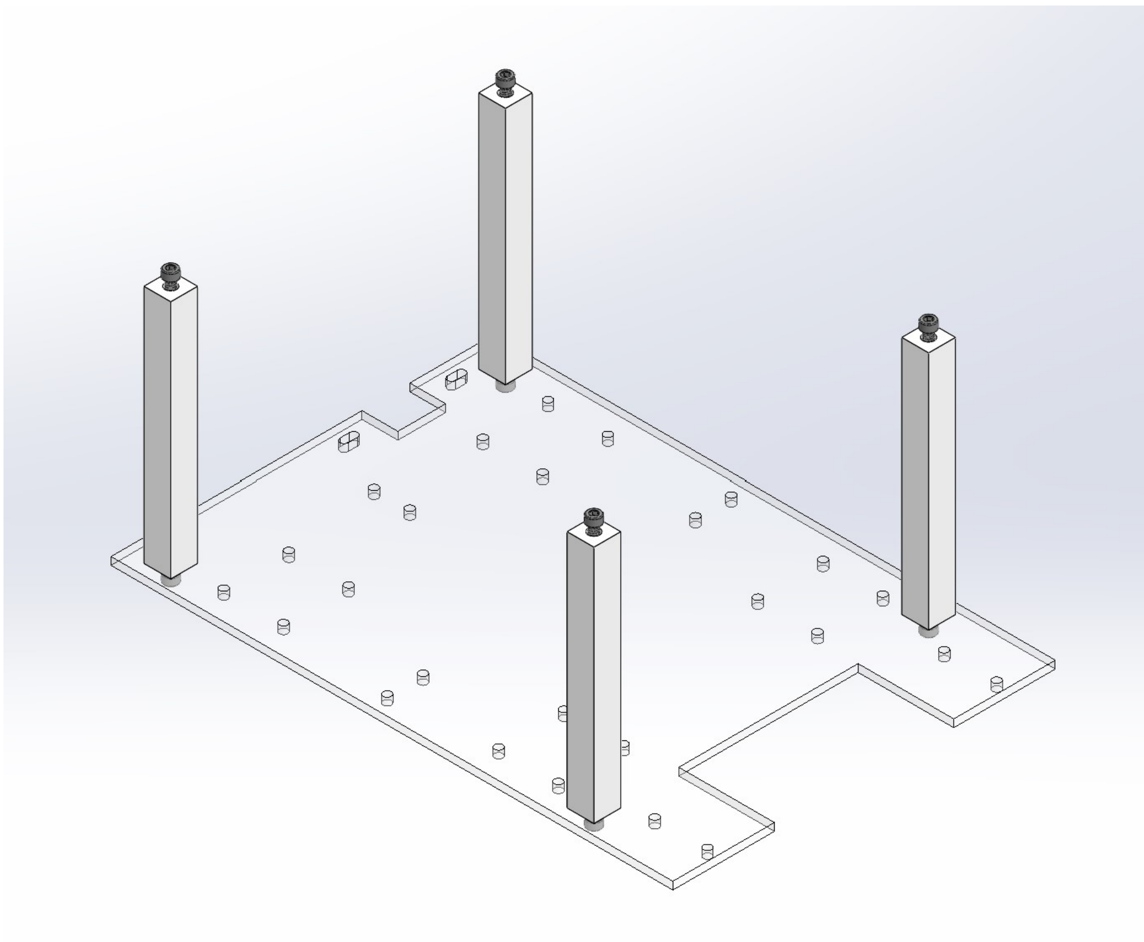


Figure 15: Structural Chassis CAD Model with Top Plate Hidden

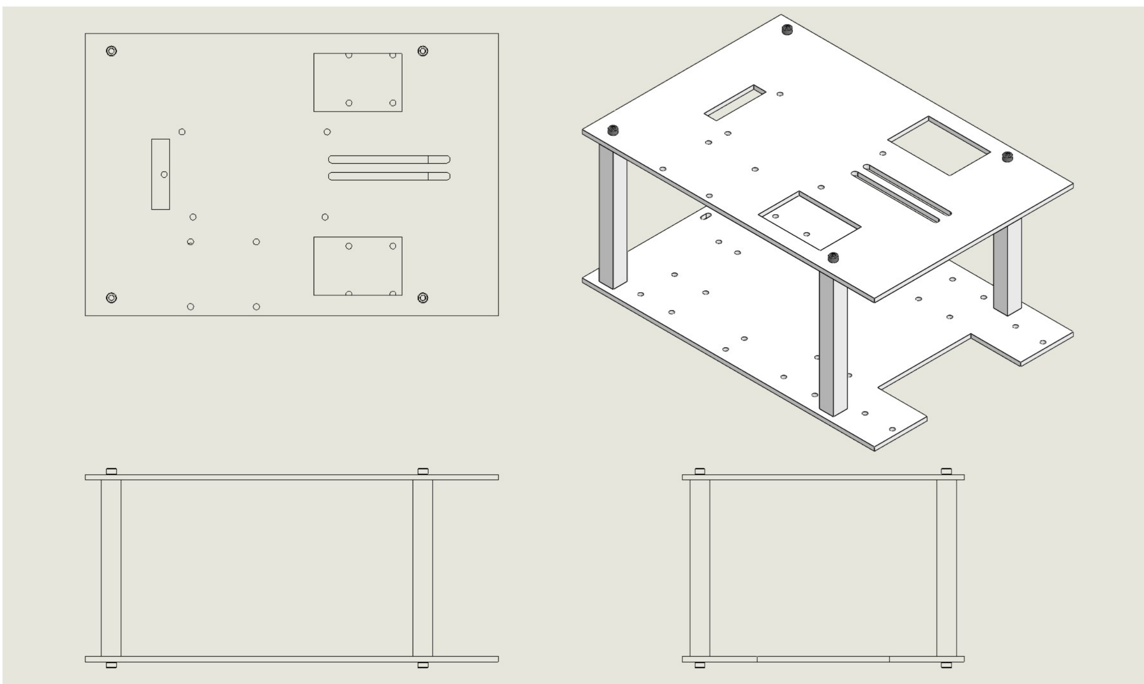


Figure 16: Structural Chassis Drawing

8.2 Drive System

8.2.1 Subsystem Description

The drive system for the device is a RWD with one drive motor on each side. The motors produce enough torque to move the device forward both on the ground and on the hill, and they are also fast enough to satisfy our time requirement for traversing through the obstacle course. Custom hubs and wheels are purchased to match the selected motors. The front wheels have similar mounts with bushing added to minimize friction between the metal rods and the plastic mounts.

No active steering system is added because skid steering was determined to be a both cost-effective and sufficient design that can turn the device consistently.

8.2.2 Design Requirements

The drive system must move the device fast enough to complete the entire obstacle course and arrives at the top of the hill within 2 minutes. It must produce enough torque without stalling to both skid steer and move upwards on the hill. The mounts for the wheels and the motors must be secure after assembly and not loosen while moving. The two motors must not contact each other to prevent possible heating and wiring entanglement issues.

8.2.3 Subsystem CAD Models and Engineering Drawings

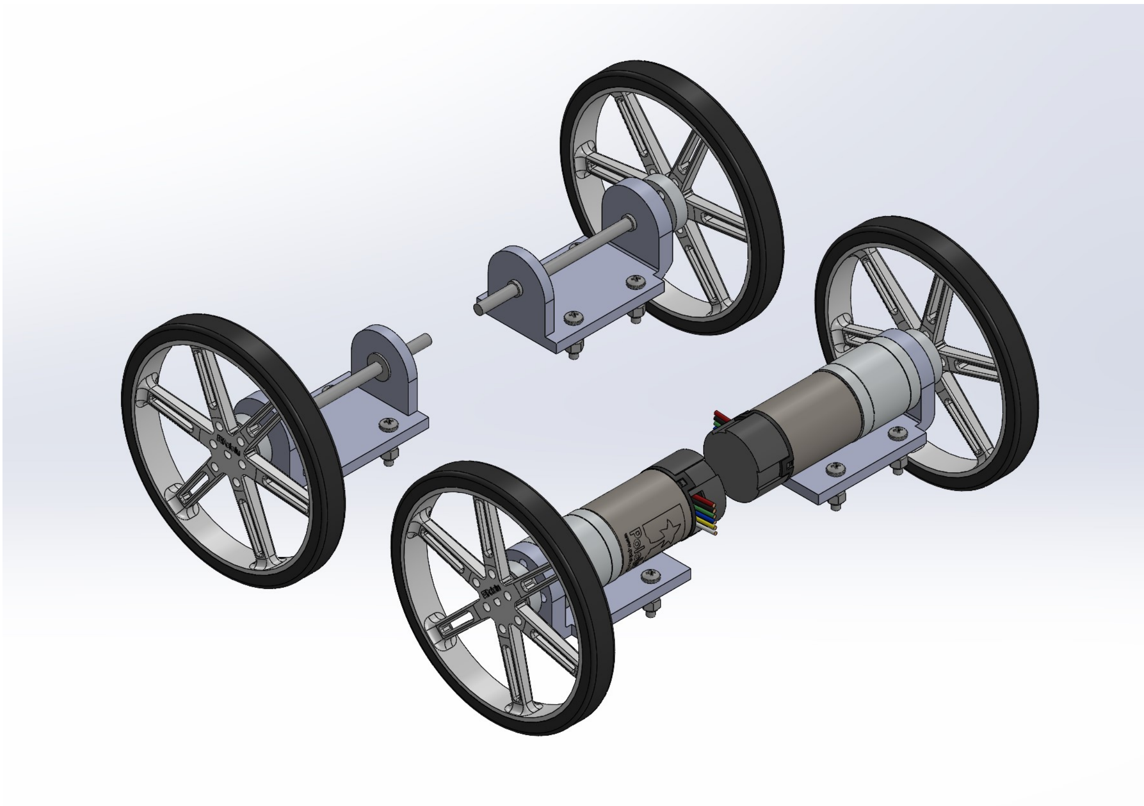


Figure 17: Drive System CAD Model

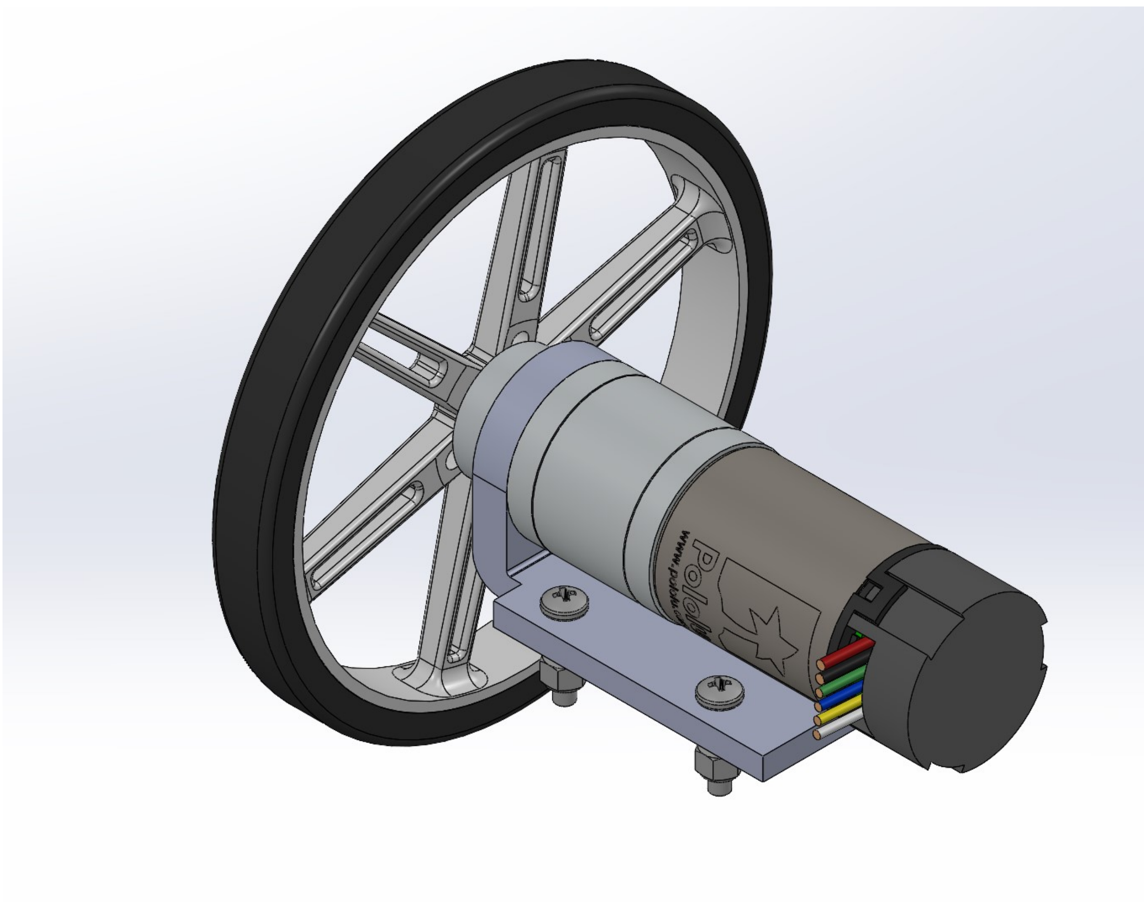


Figure 18: Rear Drive Assembly CAD Model

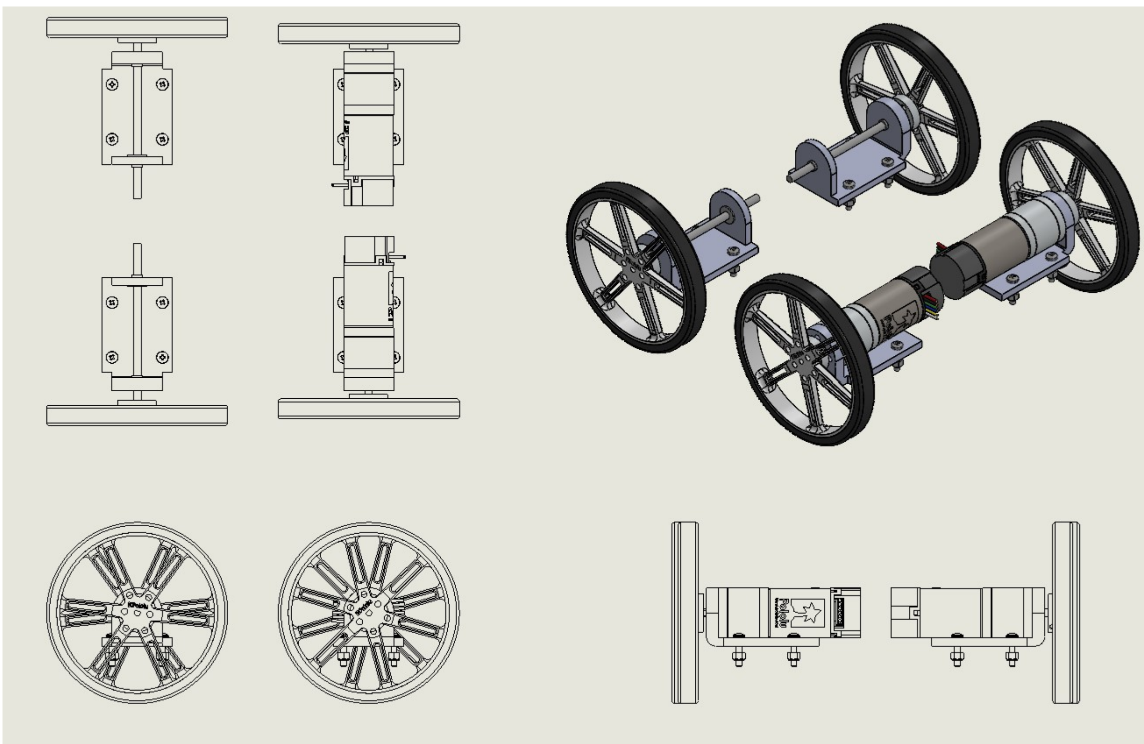


Figure 19: Drive System Drawing

8.3 Retrieval/Delivery Mechanism

8.3.1 Subsystem Description

The food retrieval/delivery mechanism is a scooper plate attached onto a hex bar rotated by a belt and pulley system, which is powered by a stepper motor. The edge of the scooper plate is chambered, when the scooper plate is lowered, allowing it to fit under the food item. Then as the robot drives forward, the food item is pushed against the wall and onto the plate. The stepper then rotates the pulley attached onto the hex bar, which raises the scooper plate. The food item sits on the plate, the rear and side walls prevent it from being accidentally dropped or knocked off during the obstacle course. When the robot reaches the top of the hill, the scooper plate is lowered by the stepper motor allowing the food item to slide down.

8.3.2 Design Requirements

The food pick up/drop off process must take no longer than 30 seconds. The entire food retrieval system must only require one powered actuators to simplify the control and reduce the power requirements for the device. If some parts of the system extend outside the boundary of the chassis, they must be able to retract/move into the chassis so the overall dimension of the device is minimized while traversing the obstacle course. It must be able to securely hold the food item even if the device makes impact against walls or obstacles.

8.3.3 Subsystem CAD Models and Engineering Drawings

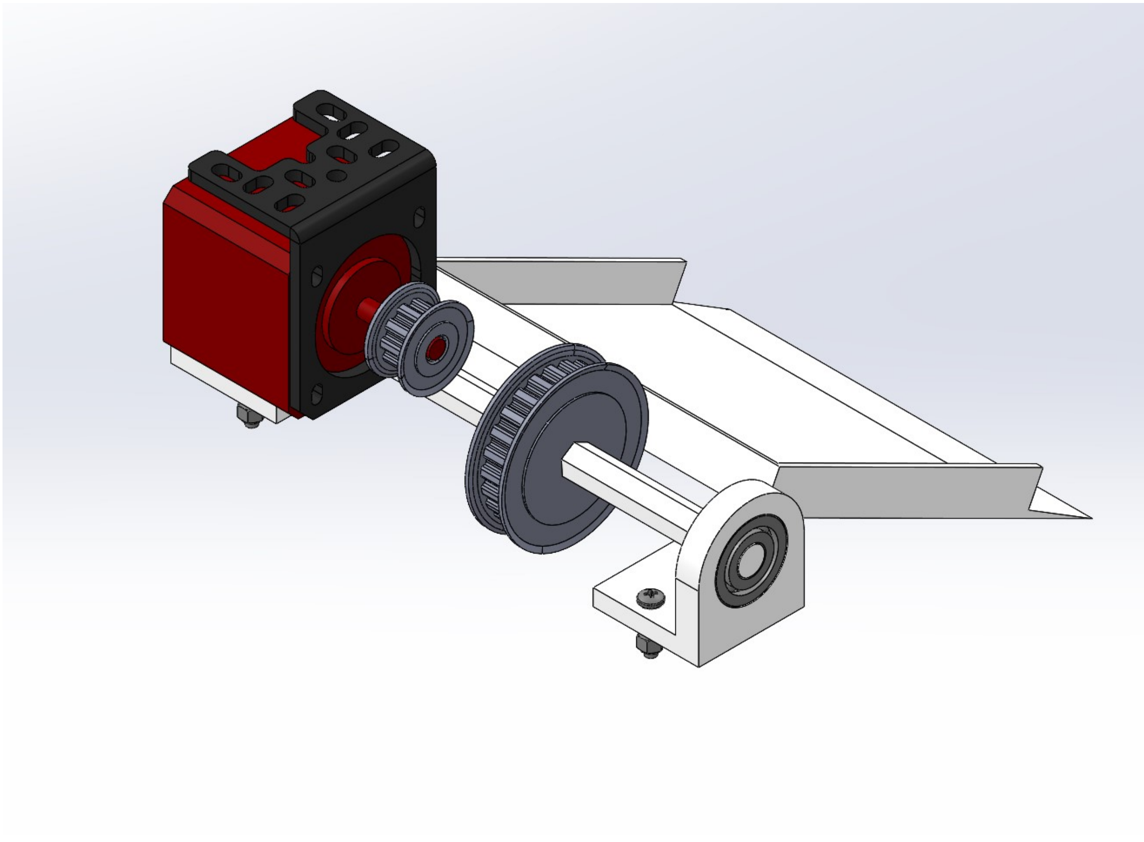


Figure 20: Food Retrieval System CAD Model

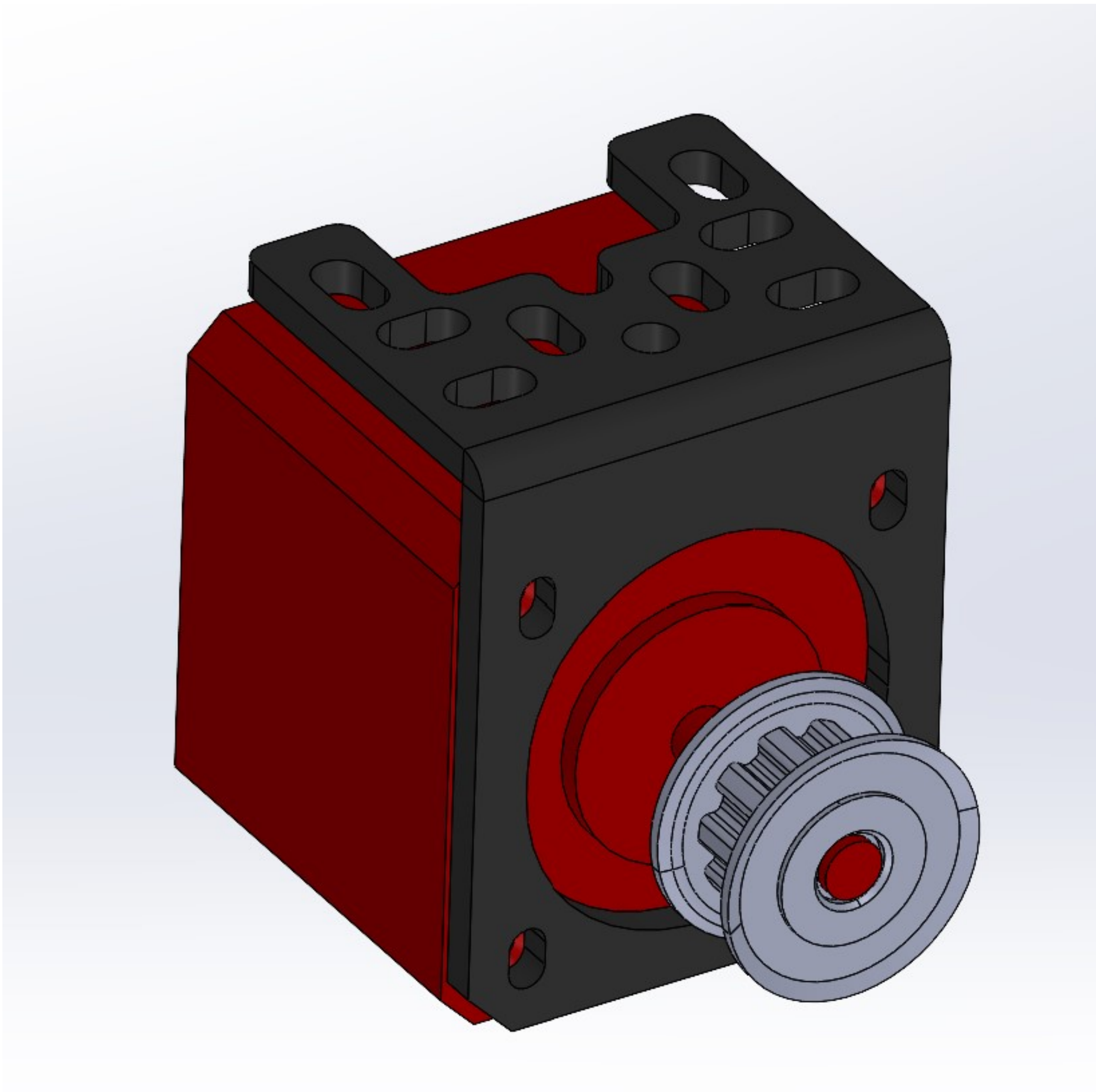


Figure 21: Stepper Motor Assembly CAD Model

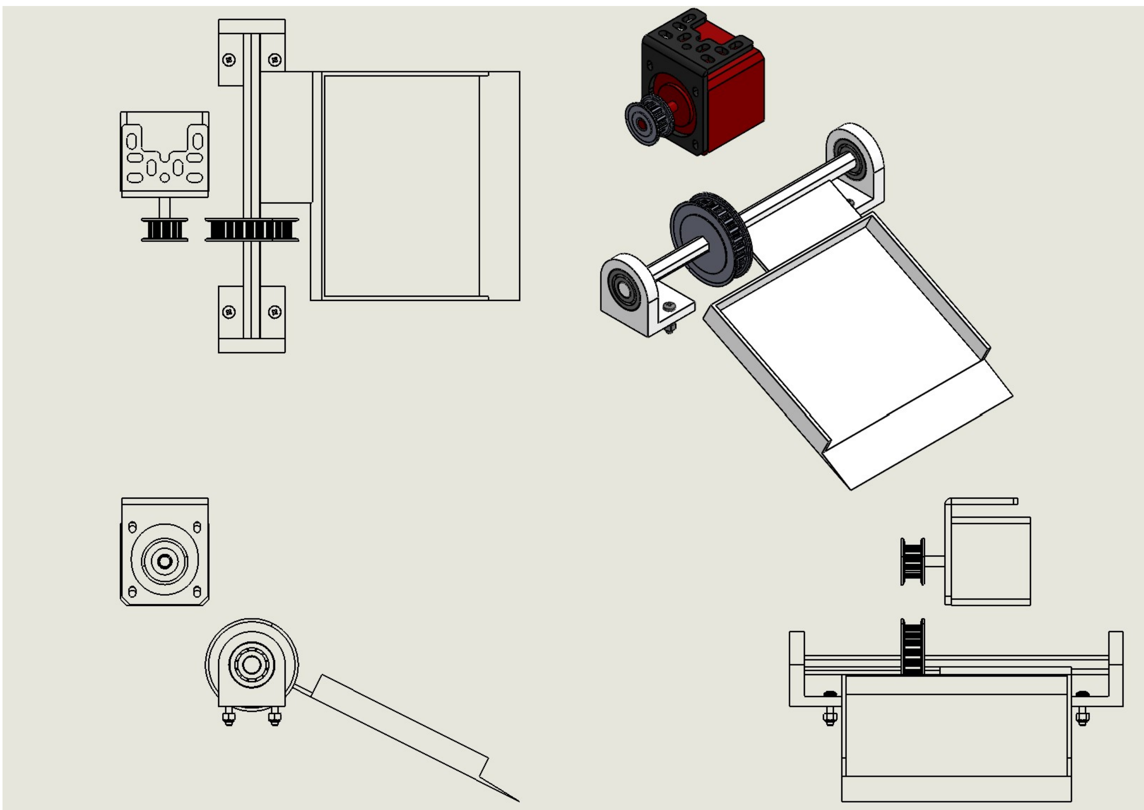


Figure 22: Food Retrieval System Drawing

8.4 Sensors

8.4.1 Subsystem Description

The device utilizes three ultrasonic sensors to navigate the obstacle course. Custom mounts were designed and 3D printed to hold each sensor in place around the device. One sensor is mounted on the front and the other two are on each side of the device. All are mounted on the lower plate to ensure accurate obstacle detection around the course. The sensors are wired through the bread board mounted on top of the device which connects the arduino.

8.4.2 Design Requirements

The sensors must be mounted so that there is no interference from the device. The mounts were designed to hold the sensors extended out ahead of other device components. The sensors were programmed to stop or turn the device to prevent it from colliding with any part of the obstacle course during the run. The sensors have an operating current of 5V DC and an operating current of 15mA. The ranging distance for each sensor is 2cm - 4m.

8.4.3 Subsystem CAD Models and Engineering Drawings

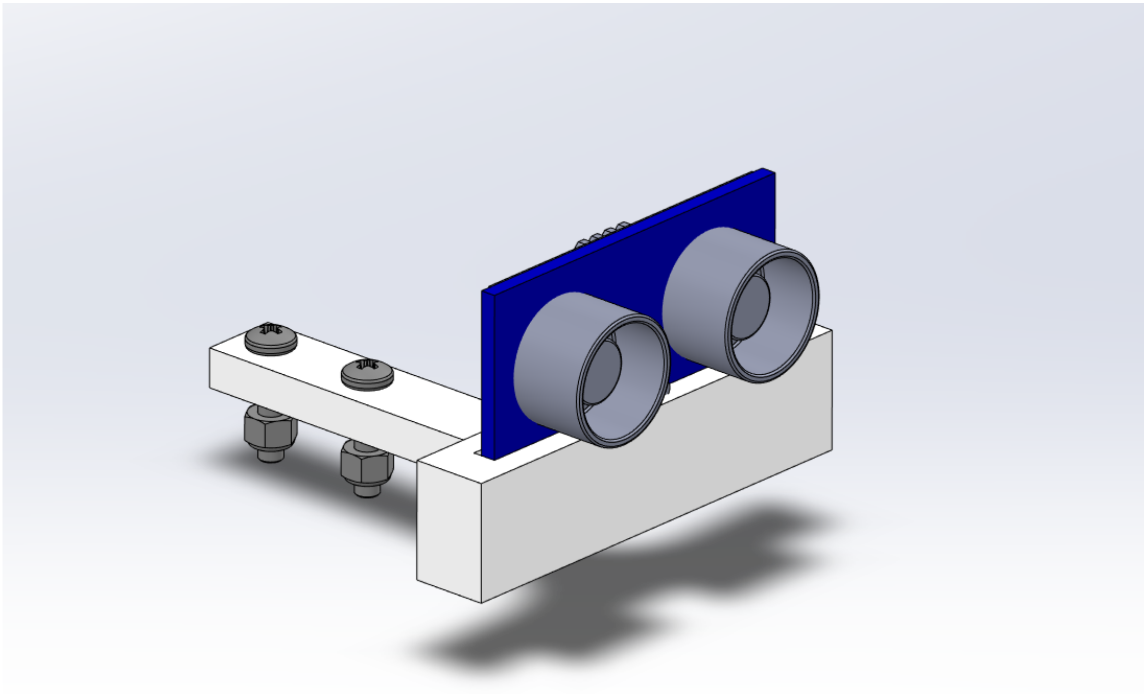


Figure 23: Ultrasonic sensor and mounting bracket CAD model

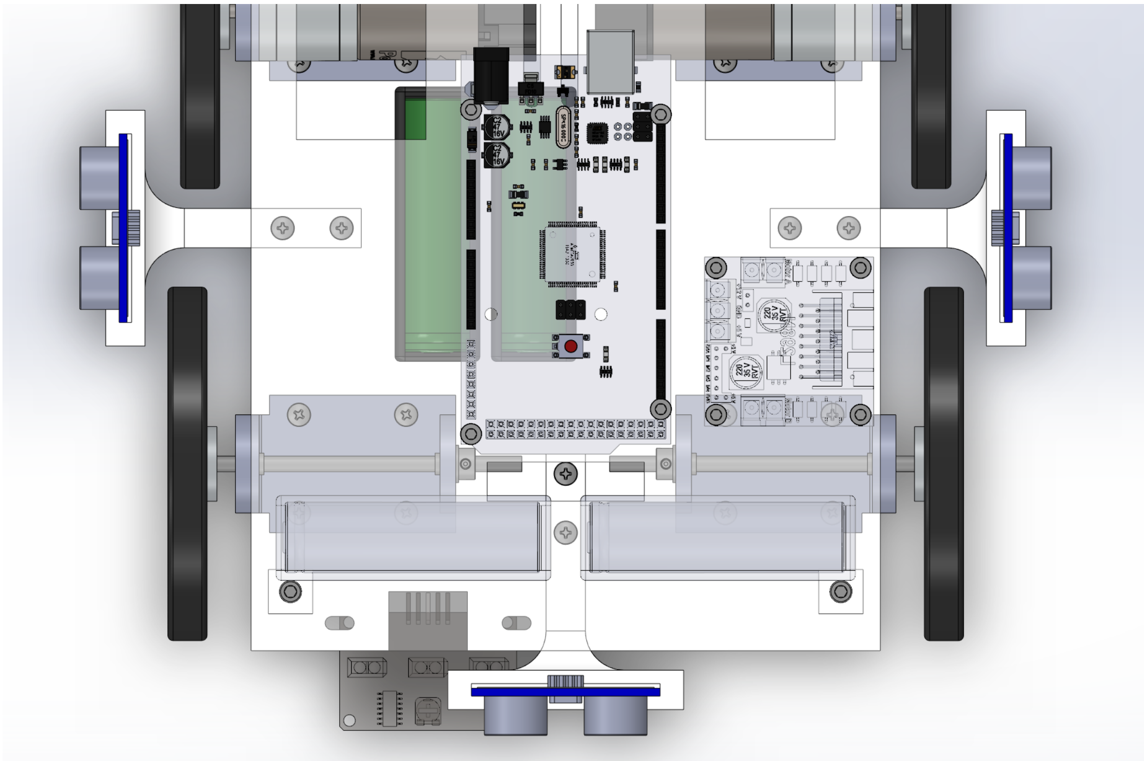


Figure 24: Ultrasonic sensor positions in CAD model: Two are mounted on either side of the device, one is mounted on the front

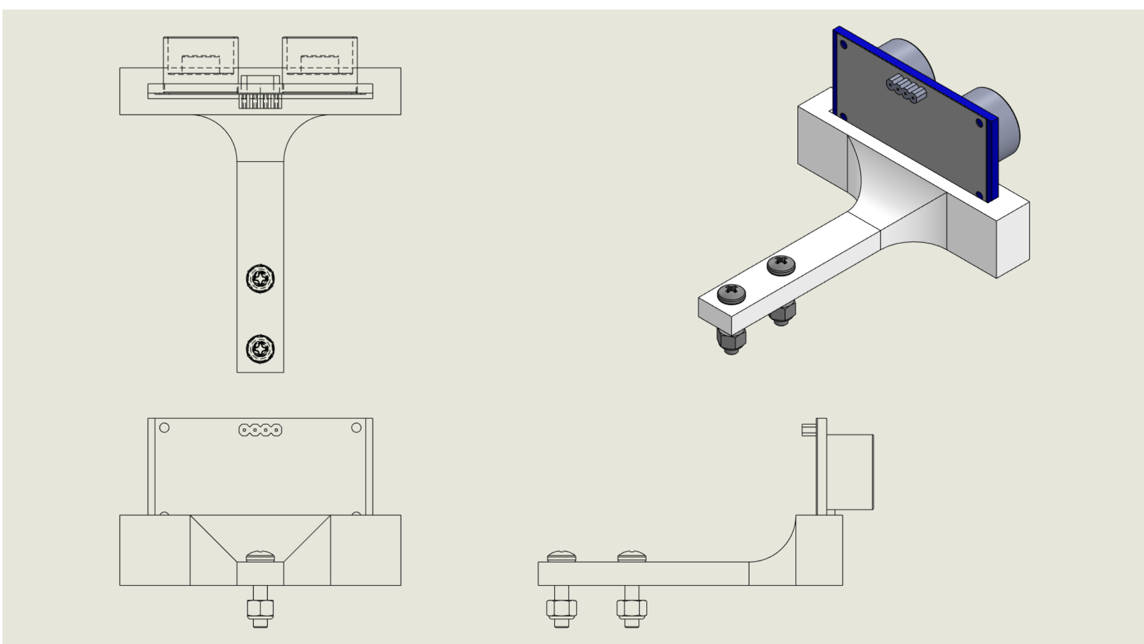


Figure 25: Ultrasonic sensor and mount drawing

8.5 Electronics

8.5.1 Subsystem Description

The main electronics for the device include the Arduino Mega board, a bread board, The l298n motor driver, a line tracking sensor, and four LiPo batteries.

8.5.2 Design Requirements

The Arduino mega board was chosen so that there would be enough pins to control 3 ultrasonic sensors, a line sensor, the two drive motors with encoders, and the stepper motor. A small breadboard was chosen to wire these components to the Arduino. The l298n motor driver was selected to support both drive motors. The line sensor was chosen to detect the black space at the top of the obstacle course and stop the device and lower the tuna can. Based on the required voltage to run all components simultaneously, four LiPo batteries were fastened on to the device. Three of the batteries run together to supply power to the drive motors, line sensor, and ultrasonic sensors. The fourth battery is dedicated to supplying power only to the stepper motor.

8.5.3 Subsystem CAD Models and Engineering Drawings

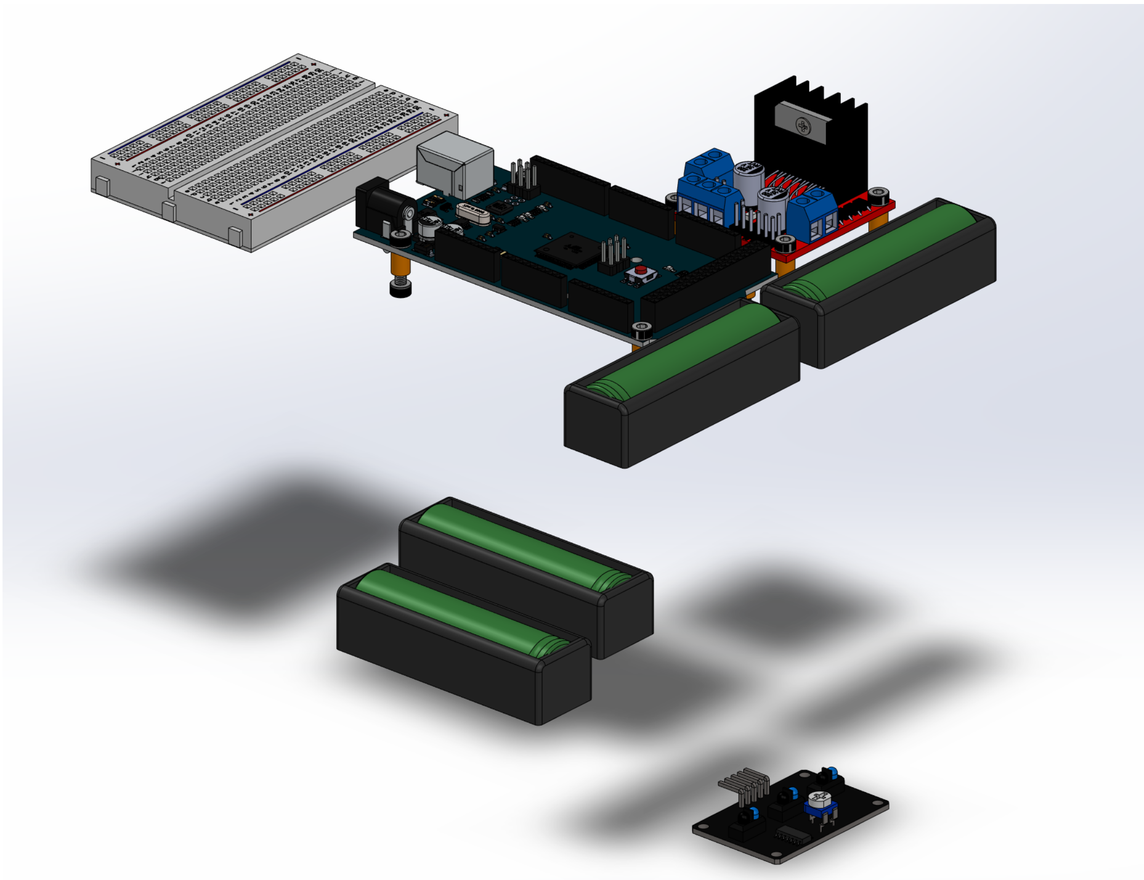


Figure 26: Isolated Cad Model of main electronics

9 Design Analysis

9.1 Analysis and Calculations

9.1.1 Drive System Power Requirements

Path Segment	F_i (N)	F_w (N)	F_f (N)	F_{rol} (N)	F_{prop} (N)	P_{prop} (W)
1	0.510	0.000	4.136	0.044	4.690	1.595
2	0.038	0.000	4.136	0.044	4.218	1.075
3	0.510	0.000	4.136	0.044	4.690	1.595
4	0.035	0.000	4.136	0.044	4.214	1.075
5	0.050	0.000	4.136	0.044	4.230	1.079
6	0.199	0.000	4.136	0.044	4.379	1.117
7	0.199	0.000	4.136	0.044	4.379	1.117
8	0.102	0.000	4.136	0.044	4.281	1.092
9	0.061	0.000	4.136	0.044	4.241	1.082
10	0.138	0.000	4.136	0.044	4.318	1.101
11	0.043	4.302	3.955	0.042	8.343	2.127
12	0.199	0.000	4.136	0.044	4.379	1.117

Figure 27: Required propulsion force and propulsion power for each path segment illustrated in Figure 28

The required propulsion power for each segment was calculated using the required propulsion force. Results are summarized in Figure 27. The maximum required propulsion power is 2.127 W, for Segment 11. As expected, this is the path segment in which the vehicle is driving up the hill.

9.1.2 Move Profile

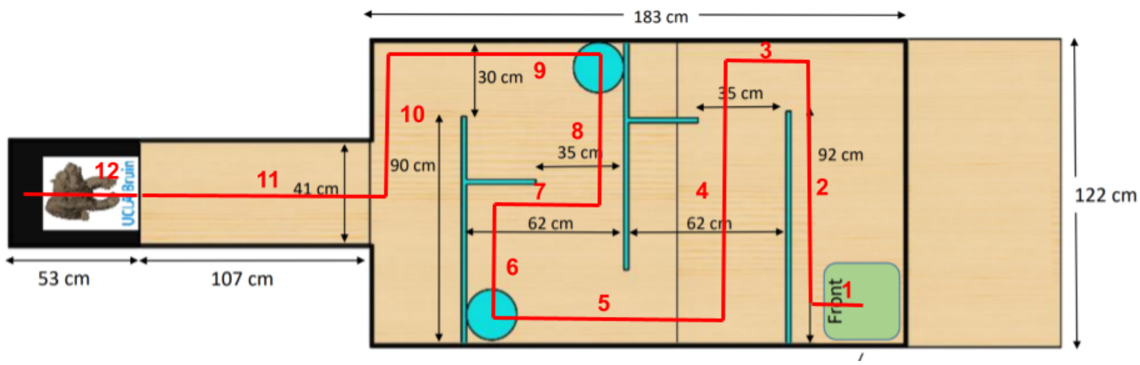


Figure 28: Vehicle path through the Mount Bruin obstacle course, made up of 12 path segments

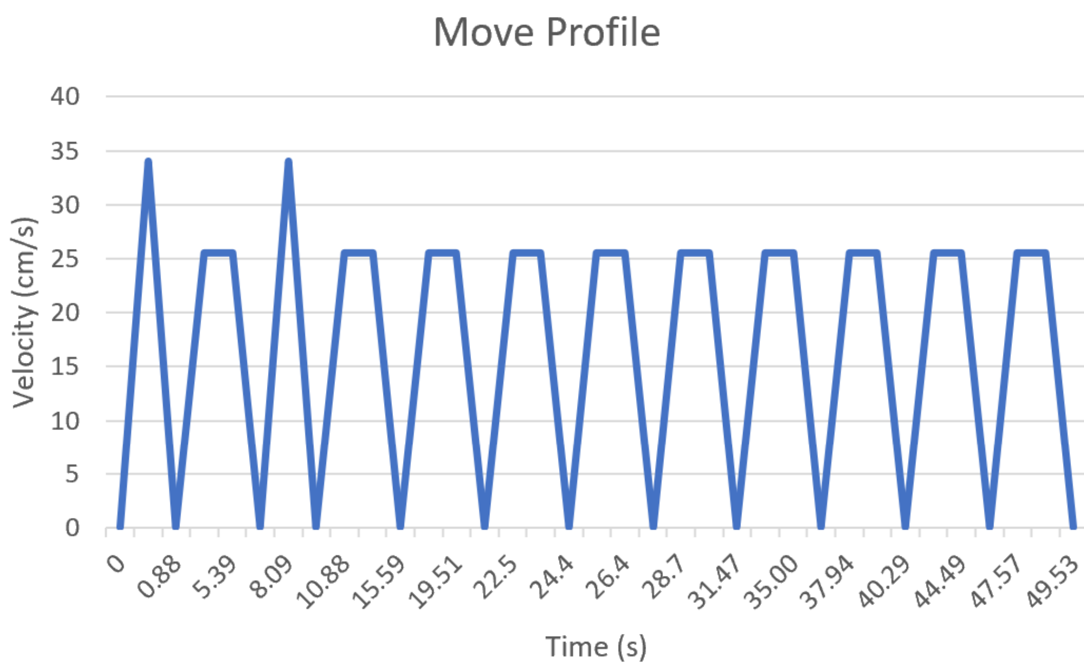


Figure 29: Move Profile Plot

9.1.3 Motor Torque Requirements

Path Segment	P_{prop} (W)	T_{prop} (N-m)
1	1.595	0.301
2	1.075	0.271
3	1.595	0.301
4	1.075	0.271
5	1.079	0.272
6	1.117	0.281
7	1.117	0.281
8	1.092	0.275
9	1.082	0.273
10	1.101	0.278
11	2.127	0.536
12	1.117	0.281

Figure 30: Required propulsion torque calculated from propulsion power for each path segment illustrated in Figure 28

The maximum required propulsion torque for the vehicle is 0.536 N-m (Segment 11). This is the minimum amount of torque that the drive motors must supply in order for the vehicle to drive up the hill. Our drive motors are rated for 3.6 kg-cm, or 0.353 N-m, each, for a total rated torque of 0.706 N-m. This rated torque allows for a factor of safety of 1.32.

9.1.4 Food Retrieval Calculations

In order to lift the tuna can with the scooper, the device will first need to slide the scooper plate under the tuna by pinning it against one of the walls of the Mount Bruin obstacle course in the starting area. The tuna can should then slide into place onto the slanted scooper surface as the device drives toward it. In order to calculate the required torque of the stepper motor we assume a tuna can mass of 160g, and a scooper ramp length of 15cm.

$$\begin{aligned} F_{min} &= ma = (0.16kg) * (9.8m/s^2) = 1.568N \\ T_{min} &= Fr = (1.568N) * (0.15m) = 0.2352Nm \end{aligned} \tag{1}$$

10 Control System Design

10.1 Drive Motor Selection and Motor Specifications

10.1.1 Motor Selection

The motor selection process was dependent on four criterion: the power requirements calculated in section 9.1.3, the stall current of the motor, whether the motor had attached encoders, and the availability of motors from Pololu.com. With respect to the motor torque requirements, the calculated maximum amount of motor torque is 0.526 N-m. Additionally, the stall current should be less than 2 A to accommodate for the power requirements of the LN298 motor driver. When perusing through Pololu's selection of DC motors, there are four options: (1) Micro metal gearmotors, (2) 20D metal gearmotors, (3) 25D metal gearmotors, and (4) 37D metal gearmotors. The micro metal gearmotors were not an option, as they did not provide enough torque and did not come with attached encoders. The 20D motors had a stall current of 1.6 A and 2.9 A. While the 1.6 A stall current is acceptable, these motors also do not come with attached encoders and thus were ruled out. Lastly, the 37D gearmotors proved to be too large for our robot, and their stall current was much too high (3 A and 5.5 A). Thus, the remaining options were in the the 25D gearmotor category.

Within the 25D gearmotor category, some motors required 5.0 A in stall current, which was much to large. Other motors ran on 6V, which did not provide enough power. Within the remaining set of motors, the motor with the highest gear-ratio and torque was selected to add a factor of safety of 1.32 to the required calculated torque. The selected motor is a Pololu 227:1 metal gearmotor. It draws medium power (12 V) and has a 48 CPR encoder.

Figure 31: 227:1 metal, medium power gearmotor from Pololu.com

10.1.2 Motor Description

This Pololu motor is a medium power DC motor that operates at its best at 12 Volts. However, it is still operational at 6 V. The diameter of the motor is roughly 25 mm, with a shaft extending out. The properties of the motor are summarized in the table below.

Table 3: Drive Motor Specifications

Size	25mm D x 71 mm L
Gear Ratio	226.76:1
Stall Torque (12 V)	2.35 N-m
Stall Current (12 V)	1.8 A
No-load speed (12V)	35 rpm
No-load current	0.10 A
Maximum efficiency (12V)	32 percent
Rated speed	30 rpm
Rated torque	0.35 N-m
Rated current	0.28 A

Additionally, the motor is run with a L298N motor driver. The driver's specifications are listed below.

Table 4: L298N Motor Driver Specifications

Size	3.4 cm x 4.3 cm x 2.7 cm
Input Voltage	3.2 V - 40 V
Power Supply	5 V - 35 V
Peak Current	2 A
Maximum Power Consumption	20 W

10.1.3 Circuit Diagram

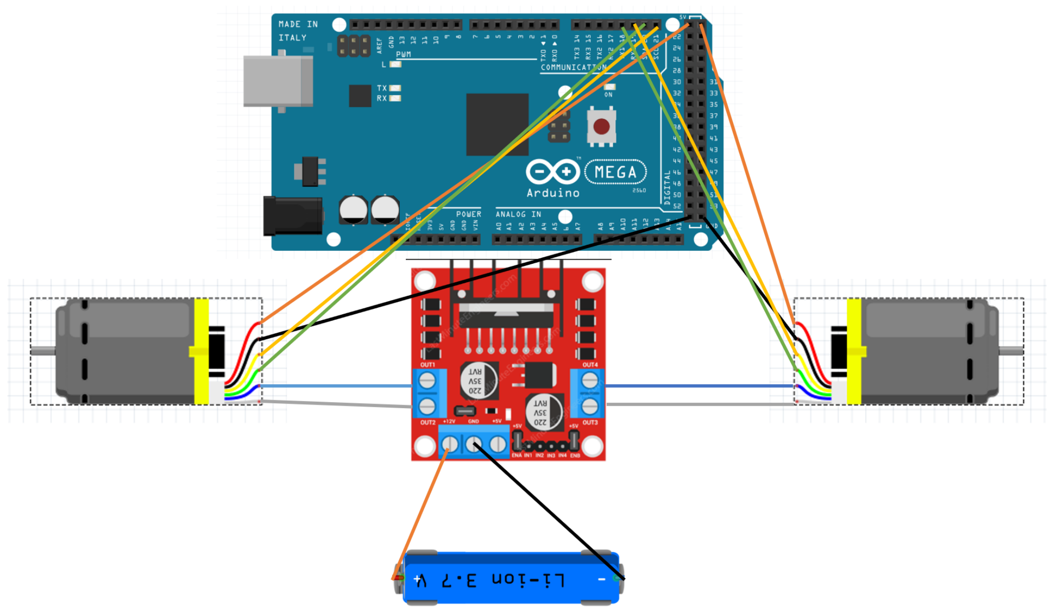


Figure 32: Circuit Diagram for Drive Motors with Encoders

10.2 Food Retrieval/Delivery Mechanism

10.2.1 Motor Selection

A stepper motor was selected to perform the food retrieval and delivery due to its high holding torque. The NEMA-17 from Pololu Robotics and Electronics was selected to hold the scooping plate in place with a tuna can.

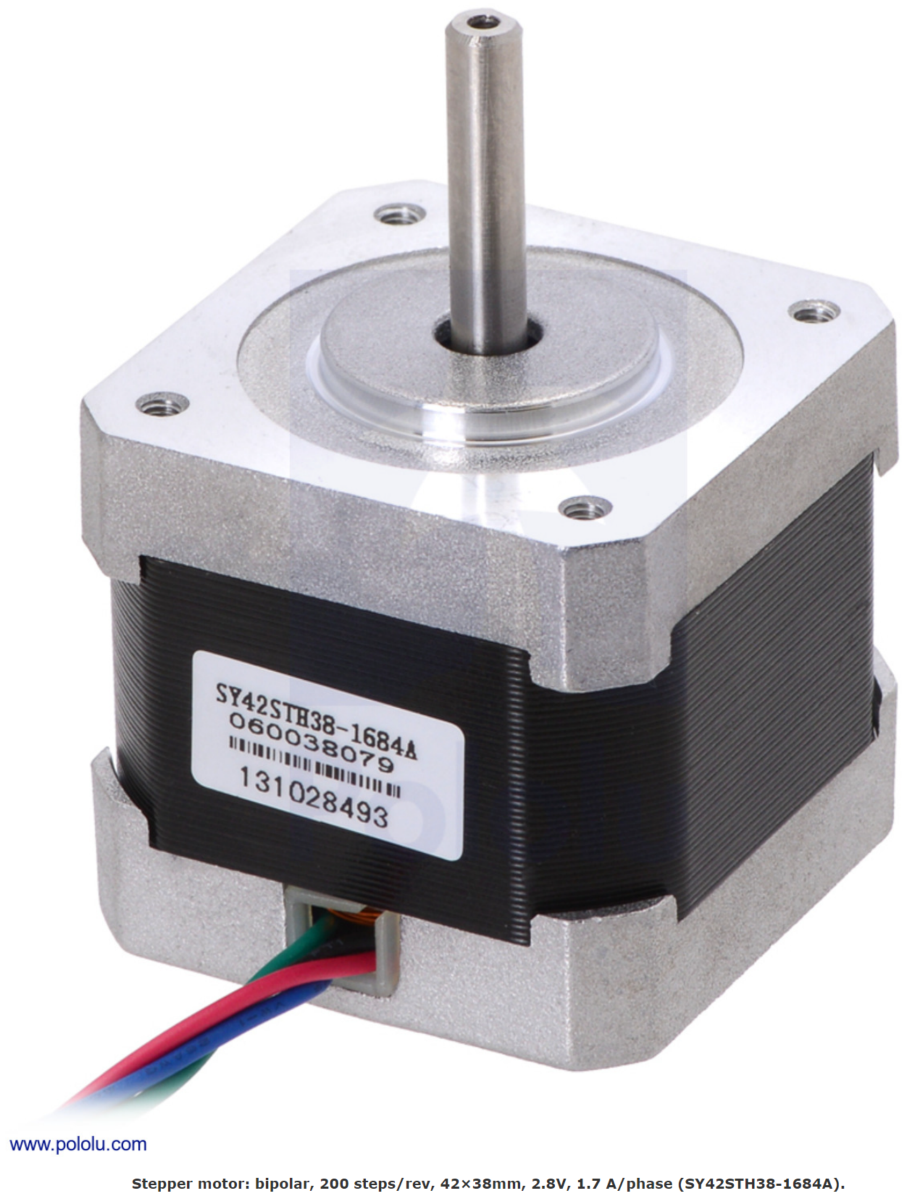


Figure 33: NEMA-17 Stepper Motor from Pololu.com

10.2.2 Motor Description

The NEMA-17 is a 2.8V bipolar stepper motor that draws 1.7A per phase. It allows for a holding torque of 3.7kg-cm.

Table 5: Stepper Motor Specifications

Size	42.3mm square x 38mm
NEMA Size	17
Weight	285g
Shaft Diameter	5mm ”D”
Current Rating	1680 mA
Voltage Rating	2.8V
Holding Torque	3.7kg-cm
Steps Per Revolution	200
Resistance	1.65 Ohm
Inductance Per Phase	3.2mH
Number of Leads	4
Lead Length	30cm

The stepper motor was paired with the DVR8834 Low-Voltage Stepper Motor Driver Carrier from Pololu, shown below.

Table 6: DRV8834 Specifications

Size	15mm x 20mm
Weight	1.6g
Minimum Operating Voltage	2.5V
Maximum Operating Voltage	10.8V
Continuous Current Per Phase	1.5A
Maximum Current Per Phase	2A
Minimum Logic Voltage	2.5V
Microstep resolutions	full, 1/2, 1/4, 1/16, and 1/32

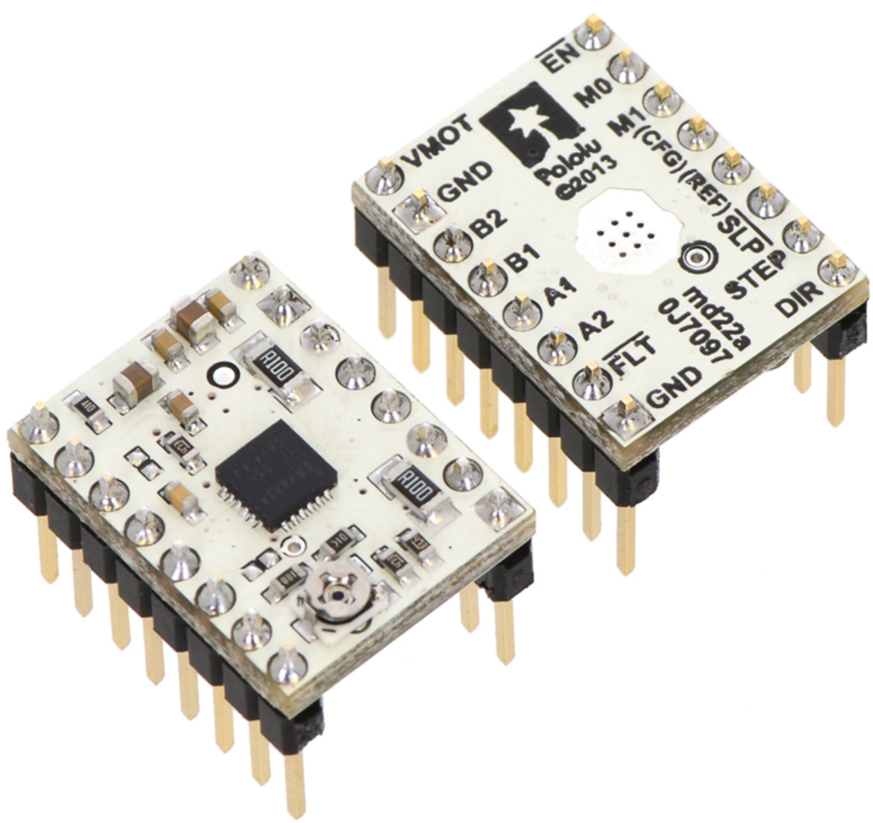


Figure 34: DRV8834 low-voltage stepper motor driver carriers with included header pins soldered

10.2.3 Circuit Diagram

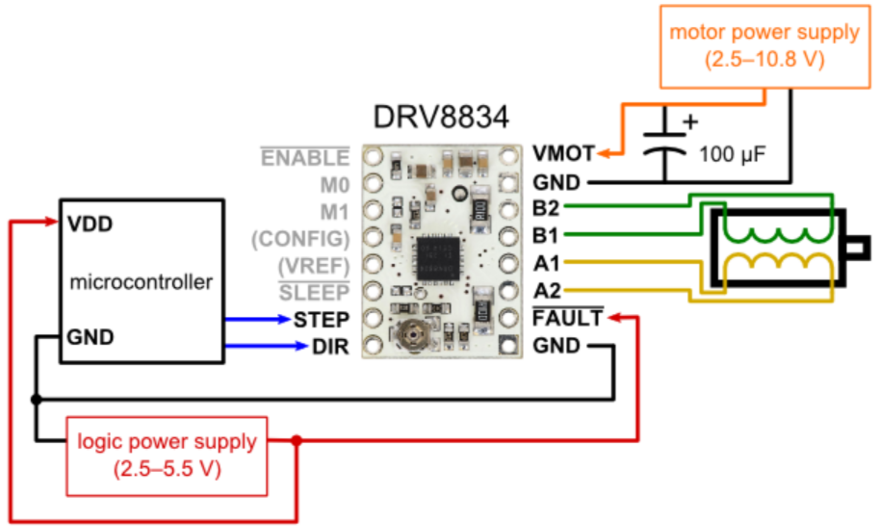


Figure 35: Wiring Diagram for connecting a microcontroller to a DRV8834 stepper motor driver carrier

10.3 Sensors and Theory of Operation

10.3.1 Sensors

Our vehicle utilizes three Ultrasonic Sensors and one Line Tracking Sensor.

The Ultrasonic Sensors work by emitting high frequency sound waves from an emitting terminal ('trig'), and sensing the sound waves after they bounce against a wall or obstacle and return to the receiving terminal ('echo'). Since the speed of sound through air is a known constant, the amount of time the sound waves take to return to the sensor after being emitted is easily and directly translated into the distance between the sensor and an obstacle. We connected one Ultrasonic Sensor to the front of the vehicle, and one on both the right and left sides between the wheels. This allows for the vehicle to sense its distance from the walls of the course from the front, right, and left sides, and use that information to adjust course accordingly.

The Line Tracking Sensor is an infrared sensor that can distinguish between light and dark surfaces. It does this by emitting infrared light, and measuring how much of the emitted light is reflected back onto it – if most or all of the light is reflected back, the surface is light, and if barely any or no light is reflected back, then the surface is dark. Our Line Tracking Sensor is calibrated to return a signal of 0 if detecting light material and a signal of 400 if detecting dark material. The Line Tracking Sensor is used to detect the black tape at the end of the course and trigger the food release and drive termination portion of the code.

10.3.2 Circuit Diagram

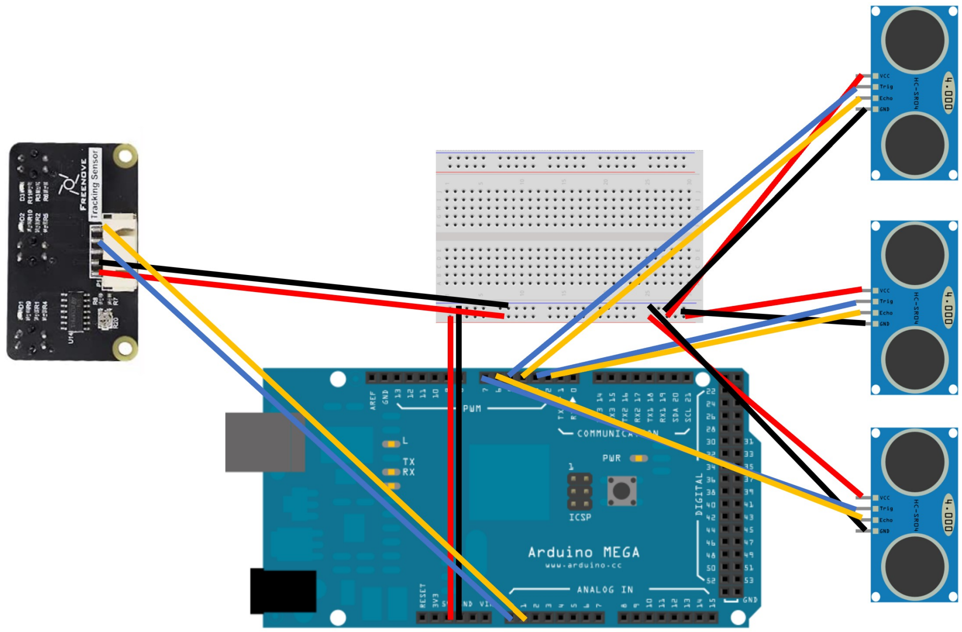


Figure 36: Circuit Diagram for All Sensors

10.4 State Diagram

10.4.1 Stateflow Charts

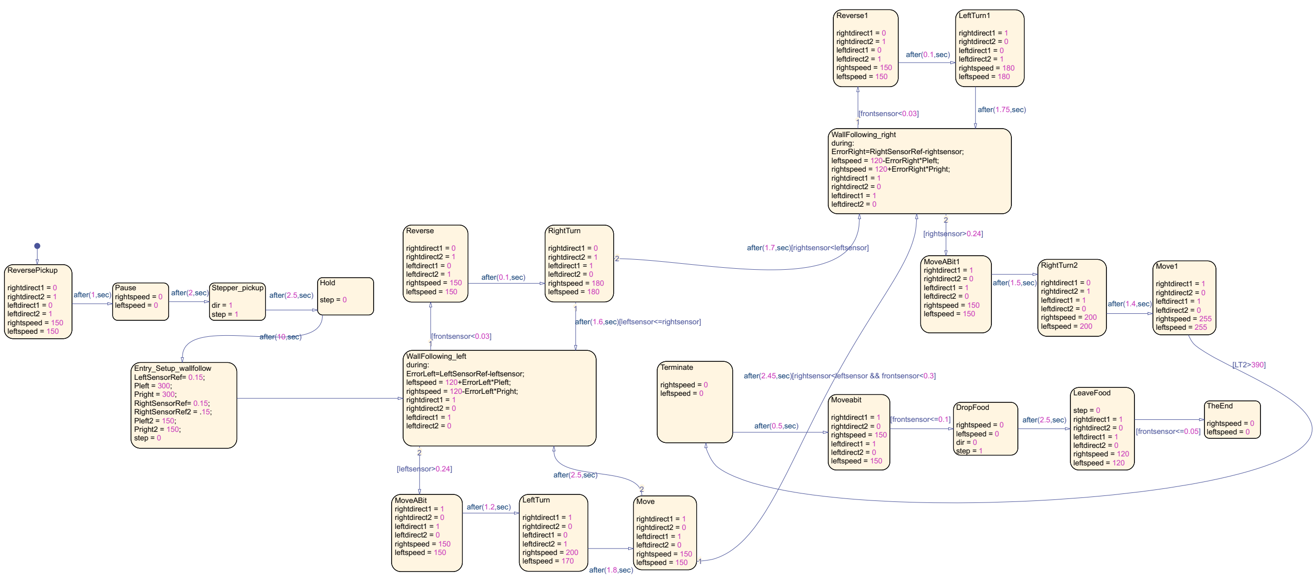


Figure 37: Overall Stateflow Chart

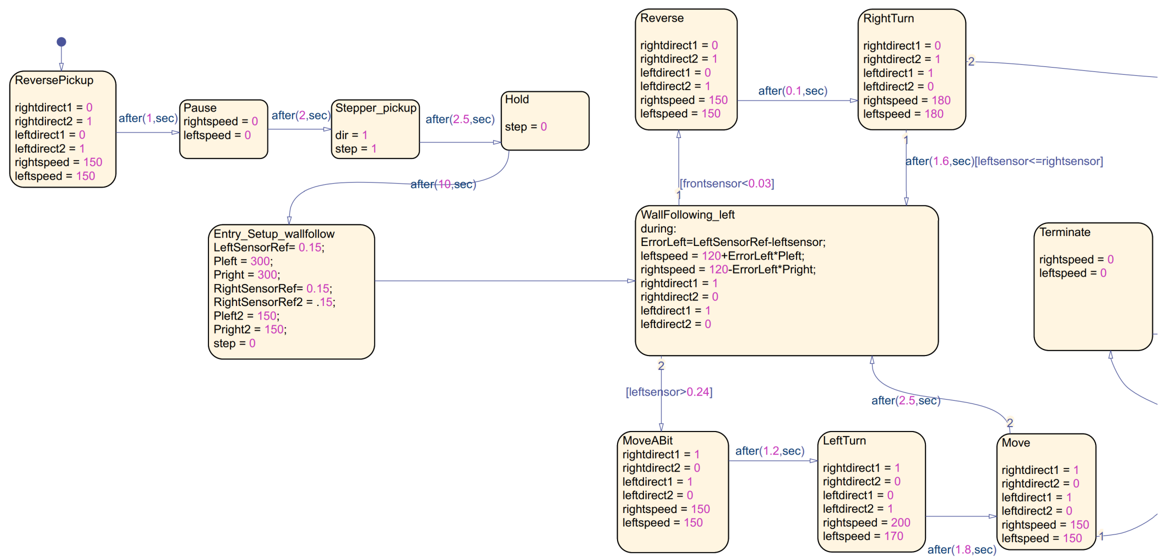


Figure 38: Left side of Stateflow Chart, zoomed in for increased legibility

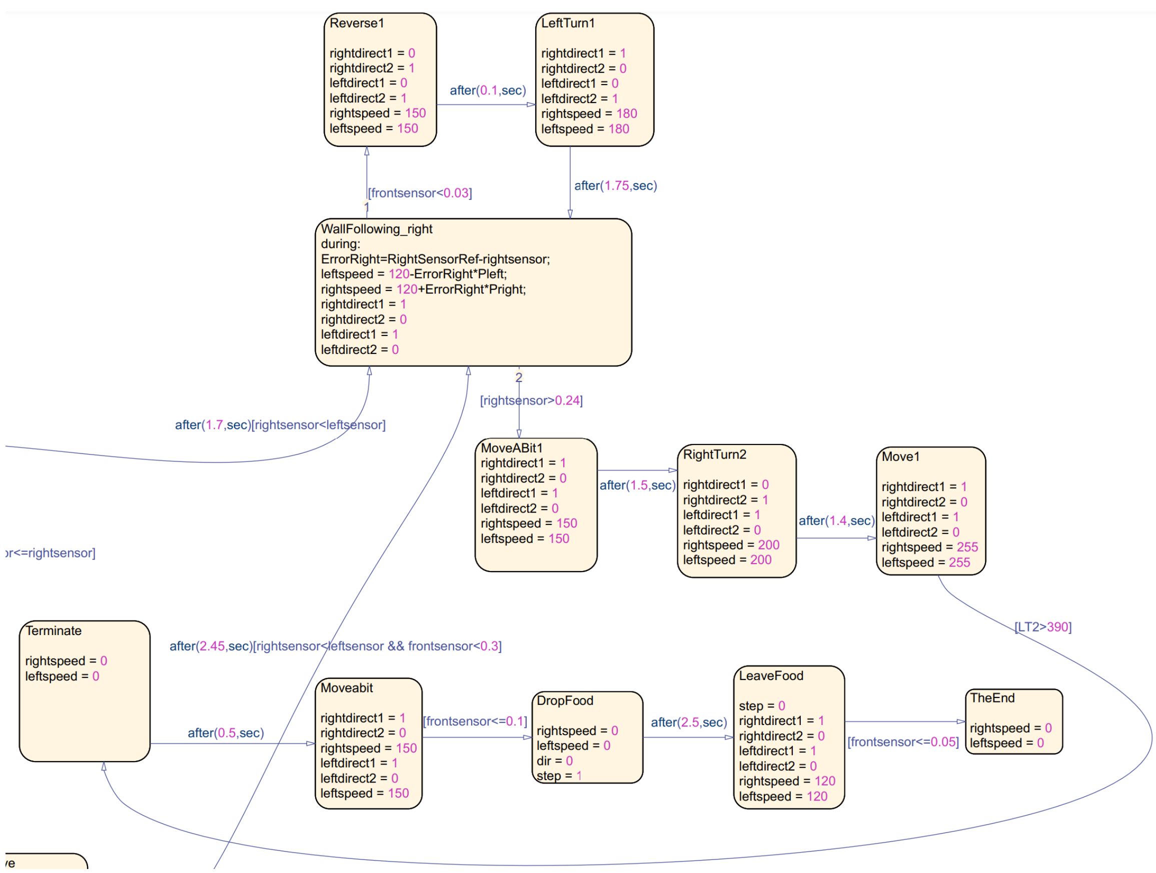


Figure 39: Right side of Stateflow Chart, zoomed in for increased legibility

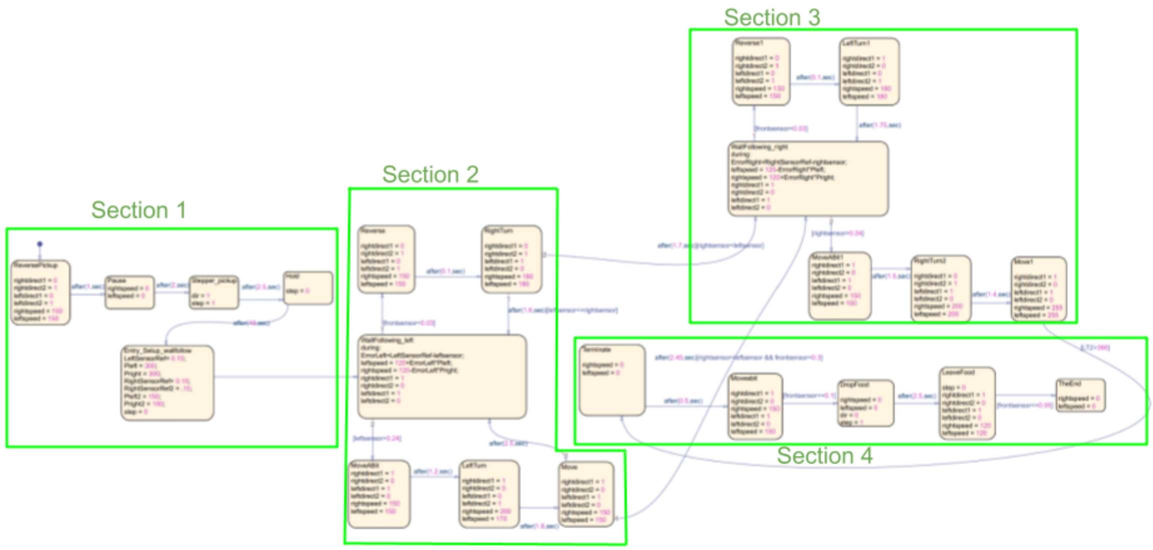


Figure 40: Overall Stateflow Chart with main sections labeled

The Stateflow has four main sections, highlighted in Figure 40, the logic of which is as follows:

Section 1: Food Pickup and Initialization. This section of code consists of the first 5 blocks, the progression of which is hard-coded. First, the vehicle reverses so that the scooper mechanism at the back of the vehicle is driven under the tuna can. After a brief pause, the stepper motor is activated to lift the tuna can up, and then paused so as to hold the tuna can up. After a 10 second pause to allow for the vehicle to be lifted and moved into the Mount Bruin track, references and gains are set to initialize the setup for the ensuing wall following code.

Section 2: Left Wall Follow. After the parameters are initialized, the vehicle proceeds into left wall following code with a base speed of 120. There are 2 ways for this block to be exited: Either the front ultrasonic sensor will detect a wall very close to it, causing the upper path to be taken (vehicle reverses very slightly, then turns right approximately 90 degrees before the vehicle returns to left wall following), or the left ultrasonic sensor will not detect any nearby walls, causing the bottom path to be taken (the vehicle will continue to move slightly to allow the rear of the vehicle to clear any obstacles, then the vehicle will turn left approximately 90 degrees and continue forwards slightly before returning once again to wall following).

Section 3: Right Wall Follow. There are two conditions that could cause the vehicle to progress from left wall following to right wall following: in the right turn condition of Section

2, if 'rightsensor' outputs a value less than 'leftsensor,' meaning that the vehicle is closer to a wall on the right side than on the left, it will enter the right wall following code instead of returning to left wall following. Additionally, in the left turn path of Section 2, if the vehicle is closer to a wall on the right side than the left, and is also close to a wall on the front, then the code will similarly progress to right wall following. Once in right wall following, the vehicle will continue to follow the right wall of the track until either 'frontsensor' detects imminent collision with a wall, in which case the vehicle will reverse slightly and turn left, or 'rightsensor' will not detect any nearby wall, in which case the vehicle will continue to move slightly for the rear of the vehicle to clear any obstacles, then turn right approximately 90 degrees, before continuing forwards in the 'Move1' block. This 'Move1' block is the code that the vehicle is running while driving up the hill portion of Mount Bruin.

Section 4: Food Dropoff and Termination. When the line tracking sensor senses dark material ('LT2 > 390'), the code progresses into its final section. After a brief pause to signal that the line tracking sensor properly recognized the dark material, the vehicle continue to move forward until close to the back wall of the track. The stepper motor is then activated, dropping the scooper so as to release the tuna can, and the vehicle then drives forward very slightly so as to ensure the tuna can is fully off of the scooper. At this point, the code is at an end: the tuna can has been delivered to the top of Mount Bruin.

10.4.2 Simulink Code

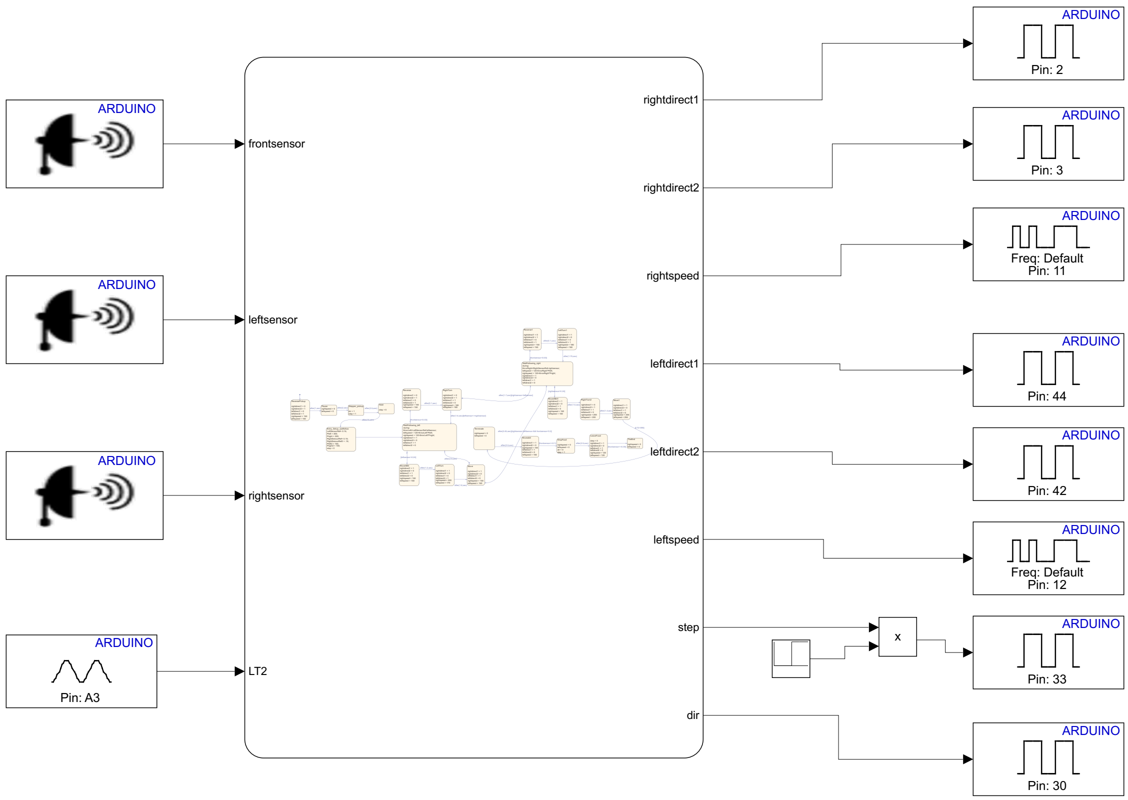


Figure 41: Overall Simulink Code

As shown in Figure 41, the stateflow chart has four inputs and 8 outputs. The inputs are readings from the vehicle's three ultrasonic sensors ('frontsensor,' 'leftsensor,' and 'rightsensor'), and from the line tracking sensor ('LT2'). These inputs from the devices sensors are used within the stateflow as described in Section 10.4.1. The functionality of these sensors are described in Section 10.3.1.

The 8 outputs are used to control the vehicle's drive and food delivery subsystems. The first three outputs control the vehicle's right wheel: 'rightdirect1' and 'rightdirect2' are digital outputs which combined control the direction of the right wheel's spin (values are binary – they can be set to either 0 or 1), and 'rightspeed' is a PWM block which controls the right wheel's speed (values range from 0-255). The next 3 outputs are analogous to the first 3, but control the vehicle's left wheel. The final 2 outputs, 'step' and 'dir,' control the stepper motor used for food retrieval. They are both digital outputs which are assigned values of 1 or 0. 'step' controls activation of the stepper motor (a value of 1 allows the repeating sequence stair block to activate, causing the stepper motor to engage, while a value of 0 multiplies with and negates the repeating sequence stair block, resulting in no stepper motion), while 'dir' controls the stepper motor's direction: a value of 1 causes the food delivery system to rise, and a value of 0 caused it to descend, when 'step' is set to 1.

11 Product Fabrication

11.1 Chassis

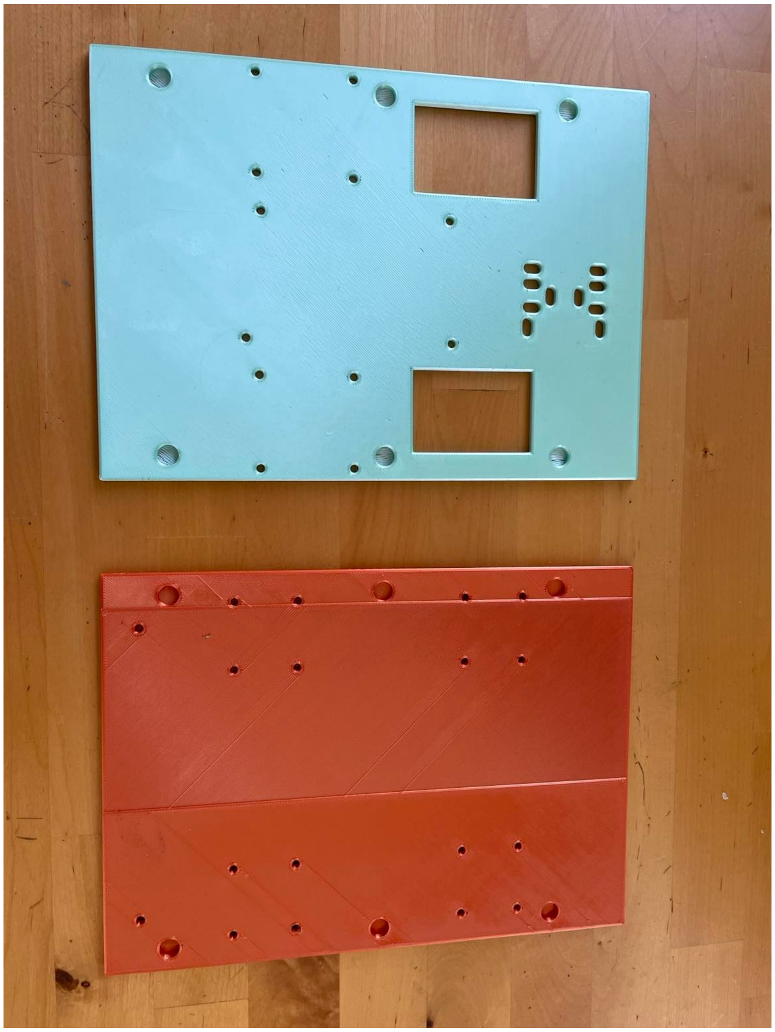


Figure 42: First top and bottom plates printed for the robot.

The original chassis design is drastically different from the current chassis design. The main difference is how the two plates are attached with standoffs. The standoffs were originally solid rods that sit in the indentations in the top and bottom plates. As can be seen in the image above, there are six large holes for the standoffs, but they are not thru holes. This allows the standoffs to be press-fit into the holes, thereby holding the chassis together.

However, these standoffs repeatedly broke when a small amount of pressure was applied due to their thickness and the way they were printed, as they were originally printed vertically. This meant that the circular layers were stacking on top of each other vertically, and when any stress was applied horizontally, the standoff would easily snap.

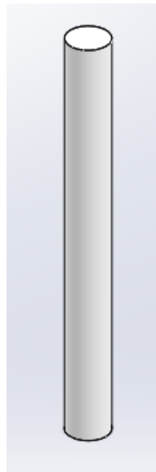


Figure 43: Initial prototype of the press-fit standoffs.

Thus, it became clear that (1) the standoff was not thick enough and (2) the standoff needed to be printed horizontally. In order to accomodate for issue 1, the thickness of the standoffs was increased. To accomodate for issue 2, the outer shape of the standoff was changed to a square to minimize any supports needed when printing horizontally, flat on the printer bed. Additionally, threaded 6/32" heat-set inserts were soldered in to the top and bottom of the standoffs to allow a screw to thread in.

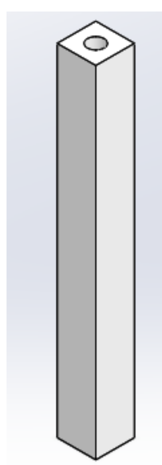


Figure 44: Final CAD model of heat-set insert standoffs.

The image below depicts the standoffs once they were printed. The heat set inserts are soldered in and appear as a yellow color. Because the standoffs had threaded inserts, the top and bottom plate could now be laser-cut out of Acrylic sheets in the Boelter Makerspace.

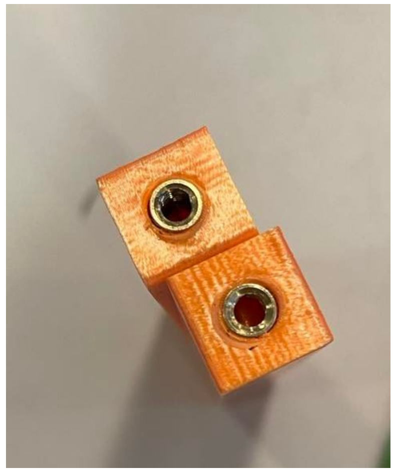


Figure 45: New square standoffs with brass heat set inserts.

The bottom plate is shown below. There are many holes, with each set designated for mounting different parts. There are four sets of four M3 holes on the plate, and these are used for mounting the front and rear wheel assemblies. There are also three sets of holes for mounting the ultrasonic sensor holder, and one set for mounting the line tracking sensor in the front of the robot. Additionally, there are also holes for mounting the scooping assembly, as well as holes for the threaded standoffs to hold the top and bottom plates together.

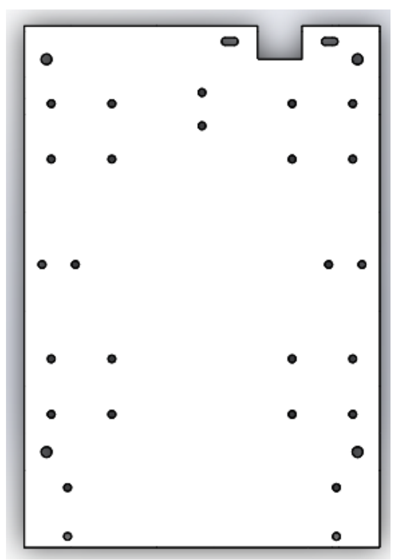


Figure 46: New square standoffs with brass heat set inserts.

The top plate is depicted below as well, and there a few iterations of the top plate. The first is depicted in green at the top of Figure 42. There are holes for mounting the standoffs for the Arduino Mega board and the LN298 motor driver. There are multiple slots for mounting the stepper motor, and two large holes for wiring. The final version of the top plate is shown below. The main difference is the added slot at the top to allow for better wiring routes. Additionally, the many smaller slots that originally were for mounting the stepper motor were combined into two large, narrow slots to allow for simpler mounting. The stepper motor could be pushed along the slots to adjust for tension in the belt.

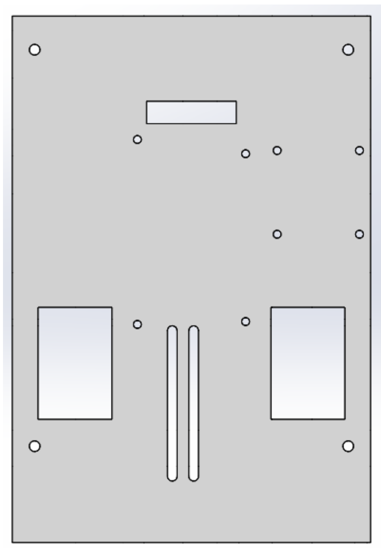


Figure 47: Final CAD model of top plate.

Both the top and bottom plate were laser-cut from 0.125” acrylic from the Makerspace. The use of acrylic is important, as the initial 3D printed plates in Figure 42 began to bend due to the weight of the robot. There was less deflection in the acrylic plates.

11.2 Drive System

The drive system consists of two front wheel assemblies and two rear wheel assemblies. As explained in the section above, there are mounting holes in the bottom plate for the mounts to attach to. An image of the first prototype of the drive system is shown below. The only part of this subsystem that was manufactured at UCLA are the motor and axle

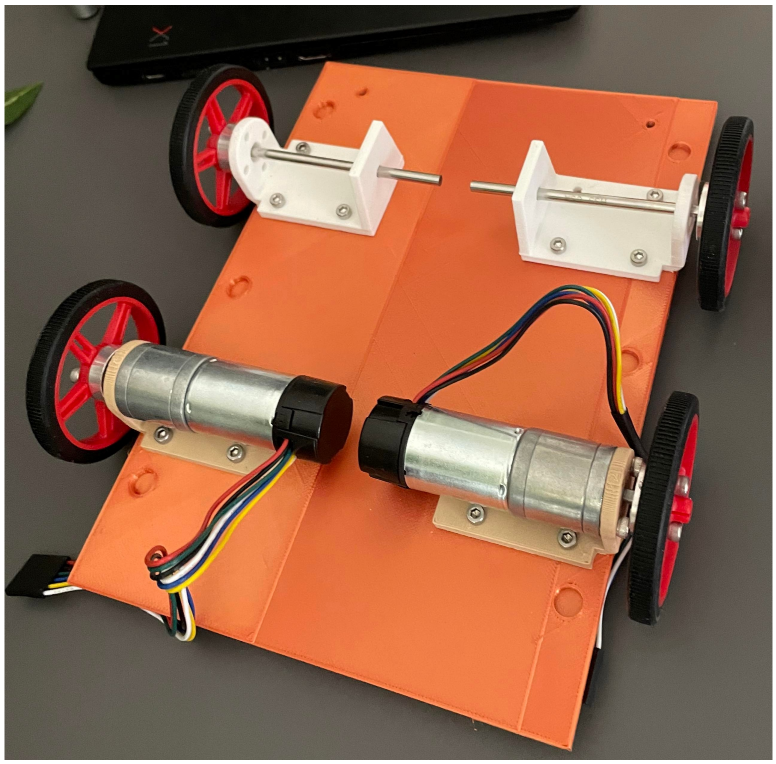


Figure 48: First time attaching the drive system to the bottom plate.

mounts. However, there were still a few issues throughout fabrication.

The first issue surrounded the durability of the rear wheel motor mounts. The mounts were printed at the Boelter Makerspace with 50 percent infill and a layer height of 0.30 inches. However, two mounts broke twice along the blue line. There was a clean crack in the mount, most likely due to the number of holes in the area and the relatively large layer height. When the layer height was decreased to 0.15 in, the mounts functioned much better and did not break.

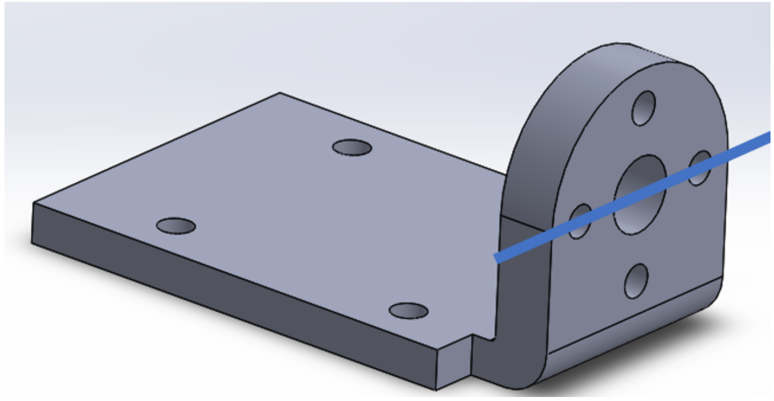


Figure 49: A CAD model of the motor mounts.

The second issue with fabricating the drive system surrounded the front wheel subassembly. As shown in Figure 50, there is an axle that feeds through the mount to move the wheel. There are two sleeve bushings along the axle to ensure that it rotates smoothly through the mount (items 2.10). However, one of the bushings was lost during assembly. This caused the wheel to wobble up and down, causing the drive system to be relatively unstable. Whenever the robot turned, it would turn a different number of degrees due to the lost bushing and the variability in its movement. Once the lost bushing was found and inserted, the drive system moved much more reliably and predictably.

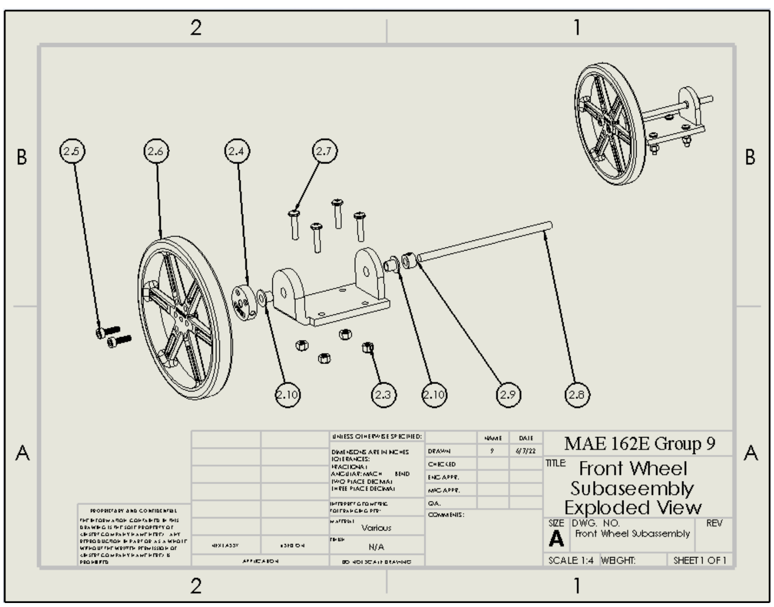


Figure 50: An exploded view of the front wheel subassembly.

11.3 Food Retrieval/Delivery Mechanism

The majority of the components of the food retrieval system were 3D printed. This includes the scooper plate with hex bar, the pulleys, and the mounts for the bearings. The bearings, stepper motor, stepper motor mounting bracket, and the timing belt were all ordered online. The stepper motor was designed to be bolted into and hang from the top plate. Long slots were used so that the distance between the pulleys could be adjusted according to the timing belt. The small pulley with 10 teeth has a ”D” shaft profile while the larger pulley has a hexagon profile. The 3D printed pulleys were printed as not to slide on the shafts. The mounting brackets are set in the bottom plate with two M3 bolts each.

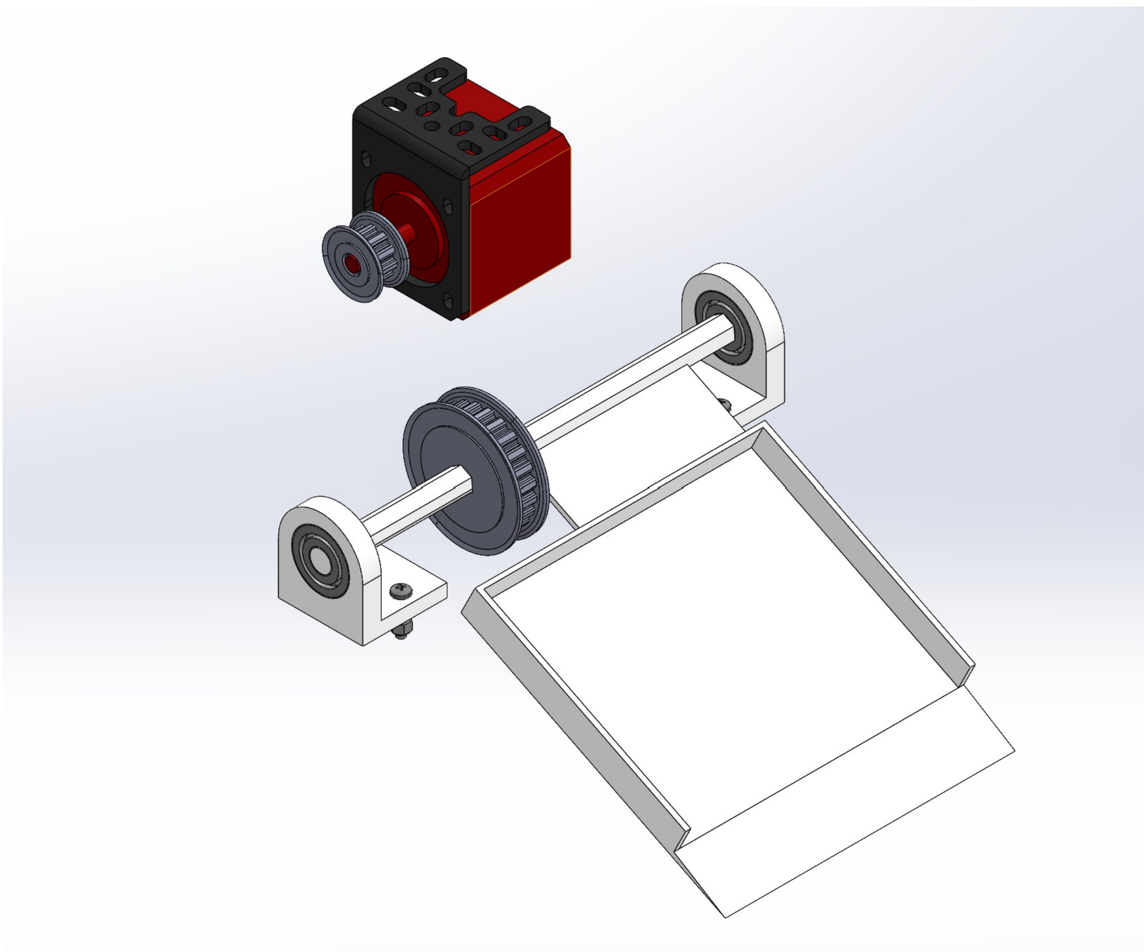


Figure 51: CAD Model of the Food Retrieval Sub-assembly

11.4 Final Product

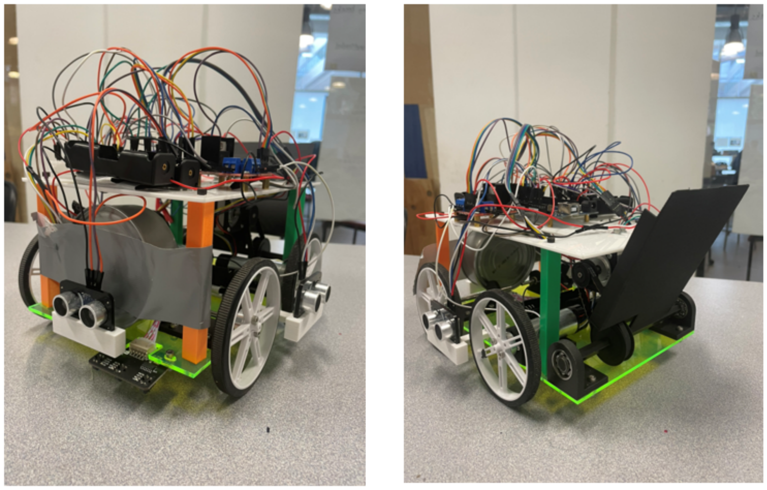


Figure 52: Front and rear isometric views of the robot.

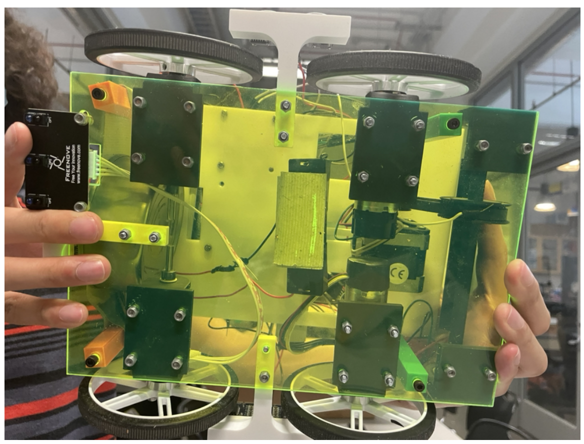


Figure 53: Bottom view of the robot.

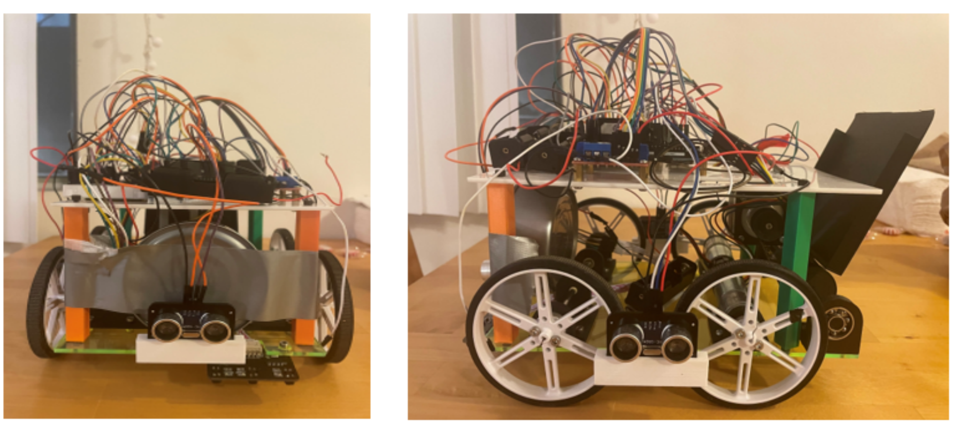


Figure 54: Front and side views of the robot.

Above are the isometric, front, side, and bottom views of the finished robot. As can be seen, the top and bottom plate are cut out of acrylic. The bottom plate has all sensors and wheel assemblies attached. Although it is hard to tell, there are bushings in all front wheel subassemblies to ensure smooth, consistent rotation of the axles. The wires for electrical components are strung through the slits in the top plate for easier routing, and the electronics are mounted to the top.

12 Product Performance Testing and Evaluation

12.1 Run Times

12.1.1 Food Retrieval

Table 7: Run Times for Food Retrieval

Trial	Time (s)
1	8.2
2	8.3
3	7.9

12.1.2 Starting Area

Table 8: Run Times for Starting Area

Trial	Time (s)
1	2.5
2	3
3	2.6

12.1.3 Obstacle Area

Table 9: Run Times for Obstacle Area

Trial	Time (s)
1	85
2	95
3	90

12.1.4 Mt.Bruin Hill

Table 10: Run Times for Mt.Bruin Hill

Trial	Time (s)
1	20
2	23
3	22

12.1.5 Food Delivery

Table 11: Run Times for Food Delivery

Trial	Time (s)
1	4.5
2	5
3	4.8

12.2 Overall Performance

Table 12: Total Run Time

Trial	Time (s)
1	120.2
2	134.3
3	127.3

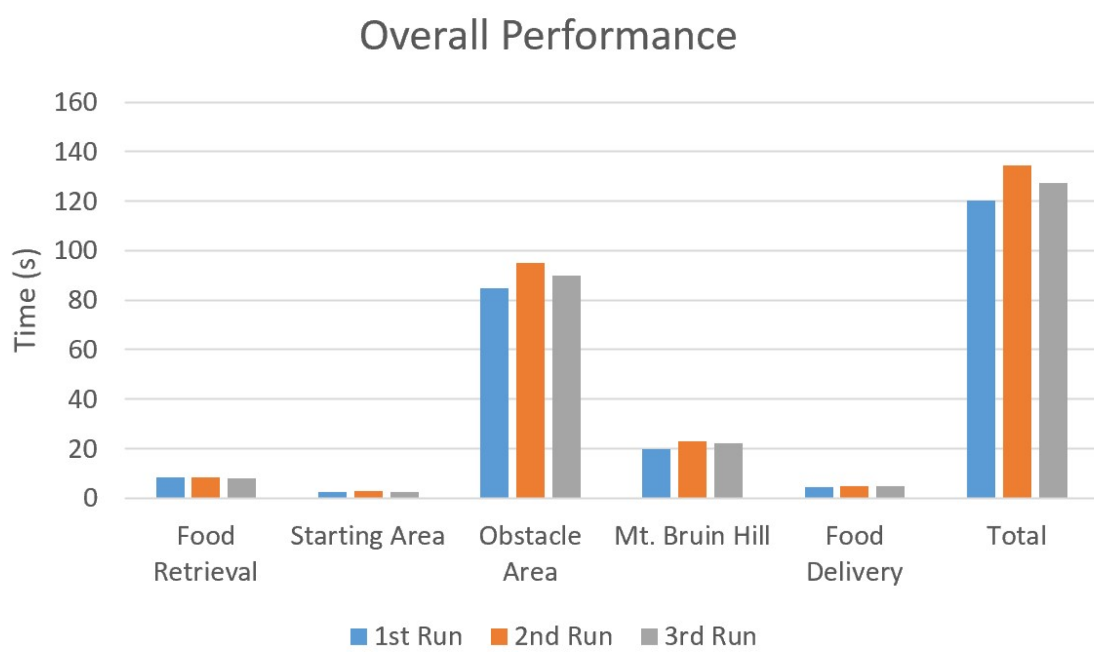


Figure 55: Overall Performance of 3 Runs

To conduct a simple analysis, we will evaluate the standard error of the time measured for all the segments, ensuring our sample data is representative.

We will utilize the formula:

$$SE = \frac{\sqrt{\frac{1}{n}\Sigma(x_i - \bar{x})^2}}{n-1} \tag{2}$$

Resulting in:

Table 13: Standard Error Calculation

Error	Segment
0.12	Food Retrieval
0.15	Starting Area
2.87	Obstacle Area
0.88	Mt. Bruin Hill
0.15	Food Delivery
4.07	Overall

The only segment with significant error is during the obstacle course, which makes sense since there were occasional adjustments that had to be made manually, resulting in longer time if extra help is needed on a specific run. Overall, the error is small and we can have confidence in our measurements.

13 Work Breakdown Schedule

13.1 Work Breakdown Schedule Diagram

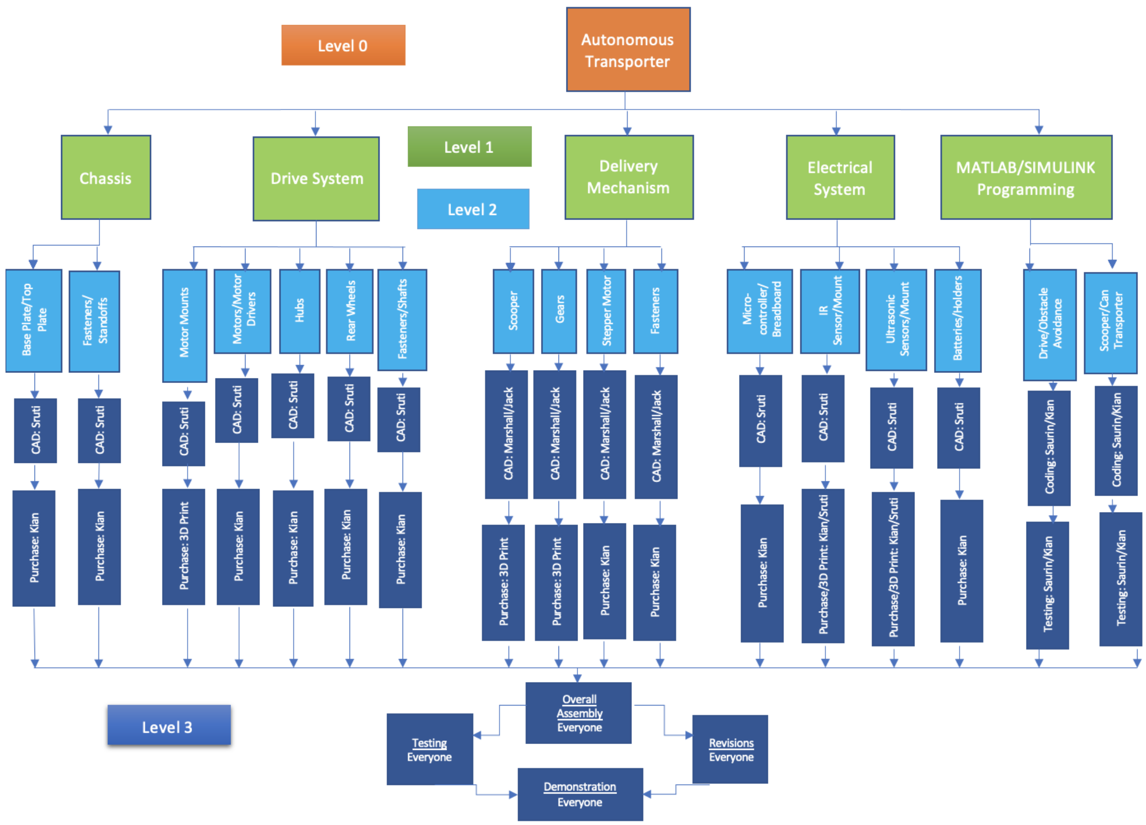


Figure 56: Work Breakdown Schedule Tree Structure View

Diagram shows the work broken down into 4 levels of smaller pieces called activities. Each activity is broken down into smaller tasks and handled by individuals.

13.2 Work Breakdown Schedule Dictionary

Table 14: Work Breakdown Schedule Dictionary

WBS Component	Definition
0. Autonomous Transporter	Robot that travels through pre-designed obstacles on a ramp and delivers food item at the top
1. Deliverables	High-Level Sub-Assemblies of the Autonomous Transporter
1.1 Chassis	The base of the robot that supports the entire structure
1.2 Drive System	Combination of wheels and motors that allow the robot to travel
1.3 Delivery Mechanism	Scooper driven by a stepper motor that delivers the tuna can to the top of Mt. Bruin
1.4 Electrical System	Combination of electronic components that enable the robot
1.5 MATLAB/SIMULINK Programming	Generating logic and state code to allow the robot to behave autonomously
2. Modules	Components of the Sub-Assemblies
2.1 Chassis	*Same definition as 1.1
2.1.1 Base Plate/Top Plate	Acrylic Plate that supports the electronic components and drive systems
2.1.2 Fasteners/Standoffs	Rods placed between the two plates to support the electronics and structure of the robot
2.2 Drive System	*Same definition as 1.2
2.2.1 Motor Mounts	Placed on base plate, encases the motors and holds them in place
2.2.2 Motors/Motor Drivers	Motors spin the shaft, acting on the gear system to drive the wheels
2.2.3 Hubs	Piece that connects motor shaft to wheels
2.2.4 Rear Wheels	Wheels that are driven by the motors; dictate speed and direction of robot
2.2.5 Fasteners/Shafts	Prevents the wheels from shifting positions along the motor shaft
2.3 Delivery Mechanism	*Same definition as 1.3
2.3.1 Scooper/Tuna Can Holder	When actuated, rotates up and down along the shaft to pick-up and drop off tuna can
2.3.2 Gears/Shaft/Timing Belt	Used to connect the stepper motor to the scooper and decrease the required torque
2.3.3 Stepper Motor	DC electric motor that divides a full rotation into a number of equal steps
2.3.4 Fasteners	Used to secure the scooper and motor to the bottom and top plates, respectively
2.4 Electrical System	*Same definition as 1.4
2.4.1 Microcontroller/Breadboard	Placed on top of top plate and wired to all other electrical components
2.4.2 IR Sensor/Mount	Used to sense black tape at the top of the hill to signal tuna can drop-off
2.4.3 Ultrasonic Sensors/Mount	Used to sense walls in front and on sides of device for turning and wall following
2.4.4 Batteries/Holders	Used to power the device and placed all throughout the robot individually
2.5 MATLAB/SIMULINK Programming	*Same definition as 1.5
2.5.1 Drive/Obstacle Avoidance	Logic used to maneuver through the obstacle course and up the hill
2.5.2 Scooper/Tuna Can Transport	Logic used to pick-up the tuna can and drop it off where applicable

14 BOM and Cost Analysis

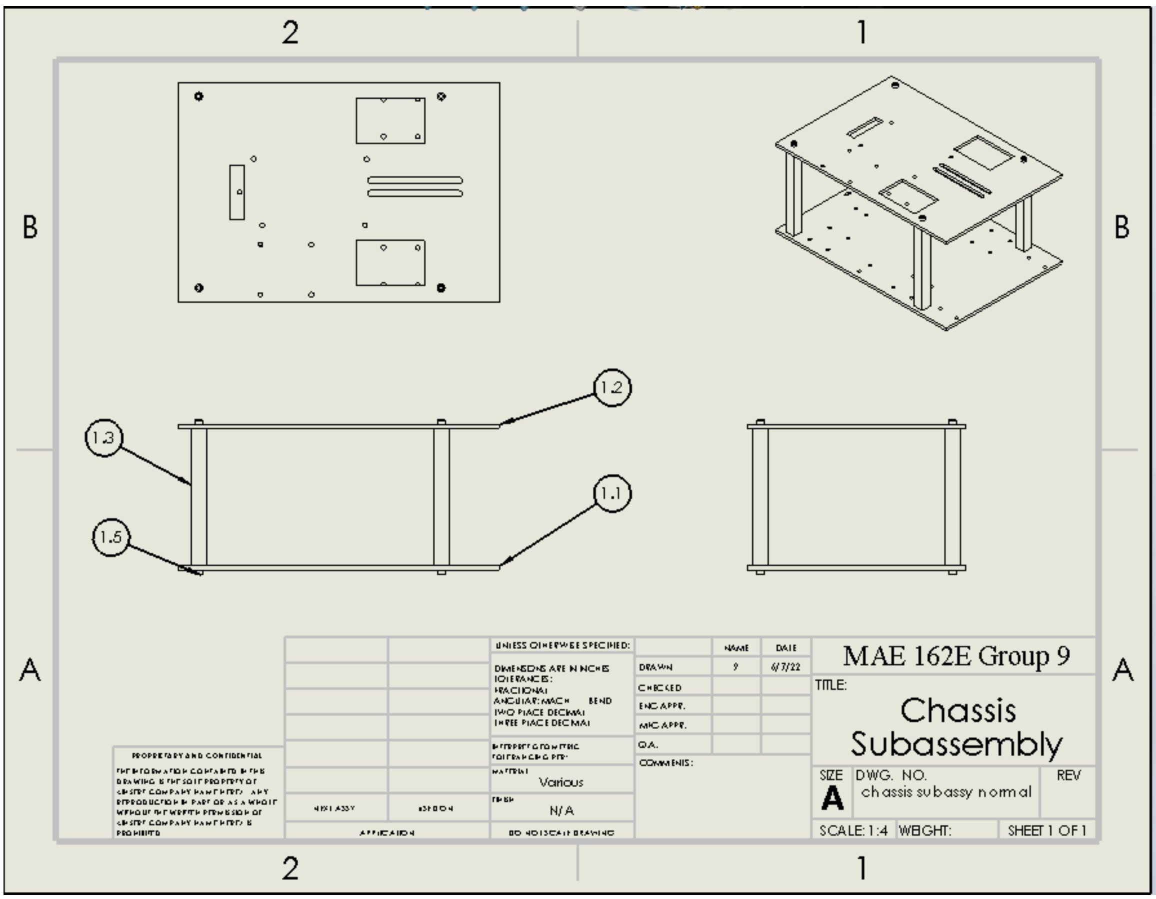
14.1 Assembly Drawings

In this section, there is a table for the subsystem that lists all the components included. Then, there are assembly drawings, followed by exploded views to demonstrate how the parts fit together. This format will be followed for every subsystem: Chassis, Drive, Delivery Mechanism, Sensors, and Electronics.

14.1.1 Chassis Subassembly

Table 15: Chassis Bill Of Materials

Item No.	Part Name	Description	Qty.	Make or Buy	Vendor	Serial Number	Cost	Total Cost
1	**Chassis**							
1.1	Bottom Plate	160 mm by 235 mm Acrylic plate	1	M			0	0
1.2	Top Plate	160 mm by 235 mm Acrylic plate	1	M			0	0
1.3	Standoffs	11.25 mm by 11.25 mm square standoff with holes for 6/32 screw to connect top and bottom plates	1	M			0	0
1.4	Heat set inserts	6/32, 0.25" length heat set inserts	8	B	McMaster Carr	92395A113	0	0
1.5	Standoff Screws	6/32, 5/8" length socket cap screws to attach heat set inserts to chassis plates	8	B	McMaster Carr	91251A150	0	0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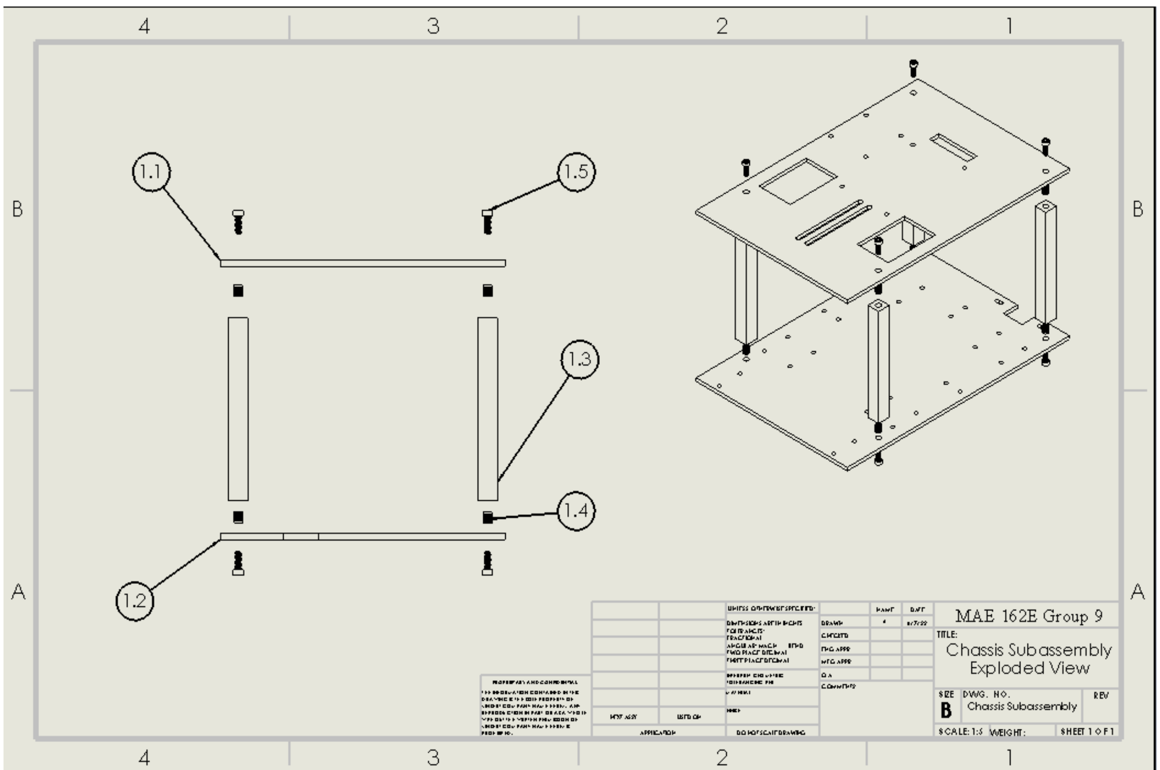
1.3
1.1
1.5
UNLESS OTHERWISE SPECIFIED:
NAME
DATE
DRAWN
9
6/7/22
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
Various
N/A
MAE 162E Group 9
TITLE:
Chassis Subassembly
SIZE
A
DWG. NO.
chassis subassy normal
REV
SCALE: 1:4
WEIGHT:
SHEET 1 OF 1

Figure 57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1.2
1.3
1.4
1.5
MAE 162E Group 9
TITLE:
Chassis Subassembly
Exploded View
SIZE
B
DWG. NO.
Chassis Subassembly
REV
SHEET 1 OF 1

Figure 58

14.1.2 Drive System Subassembly

Table 16: Drive System Bill Of Materials

Item No.	Part Name	Description	Qty.	Make or Buy	Vendor	Serial Number	Cost	Total Cost
2	**Drive System**							
2.1	Drive motor	227:1 metal gearmotor 25Dx71L mm	2	B	Pololu	4869	45.95	91.9
2.2	Drive motor mount	6 mm thick 3-D printed mount for Pololu motor	2	M			0	0
2.3	M3 locknut	Nylon-insert locknut, M3x0.5mm thread, 4 mm high	4	B	McMaster Carr	90576A102	4.65	4.65
2.4	Mounting hub	Universal mounting hub for 4 mm shaft to connect motor to wheel	4	B	Pololu	1997	8.49	16.98
2.5	M3 screws, 10 mm long	M3x0.5mm thread, 10 mm long socket head screw to connect wheel to hub	4	B	McMaster Carr	9129A113	6	6
2.6	Wheel	90x10 mm white Pololu wheel	4	B	Pololu	1439	7.95	15.9
2.7	M3 screws, 14 mm long	M3x0.5mm thread, 14 mm long Phillips head screw to connect motor mounts to chassis	4	B	McMaster Carr	92005A124	5.79	5.79
2.8	Front wheel axle	4 mm diameter, 3.25" long	2	B	McMaster Carr	2900A278	3.48	6.96
2.9	Axle shaft collar	Set screw collar, 4 mm shaft diameter to keep axle in place	2	B	McMaster Carr	6056N12	1.77	3.54
2.10	Axle bushing	Dry running flanged sleeve bearing, 4 mm shaft, 6 mm long to ensure smooth rotation of axle	4	B	McMaster Carr	2705T114	1.38	5.52

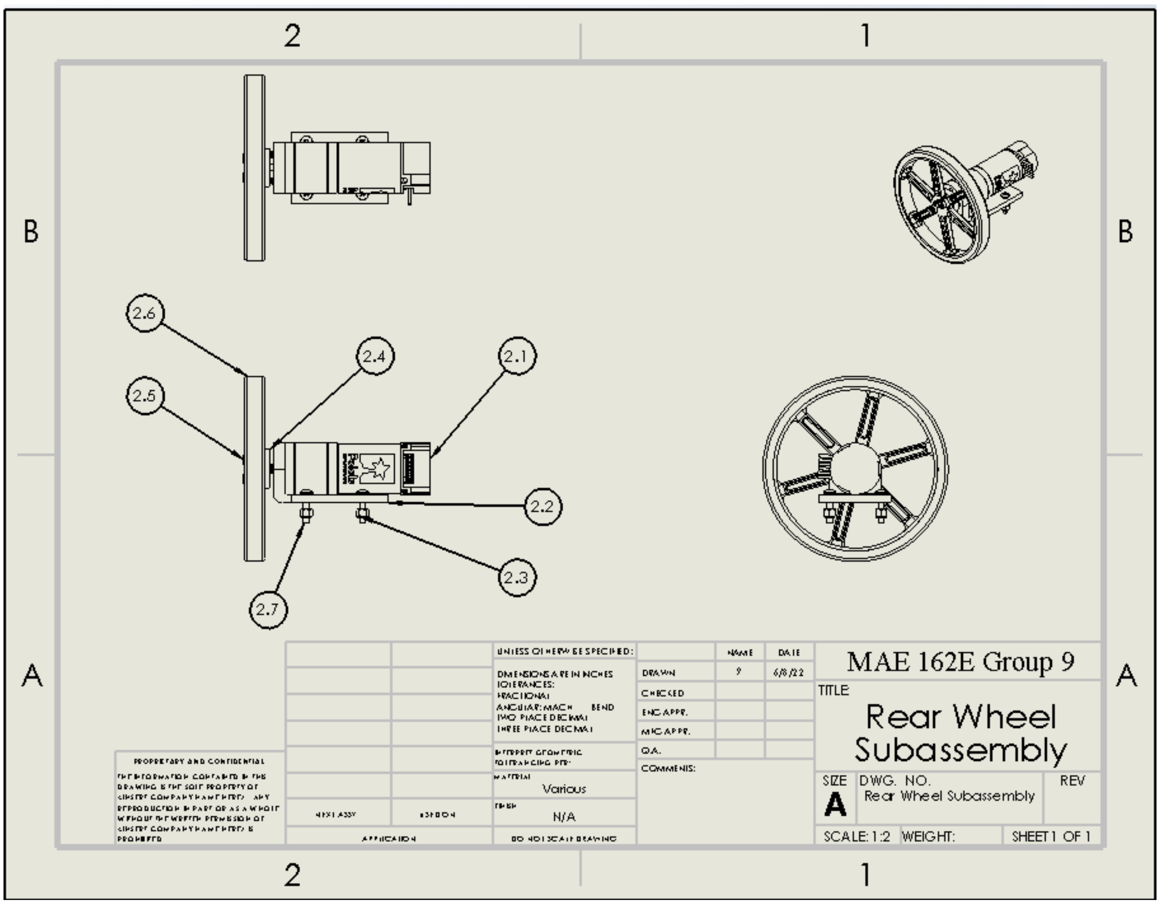
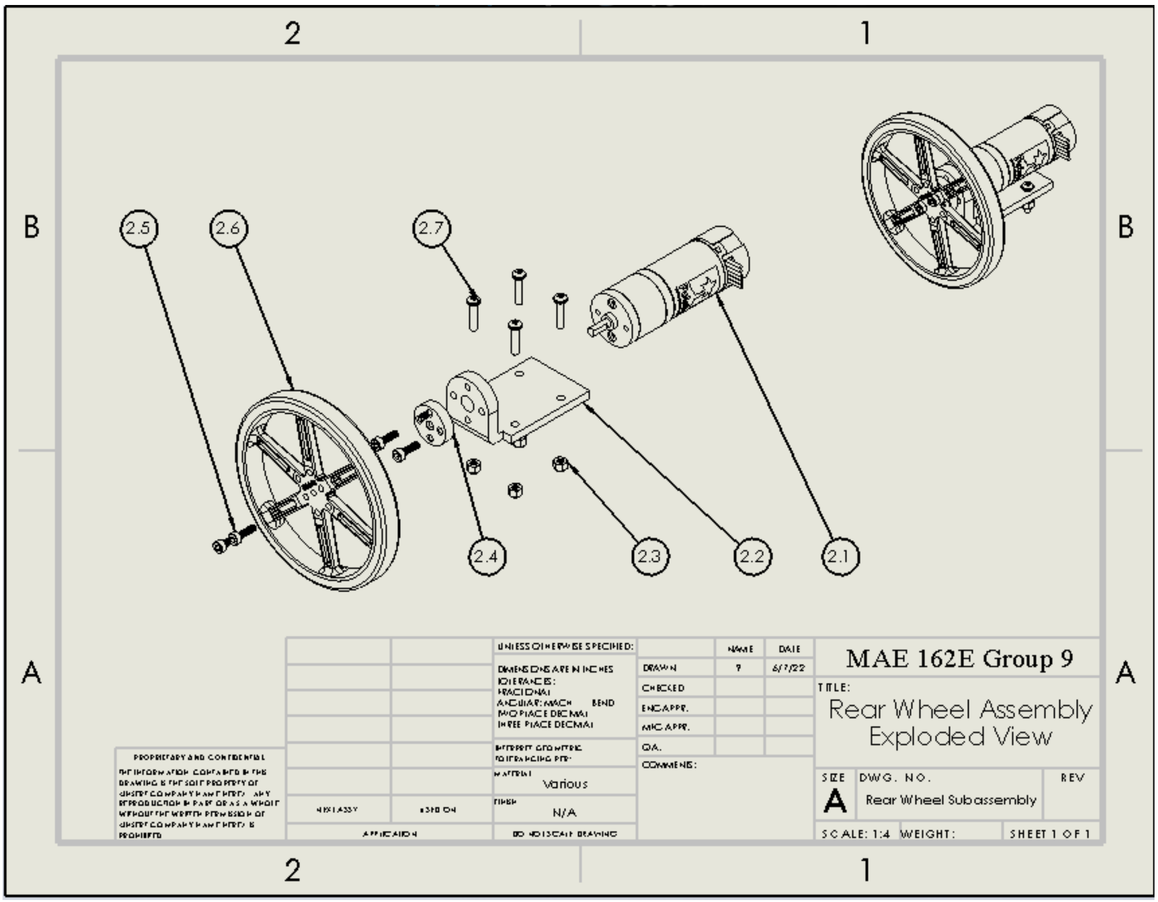


Figure 59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2.6
2.7
2.4
2.3
2.2
2.1
MAE 162E Group 9
Rear Wheel Assembly Exploded View
Rear Wheel Subassembly
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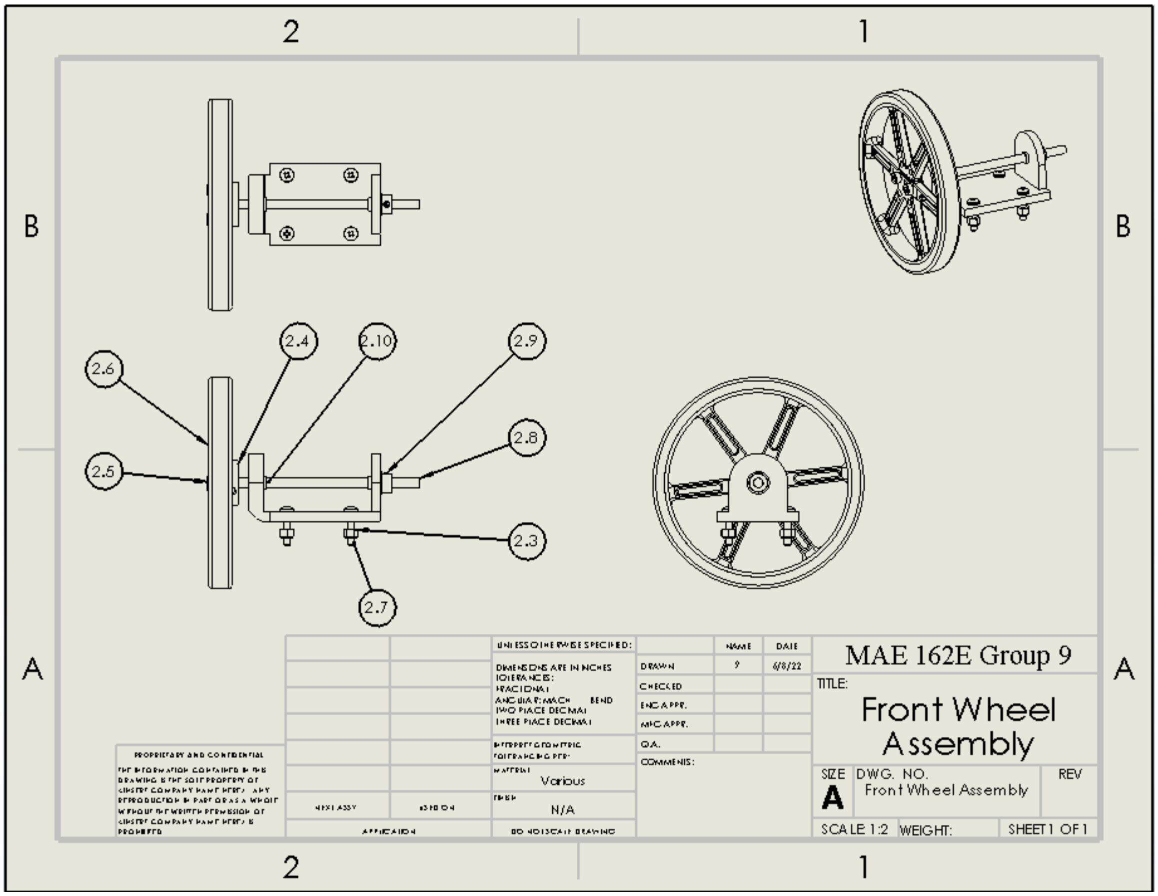
N/A
SCALE: 1:4
SHEET 1 OF 1

Figure 60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2.8
2.5
2.3
2.7
MAE 162E Group 9
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DRAWN
9
6/8/22
MATERIAL
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FINISH
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SIZE
A
DWG. NO.
Front Wheel Assembly
REV
SCALE 1:2
WEIGHT:
SHEET 1 OF 1

Figure 61

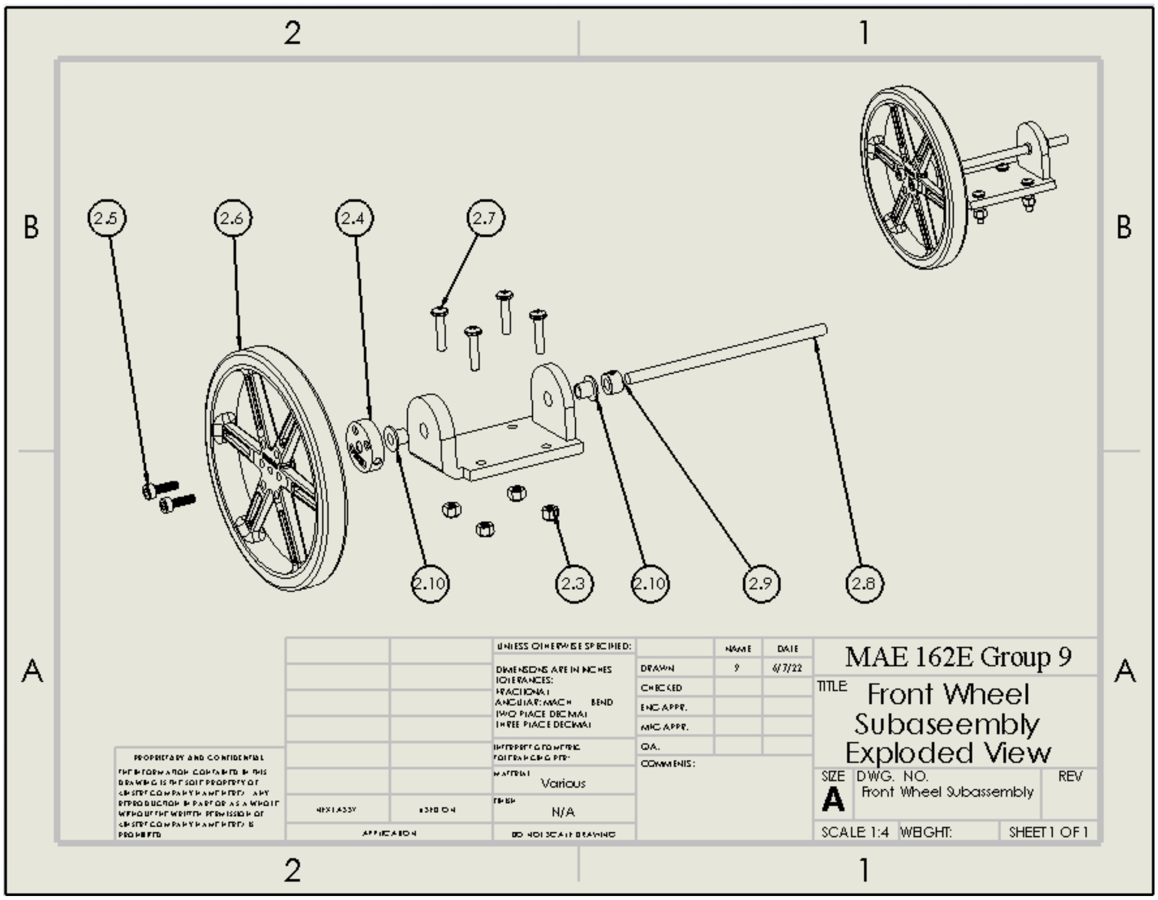

2.5
2.6
2.4
2.7
2.10
2.3
2.10
2.9
2.8
MAE 162E Group 9
TITLE Front Wheel Subaseembly Exploded View
DRAWN 9 6/7/22
MATERIAL Various
FINISH N/A
SIZE A
DWG. NO. Front Wheel Subassembly
REV
SCALE 1:4 WEIGHT: SHEET 1 OF 1

Figure 62

14.1.3 Delivery Mechanism Subsystem

Table 17: Delivery Mechanism Bill Of Materials

Item No.	Part Name	Description	Qty.	Make or Buy	Vendor	Serial Number	Cost	Total Cost
3	Delivery Mechanism							
3.1	Stepper motor	Bipolar stepper motor, 200 steps/rev for food retrieval	1	B	Pololu	2267	21.95	21.95
3.2	Larger pulley	Larger pulley, gear ratio 1:2	1	M			0	0
3.3	Scooper mounting plate	3D printed plate to mount scooping plate	1	M			0	0
3.4	Scooper plate	Scooper plate to retrieve tuna can	1	M			0	0
3.5	Shaft bearing	Ball bearing, 8 mm shaft diameter to ensure smooth rotation of scooper plate	2	B	McMaster Carr	5972K91	4.82	9.64
3.6	Timing belt	38 teeth single sided neoprene timing belt to connect pulleys	1	B	SDP/SI	A 6R 3M038060	5.89	5.89
3.7	Smaller pulley	Smaller pulley, gear ratio 1:2	1	M			0	0
3.8	M3 screw, 12 mm long	M3x0.5mm thread, 12 mm long socket head screw to connect stepper motor to chassis	4	B	McMaster Carr	91292A114	6	6
2.5	M3 screws, 10 mm long	M3x0.5mm thread, 10 mm long socket head screw to connect motor to mounting plate (already secure, but this is a more secure attachment)	4	B	McMaster Carr	9129A113	6	6
2.7	M3 screws, 14 mm long	M3x0.5mm thread, 14 mm long Phillips head screw to connect scooper mounting plate to chassis	4	B	McMaster Carr	92005A124	5.79	5.79
2.3	M3 locknut	Nylon-insert locknut, M3x0.5mm thread, 4 mm high	4	B	McMaster Carr	90576A102	4.65	4.65

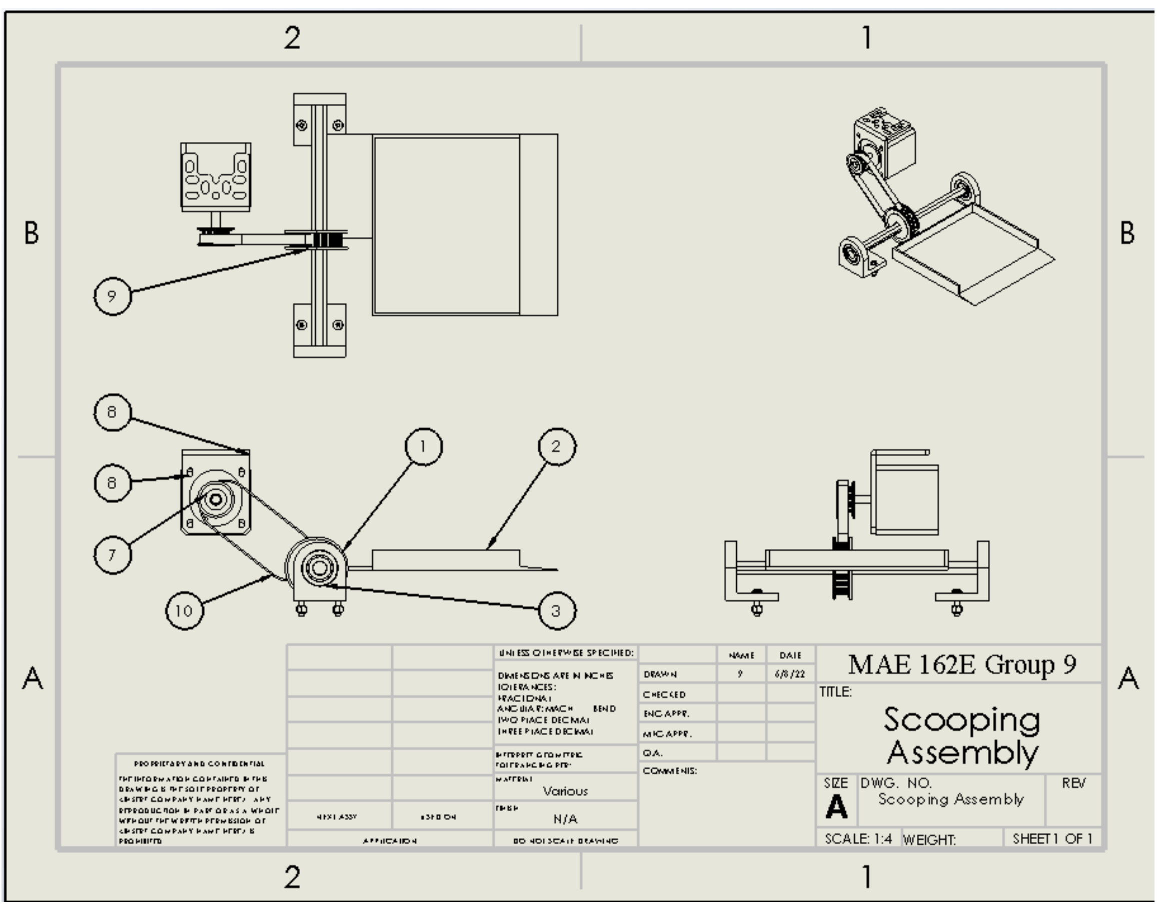
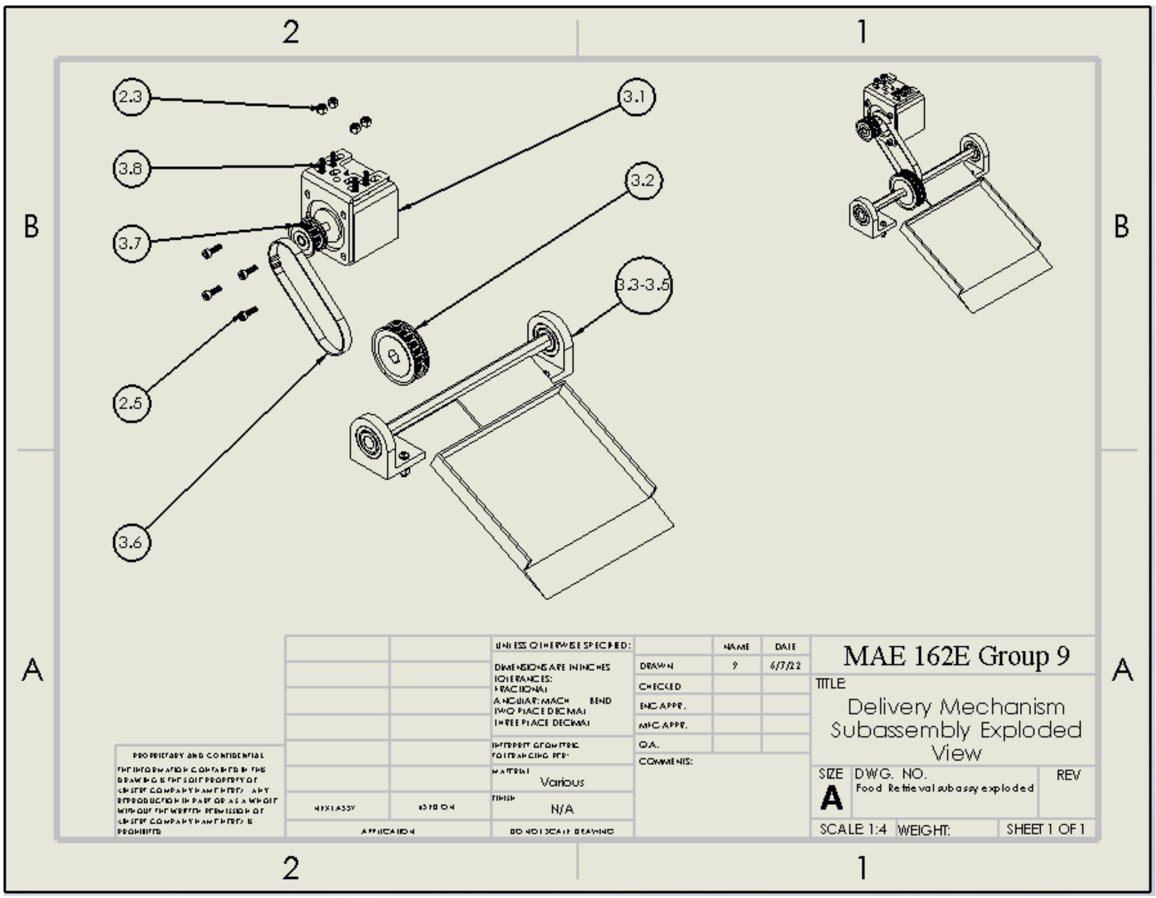


Figure 63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2.5
3.6
3.1
3.2
3.3-3.5
MAE 162E Group 9
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Delivery Mechanism Subassembly Exploded View
SIZE
A
DWG. NO.
Food Retrieval subassy exploded
REV
SCALE 1:4
WEIGHT:
SHEET 1 OF 1
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
NAME
DATE
6/7/22
UNLESS OTHERWISE SPECIFIED:
Various
N/A
PROPRIETARY AND CONFIDENTIAL

Figure 64

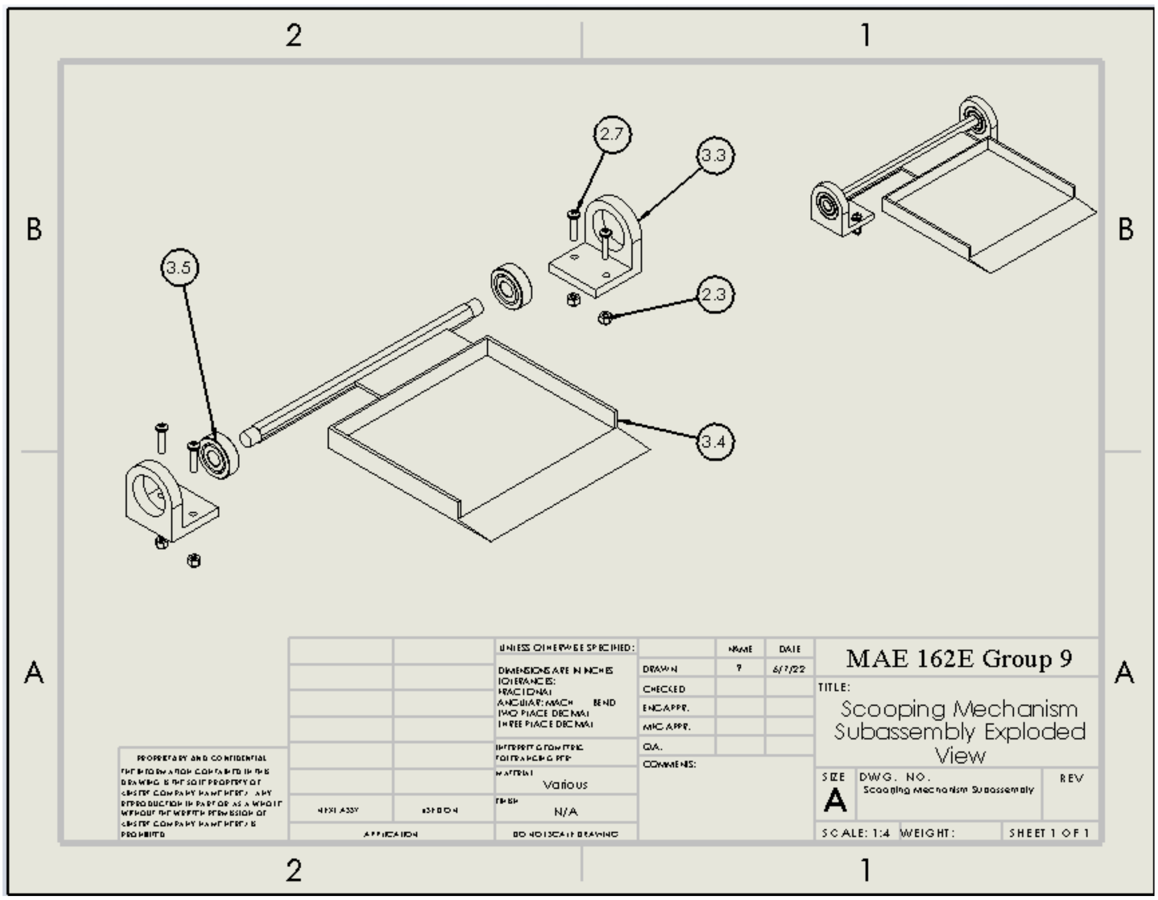

2.7
3.3
3.5
2.3
3.4
MAE 162E Group 9
TITLE:
Scooping Mechanism Subassembly Exploded View
SIZE
A
DWG. NO.
REV
Various
N/A
SCALE: 1:4
WEIGHT:
SHEET 1 OF 1

Figure 65

14.1.4 Sensor Subsystem

Table 18: Sensor Subsystem Bill Of Materials

Item No.	Part Name	Description	Qty.	Make or Buy	Vendor	Serial Number	Cost	Total Cost
4	Sensors							
4.1	Ultrasonic sensor	Ultrasonic sensor from Sparkfun	3	B			0	0
4.2	Ultrasonic sensor mount	Ultrasonic sensor mount	3	B			0	0
4.3	Ultrasonic sensor holder	Ultrasonic sensor holder that the sensor and sensor mount rest in	3	M			0	0
4.4	Line tracking sensor	Line tracking sensor	1	B			0	0
2.7	M3 screws, 14 mm long	M3x0.5mm thread, 14 mm long Phillips head screw to connect sensor holders to chassis	8	B	McMaster Carr	92005A124	5.79	5.79
2.3	M3 locknut	Nylon-insert locknut, M3x0.5mm thread, 4 mm high	8	B	McMaster Carr	90576A102	4.65	4.65

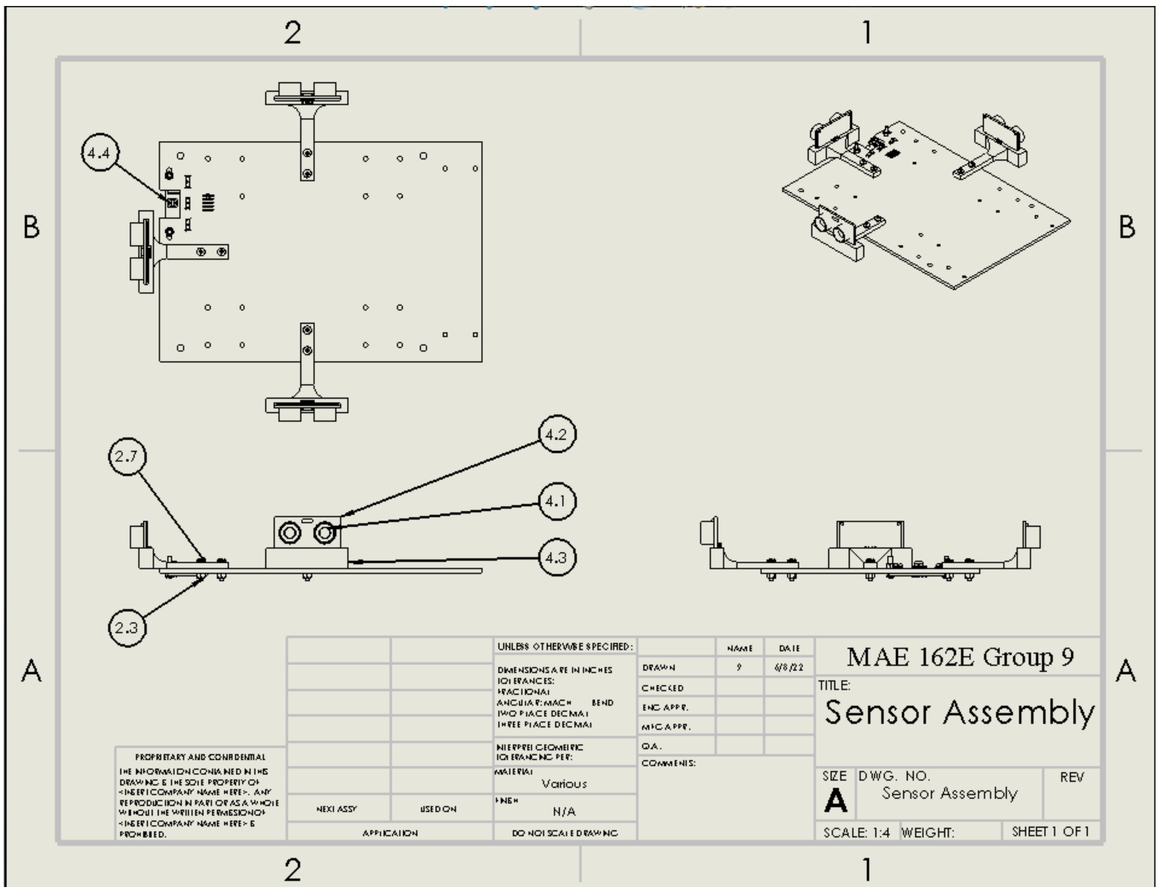


Figure 66

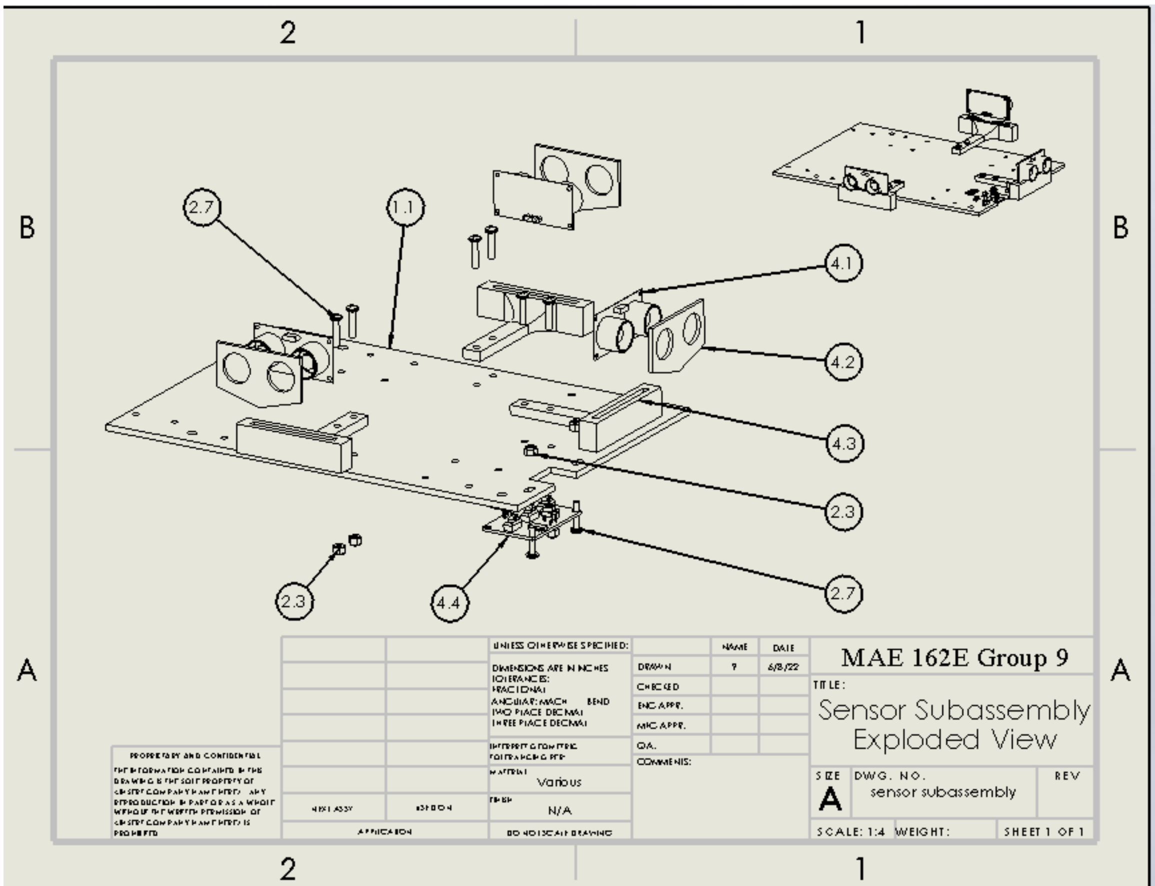

2.7
1.1
4.1
4.2
4.3
2.3
2.7
2.3
4.4
MAE 162E Group 9
TITLE:
Sensor Subassembly Exploded View
SIZE
A
DWG. NO.
sensor subassembly
REV
SCALE: 1:4
WEIGHT:
SHEET 1 OF 1
MATERIAL
Various
FINISH
N/A
DRAWN
9
6/8/22
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
NAME
DATE
UNLESS OTHERWISE SPECIFIED:
DO NOT SCALE DRAWING
NEXT ASSY
USED ON
APPLICATION
PROPRIETARY AND CONFIDENTIAL

Figure 67

14.1.5 Electronics Subsystem

Table 19: Electronics Subsystem Bill Of Materials

Item No.	Part Name	Description	Qty.	Make or Buy	Vendor	Serial Number	Cost	Total Cost
5	**Electronics**							
5.1	Lipo battery	Lipo batteries provided in class	4	B	Gift		0	0
5.2	Lipo battery holder	Case for lipo batteries with red and black leads	4	B	Gift		0	0
5.3	Standoff screws	M3 screws to connect boards to standoffs	16	B	Gift		0	0
5.4	Arduino board	Arduino Mega 2560 board	1	B	Gift		0	0
5.5	Stepper motor driver	DRV 8834 motor driver from Pololu for stepper motor control	1	B	Gift	2134	9.95	9.95
5.6	Small breadboard	Breadboard for wiring assistance	1	B	Gift		0	0
5.7	Standoff	Copper painted standoffs to connect board to chassis	8	B	Gift		0	0
5.8	Drive motor driver	LN298 motor driver for drive motor control	1	B	Gift		0	0

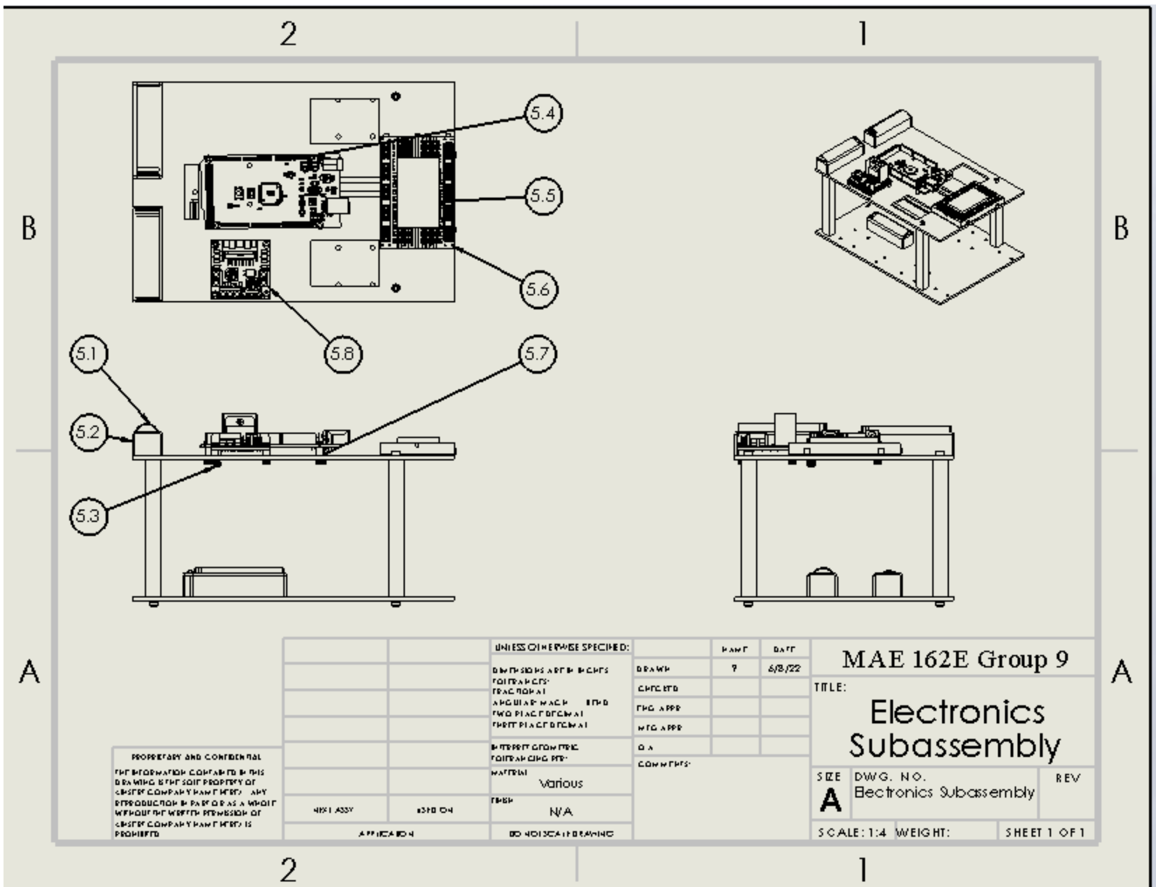


Figure 68

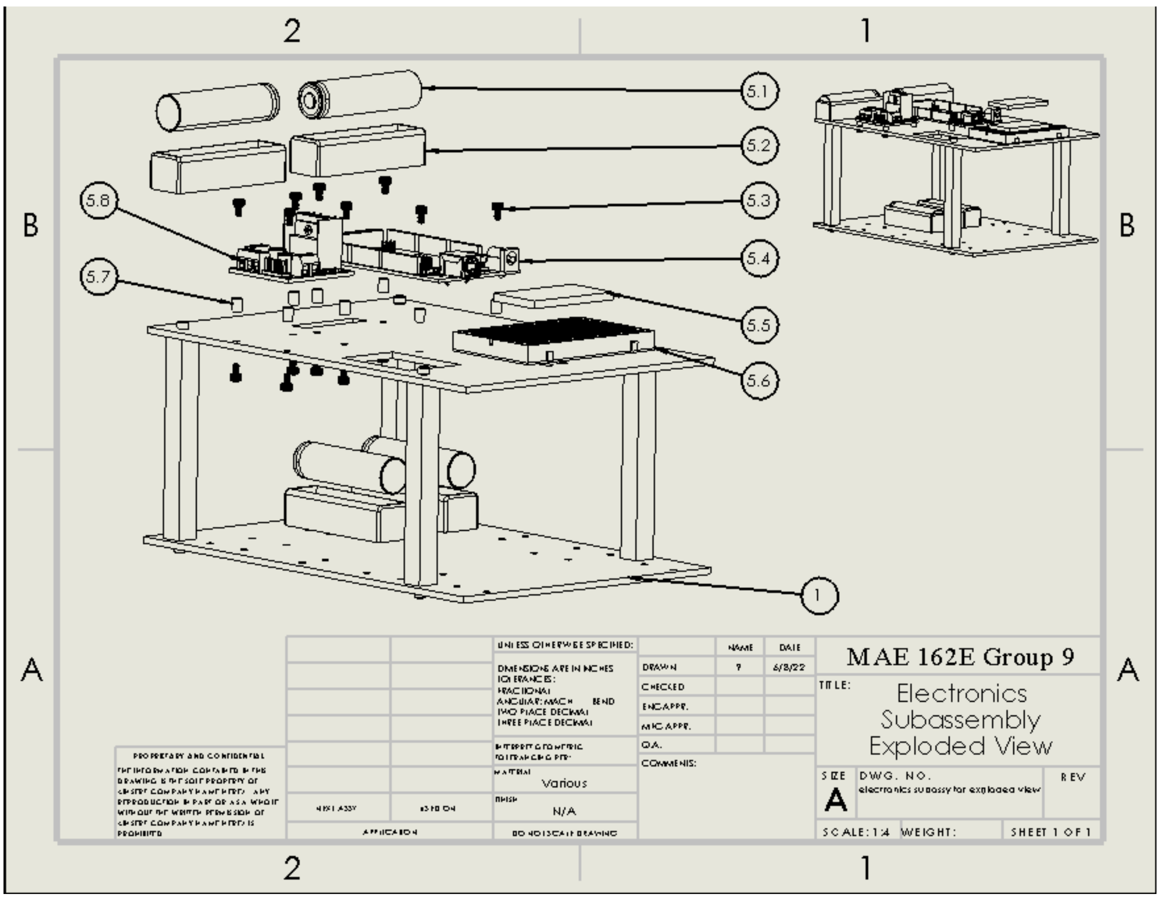

5.1
5.2
5.3
5.4
5.5
5.6
5.7
5.8
1
MAE 162E Group 9
Electronics
Subassembly
Exploded View
DRAWN
6/8/22
Various
N/A
SCALE: 1:4
WEIGHT:
SHEET 1 OF 1

Figure 69

14.2 BOM

Table 20: Overall Bill of Materials

Item No	Part Name	Description	Qty.	Make or Buy	Vendor	Serial Numbe	Cost	Total Co
1	**Chassis**							
1.1	Bottom Plate	160 mm by 235 mm Acrylic plate	1	M			0	0
1.2	Top Plate	160 mm by 235 mm Acrylic plate	1	M			0	0
1.3	Standoffs	11.25 mm by 11.25 mm square standoff with holes for 6/32 screw to connect top and bottom plates	1	M			0	0
1.4	Heat set inserts	6/32, 0.25'' length heat set inserts	8	B	McMaster Carr	92395A113	0	0
1.5	Standoff Screws	6/32, 5/8'' length socket cap screws to attach heat set inserts to chassis plates	8	B	McMaster Carr	91251A150	0	0
2	**Drive System**							
2.1	Drive motor	227:1 metal gearmotor 25Dx71L mm	2	B	Pololu	4869	45.95	91.9
2.2	Drive motor mount	6 mm thick 3-D printed mount for Pololu motor	2	M			0	0
2.3	M3 locknut	Nylon-insert locknut, M3x0.5mm thread, 4 mm high	4	B	McMaster Carr	90576A102	4.65	4.65
2.4	Mounting hub	Universal mounting hub for 4 mm shaft to connect motor to wheel	4	B	Pololu	1997	8.49	16.98
2.5	M3 screws, 10 mm long	M3x0.5mm thread, 10 mm long socket head screw to connect wheel to hub	4	B	McMaster Carr	9129A113	6	6
2.6	Wheel	90x10 mm white Pololu wheel	4	B	Pololu	1439	7.95	15.9
2.7	M3 screws, 14 mm long	M3x0.5mm thread, 14 mm long Phillips head screw to connect motor mounts to chassis	4	B	McMaster Carr	92005A124	5.79	5.79
2.8	Front wheel axle	4 mm diameter, 3.25'' long	2	B	McMaster Carr	2900A278	3.48	6.96
2.9	Axle shaft collar	Set screw collar, 4 mm shaft diameter to keep axle in place	2	B	McMaster Carr	6056N12	1.77	3.54
2.10	Axle bushing	Dry running flanged sleeve bearing, 4 mm shaft, 6 mm long to ensure smooth rotation of axle	4	B	McMaster Carr	2705T114	1.38	5.52
3	**Delivery Mechanism**							
3.1	Stepper motor	Bipolar stepper motor, 200 steps/rev for food retrieval	1	B	Pololu	2267	21.95	21.95
3.2	Larger pulley	Larger pulley, gear ratio 1:2	1	M			0	0
3.3	Scooper mounting plate	3D printed plate to mount scooping plate	1	M			0	0
3.4	Scooper plate	Scooper plate to retrieve tuna can	1	M			0	0
3.5	Shaft bearing	Ball bearing, 8 mm shaft diameter to ensure smooth rotation of scooper plate	2	B	McMaster Carr	5972K91	4.82	9.64
3.6	Timing belt	38 teeth single sided neoprene timing belt to connect pulleys	1	B	SDP/SI	A 6R 3M038060	5.89	5.89
3.7	Smaller pulley	Smaller pulley, gear ratio 1:2	1	M			0	0
3.8	M3 screw, 12 mm long	M3x0.5mm thread, 12 mm long socket head screw to connect stepper motor to chassis	4	B	McMaster Carr	91292A114	6	6
2.5	M3 screws, 10 mm long	M3x0.5mm thread, 10 mm long socket head screw to connect motor to mounting plate (already secure, but this is a more secure attachment)	4	B	McMaster Carr	9129A113	6	6
2.7	M3 screws, 14 mm long	M3x0.5mm thread, 14 mm long Phillips head screw to connect scooper mounting plate to chassis	4	B	McMaster Carr	92005A124	5.79	5.79
2.3	M3 locknut	Nylon-insert locknut, M3x0.5mm thread, 4 mm high	4	B	McMaster Carr	90576A102	4.65	4.65
4	**Sensors**							
4.1	Ultrasonic sensor	Ultrasonic sensor from Sparkfun	3	B			0	0
4.2	Ultrasonic sensor mount	Ultrasonic sensor mount	3	B			0	0
4.3	Ultrasonic sensor holder	Ultrasonic sensor holder that the sensor and sensor mount rest in	3	M			0	0
4.4	Line tracking sensor	Line tracking sensor	1	B			0	0
2.7	M3 screws, 14 mm long	M3x0.5mm thread, 14 mm long Phillips head screw to connect sensor holders to chassis	8	B	McMaster Carr	92005A124	5.79	5.79
2.3	M3 locknut	Nylon-insert locknut, M3x0.5mm thread, 4 mm high	8	B	McMaster Carr	90576A102	4.65	4.65
5	**Electronics**							
5.1	Lipo battery	Lipo batteries provided in class	4	B	Gift		0	0
5.2	Lipo battery holder	Case for lipo batteries with red and black leads	4	B	Gift		0	0
5.3	Standoff screws	M3 screws to connect boards to standoffs	16	B	Gift		0	0
5.4	Arduino board	Arduino Mega 2560 board	1	B	Gift		0	0
5.5	Stepper motor driver	DRV 8834 motor driver from Pololu for stepper motor control	1	B	Gift	2134	9.95	9.95
5.6	Small breadboard	Breadboard for wiring assistance	1	B	Gift		0	0
5.7	Standoff	Copper painted standoffs to connect board to chassis	8	B	Gift		0	0
5.8	Drive motor driver	LN298 motor driver for drive motor control	1	B	Gift		0	0

14.3 Final Cost Analysis

14.3.1 Material Costs

Table 21: Material Costs

Product Description	Vendor	Price
227:1 Metal Gearmotor 25Dx71L mm MP 12V with 48 CPR Encoder	Pololu	$91.90
Stepper Motor: Bipolar, 200 Steps/Rev, 42×38mm, 2.8V, 1.7 A/Phase	Pololu	$21.95
Pololu Wheel 60×8mm Pair - Red	Pololu	$23.00
Pololu Universal Aluminum Mounting Hub for 4mm Shaft, M3 Holes (2-Pack)	Pololu	$33.96
Pololu Stamped Aluminum L-Bracket for NEMA 17 Stepper Motors	Pololu	$3.95
Machine Screw: M3, 5mm Length, Phillips (25-pack)	Pololu	$0.99
Hardened Undersized High-Speed M2 Tool Steel Rod	McMaster	$6.96
Carbon Steel Set Screw Collar	McMaster	$3.54
18-8 Stainless Steel Narrow Cheese Head Slotted Screws	McMaster	$7.46
Zinc-Plated Steel Hex Nut	McMaster	$4.47
18-8 Stainless Steel Socket Head Screw	McMaster	$6.00
Medium-Strength Steel Nylon-Insert Locknut	McMaster	$4.65
Timing Belt A 6R 3M038060	SDP/SI	$5.89
90x10 mm Pololu wheels	Pololu	$31.80
Stepper Motor Driver	Pololu	$9.95
Ball Bearing, Open, Trade Number 608, for 8 mm Shaft Diameter	McMaster	$9.64
Steel Pan Head Phillips Screw, M3 x 0.5 mm Thread, 14 mm Long	McMaster	$5.79
Light Duty Dry-Running Flanged Sleeve Bearing	McMaster	$5.52
Total Cost		$277.42

Fortunately, our team was able to remain well below the assigned budget of 400 dollars for all our purchased materials. Therefore, we were not as stressed about the possibility of needing to order new parts if some of our materials turned out defective.

14.3.2 Labor Costs

We estimate that each member of our team spent around 20 hours this quarter in the lab working on 3D printing, machining, assembling, and testing our device. Therefore, since there are 5 people on our team and assuming that the average entry level engineering hourly wage in the United States is about 35 dollars, we can estimate our total labor costs to be approximately 3500 dollars for the fabrication of our device.

15 Design Requirement Satisfaction

Table 22: Design Requirement Satisfaction

HLDR	Satisfaction
Device must be able to deliver a food item uphill to the loading area	Satisfied, line tracking sensor detecting top of hill and plate lowers to drop off food
Device must autonomously navigate the entire obstacle course	Not completely satisfied, sometimes need human intervention
Device dimensions at the beginning of its run must not exceed 20x25x30 cm^3 (HxWxL)	Satisfied, device dimension with scooper plate raised stays within the required size
Dimensions of device can change after start	Satisfied, scooper plate lowers to pick up food item after start
The device must use electric batteries; no other sources of power (e.g. muscle, hydraulics, chemical) are permitted	Satisfied, only eletric batteries were used to power the device
Device may use torque or skid steering	Satisfied, device uses skid steering
All sensors must be mounted on device	Satisfied, all sensors mounted on structural chassis plates
No components may be left behind on the course during the device's travel	Satisfied, all components secured and do not detach during travel
Device must be able to navigate the course within 5 minutes	Satisfied, both drive system and food retrieval system satisfies more time-intensive low level design requirements
All mechanical actuators used must be designed and modeled in-house	Satisfied, all parts designed and fabricated by the team
Off-the shelf items that may be purchased are limited in terms of Hardware, Power Transmission, and Electronics	Satisfied, only purchase electrical components and mounting hardware
350 USD total budget	Satisfied, spent under $250 on purchasing
Disposable or rechargeable batteries may be used to power the vehicle	Satisfied, used rechargeable Lithium polymer batteries to power the device

The device often had trouble at 180 degree turns, it sometimes would require 1 or 2 human intervention to help the robot complete the turn. We could explore more precise control utilizing the encoders, or even using stepper motors to ensure the distance advanced and the degree of turns are more consistent.

16 Conclusion

Tasked with designing an autonomous device that can effectively deliver a food item to the top of an obstacle course, Mount Bruin, a well rounded scooper robot design was chosen. The proposal identified three different concepts as potential designs that can be used to meet all the high-level and low-level design requirements assigned to us. After careful consideration of important design factors such as cost, weight, complexity, etc. through the use of both a Pairwise Comparison Chart and Objectives Tree, Concept 2 was identified as the most favorable option to pursue. Concept 2 uses a scooping mechanism at the front of the device to lift the desired food item (the tuna can), and uses tank treads around the wheels to support the device's stability as it maneuvers around obstacles and sink holes. Therefore, this design will be successful in accomplishing all the required tasks and further research will be conducted to produce an updated concept proposal.

17 References

[1] Dee-Ann Durbin. *Robots hit the streets as demand for food delivery grows*. Associated Press, 2022.

[2] R.S. Shaefer. *Conceptual Design Report Outline*. University of California, Los Angeles, 2022.

18 Appendix

18.1 Engineering Drawings

18.1.1 Exploded Views

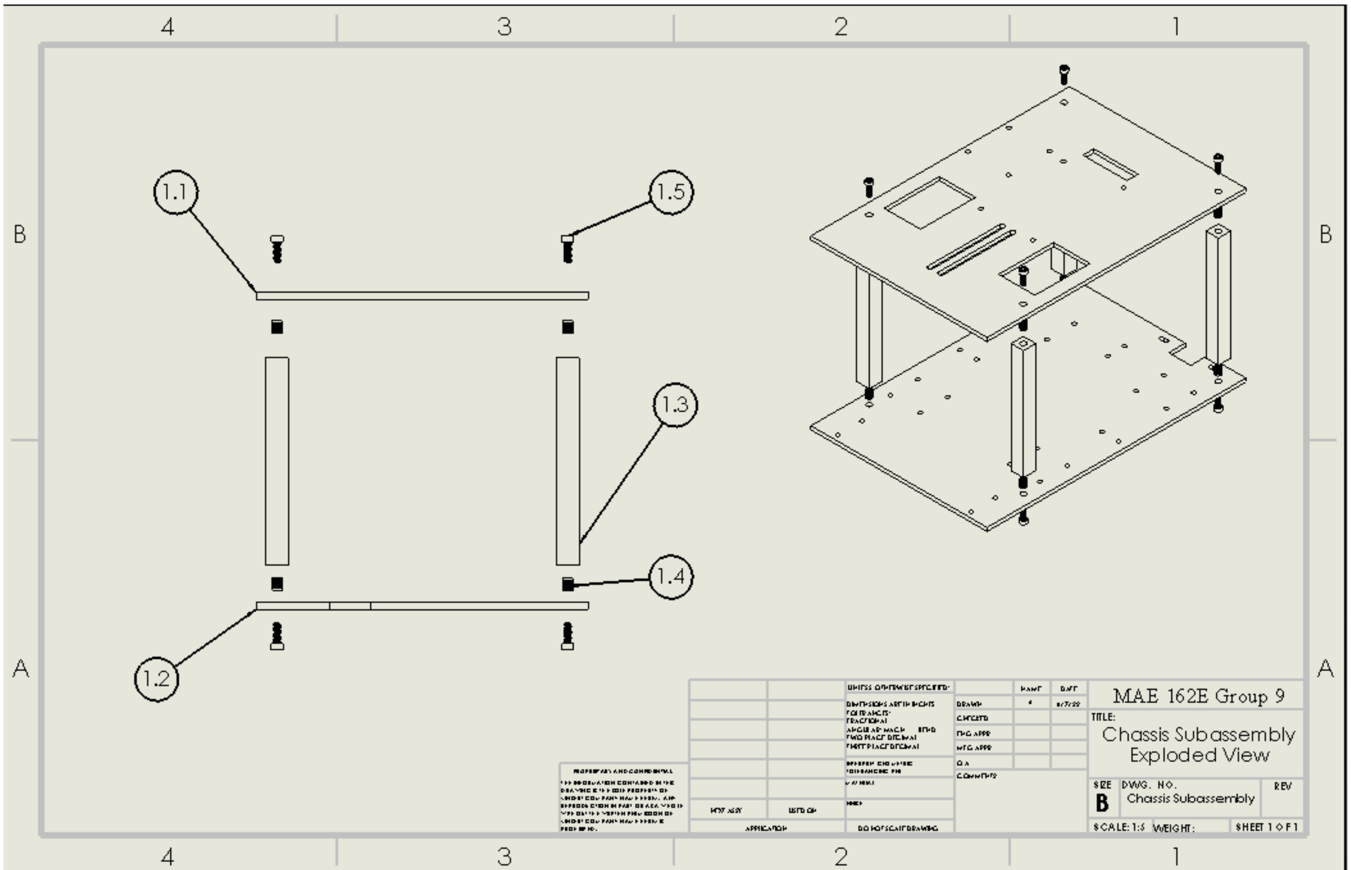


Figure 70: Chassis Subassembly Exploded View

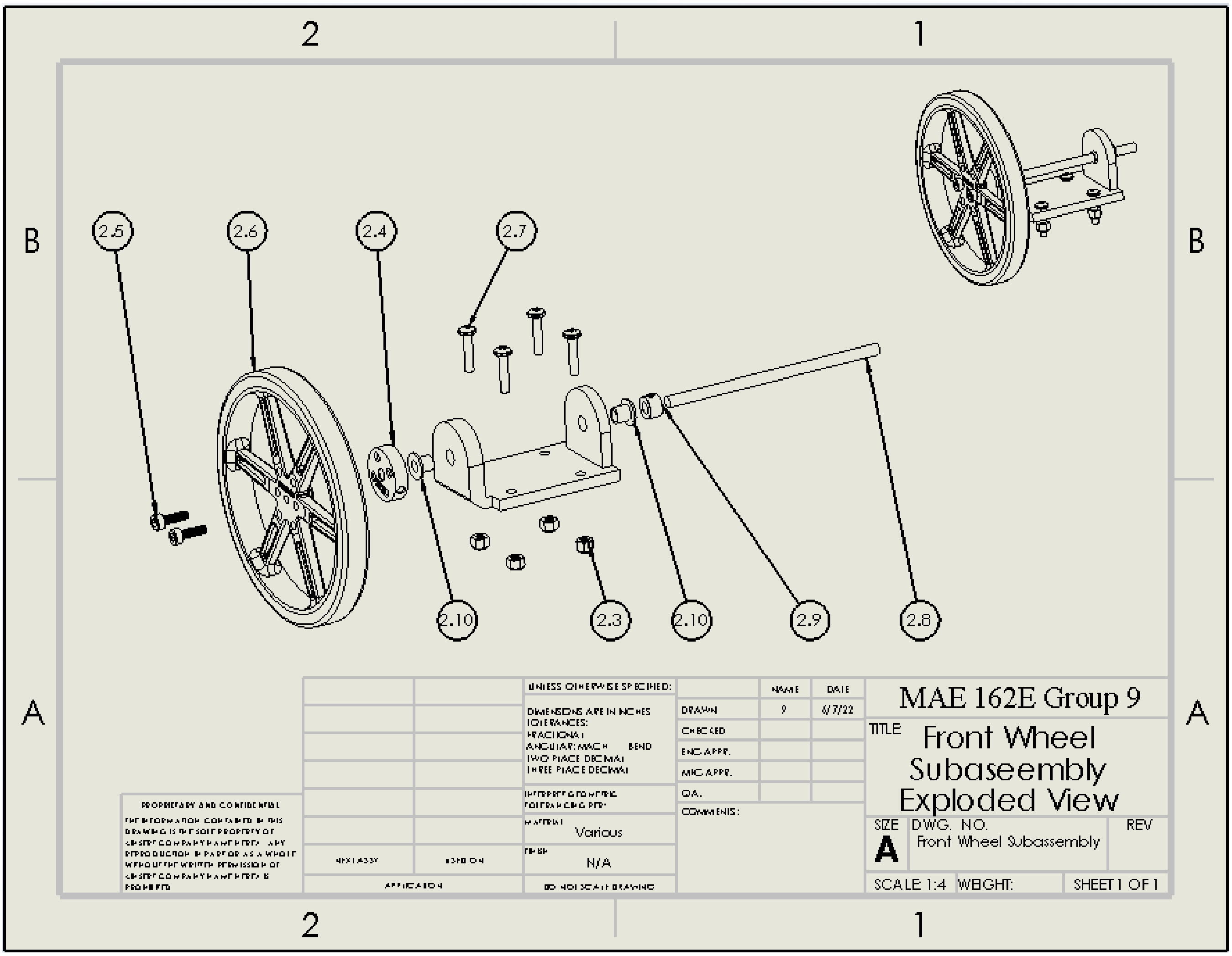


Figure 71: Front Wheel Subassembly Exploded View

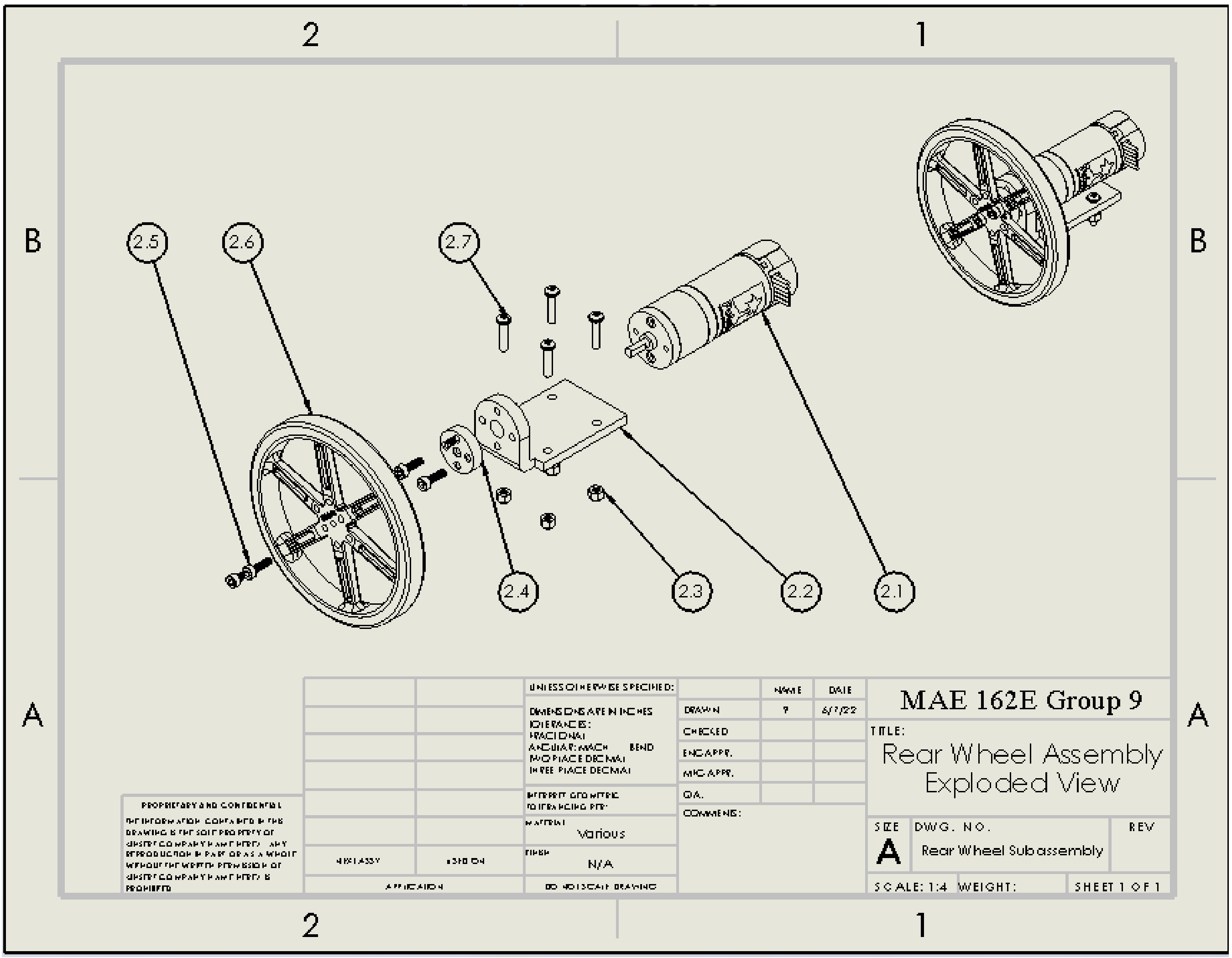


Figure 72: Rear Wheel Subassembly Exploded View

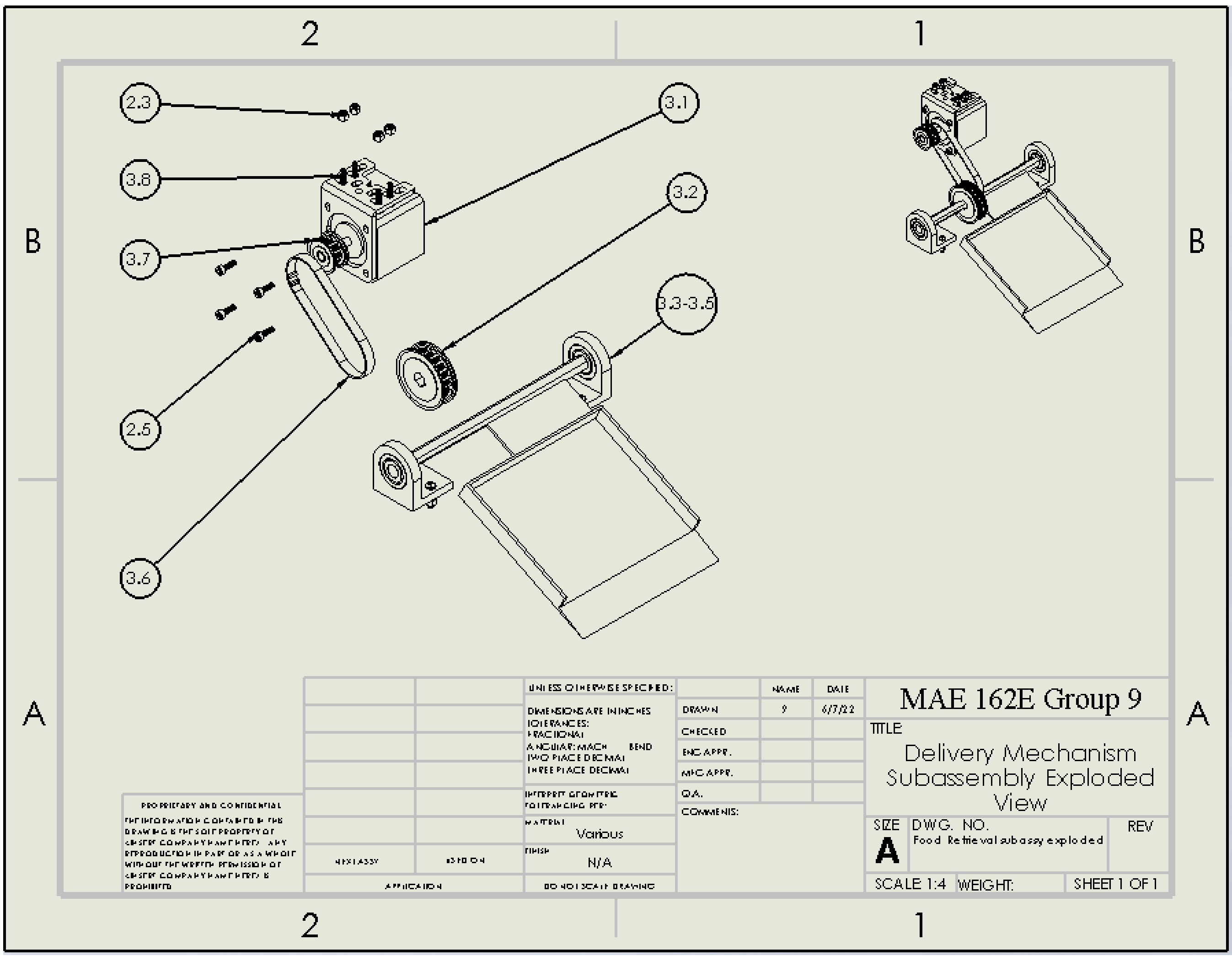


Figure 73: Delivery Mechanism Exploded View

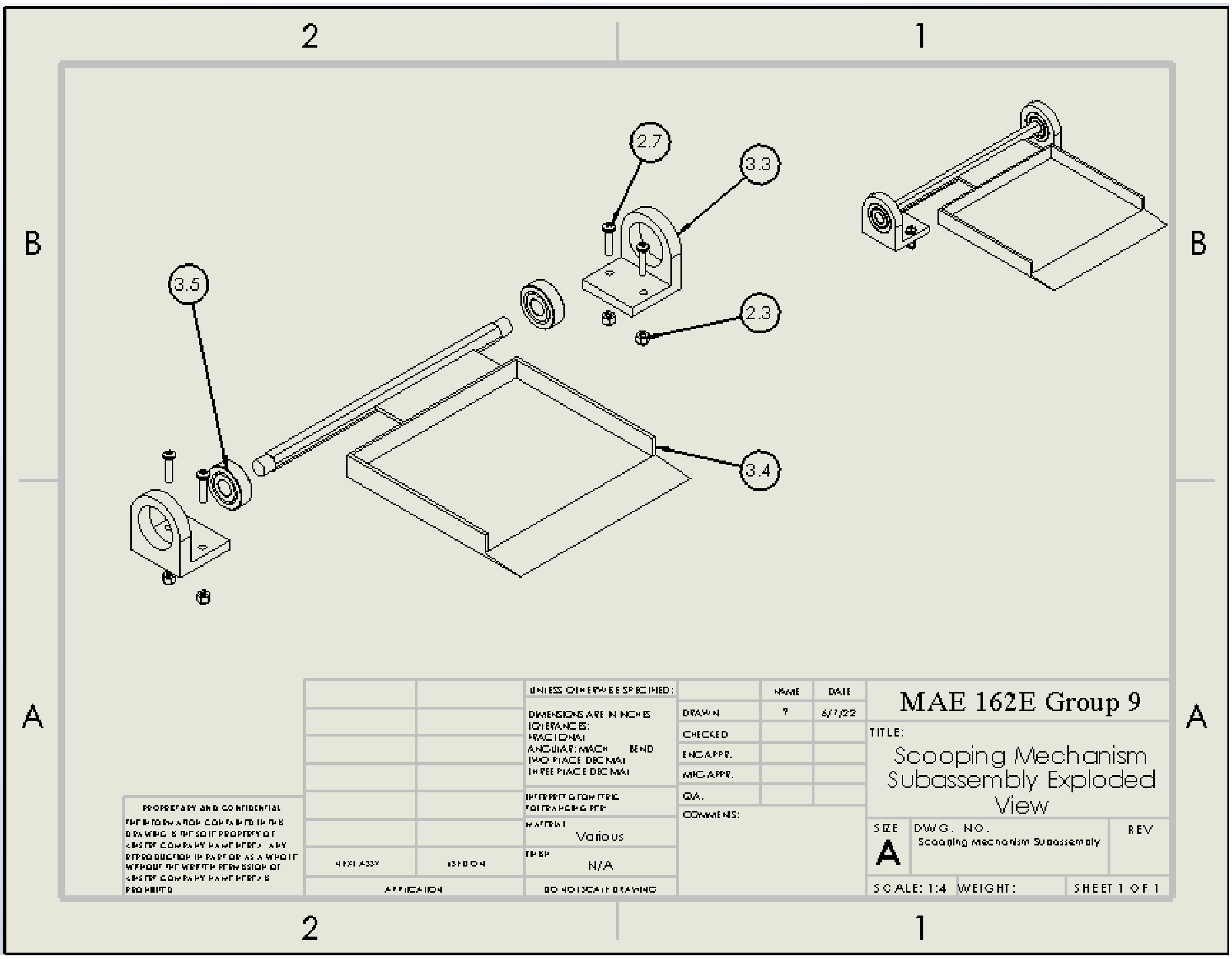


Figure 74: Scooper Exploded View

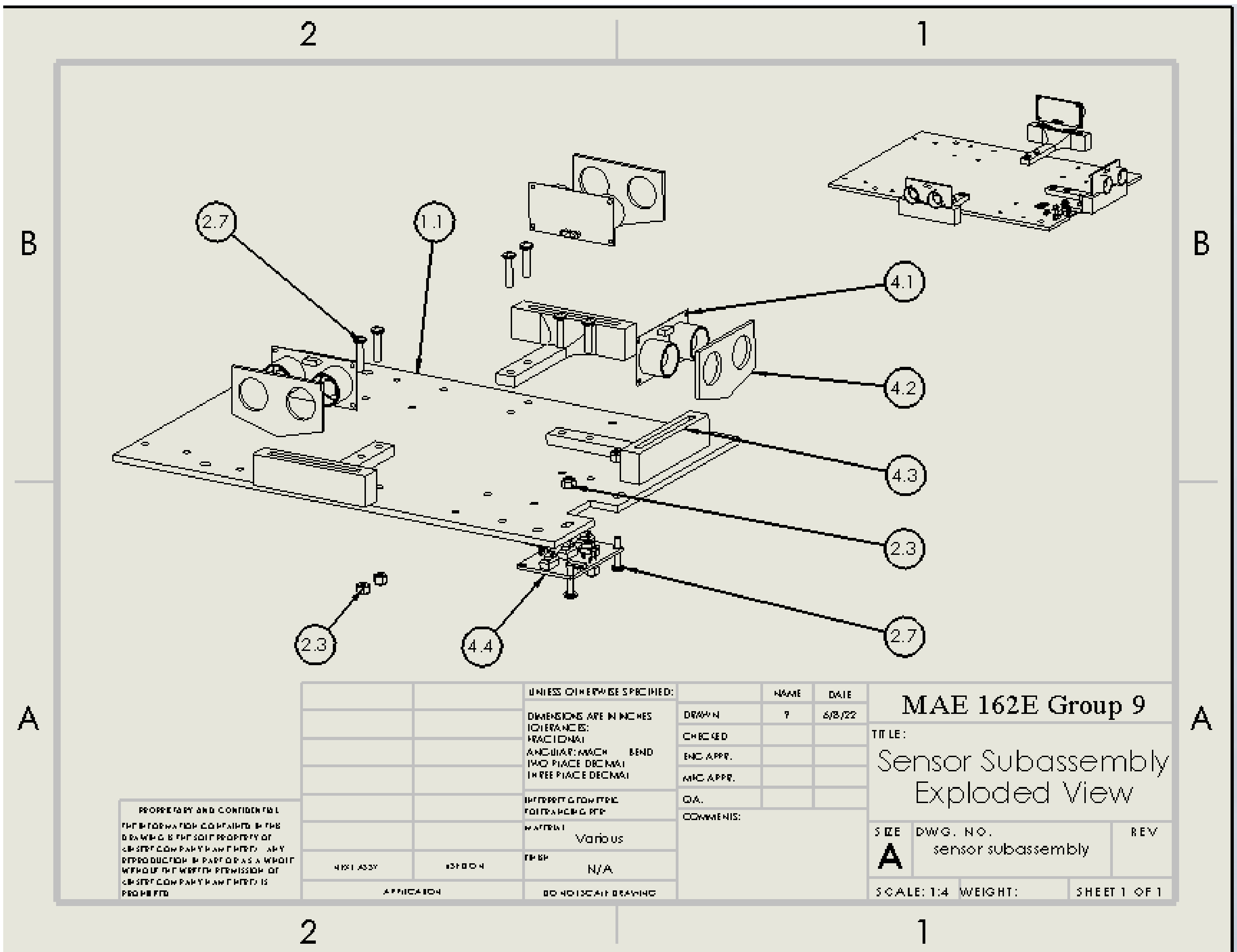


Figure 75: Sensor Subassembly Exploded View

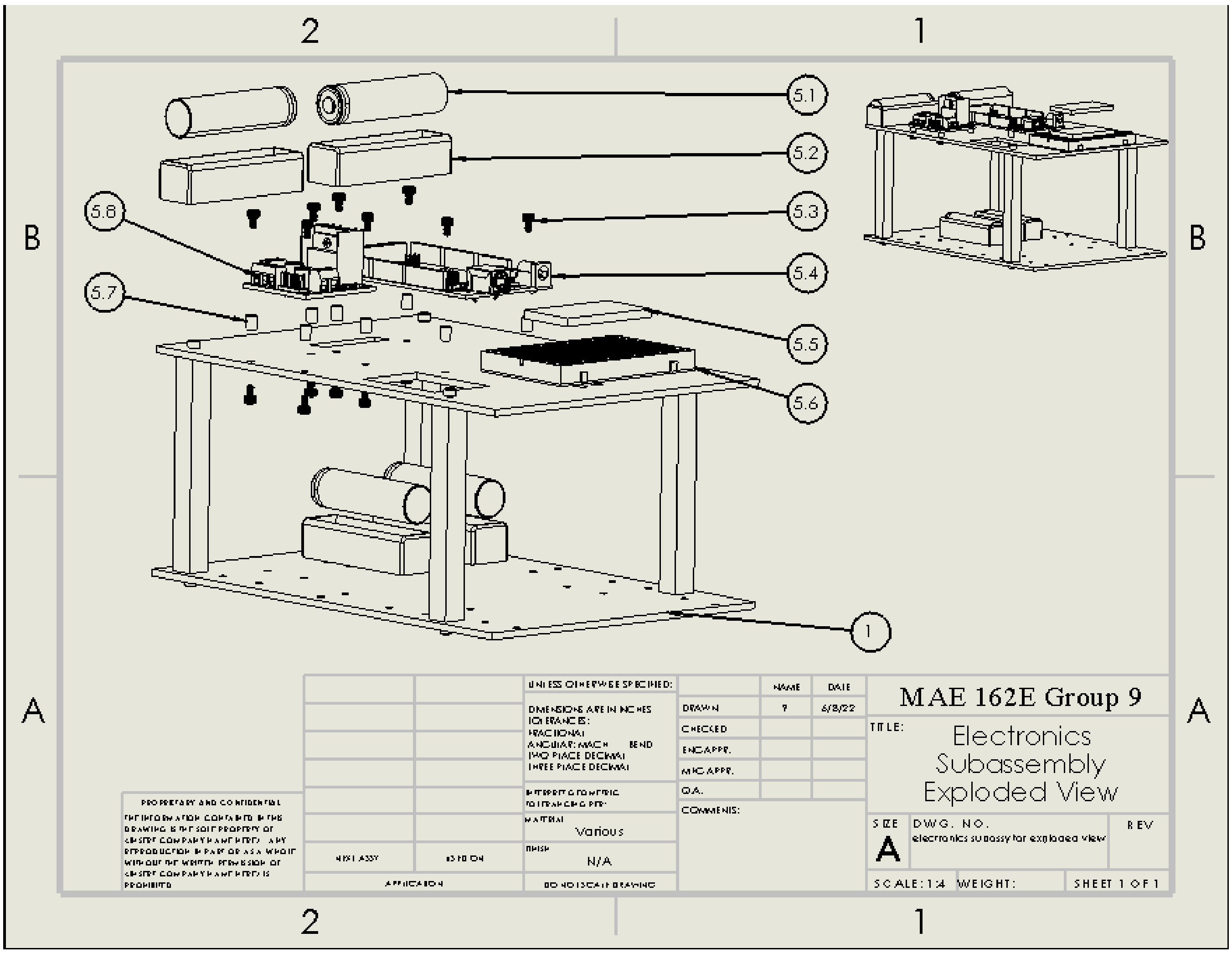


Figure 76: Electronics Subassembly Exploded View

18.1.2 Engineering Drawings of Parts

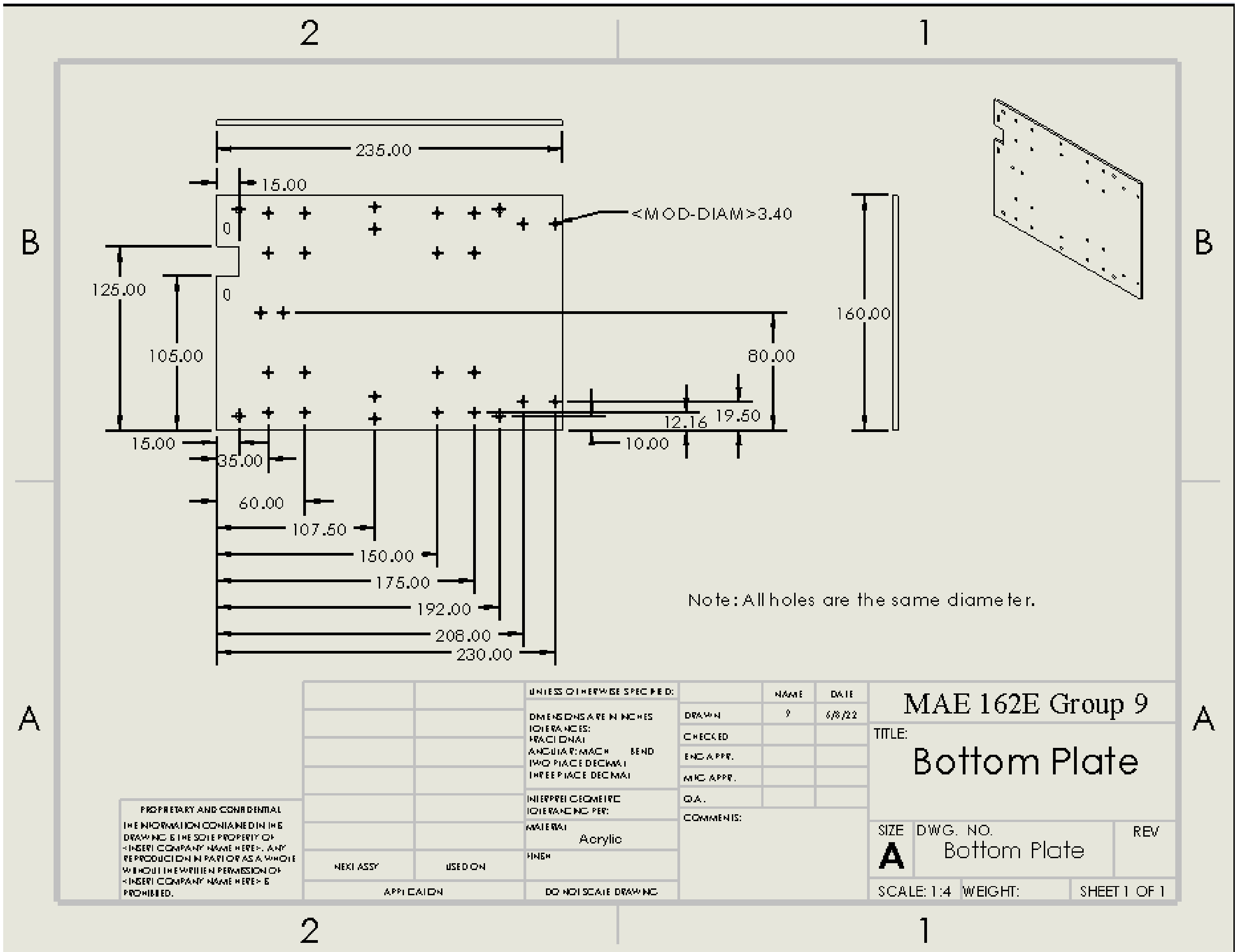


Figure 77: Bottom Plate Engineering Drawing

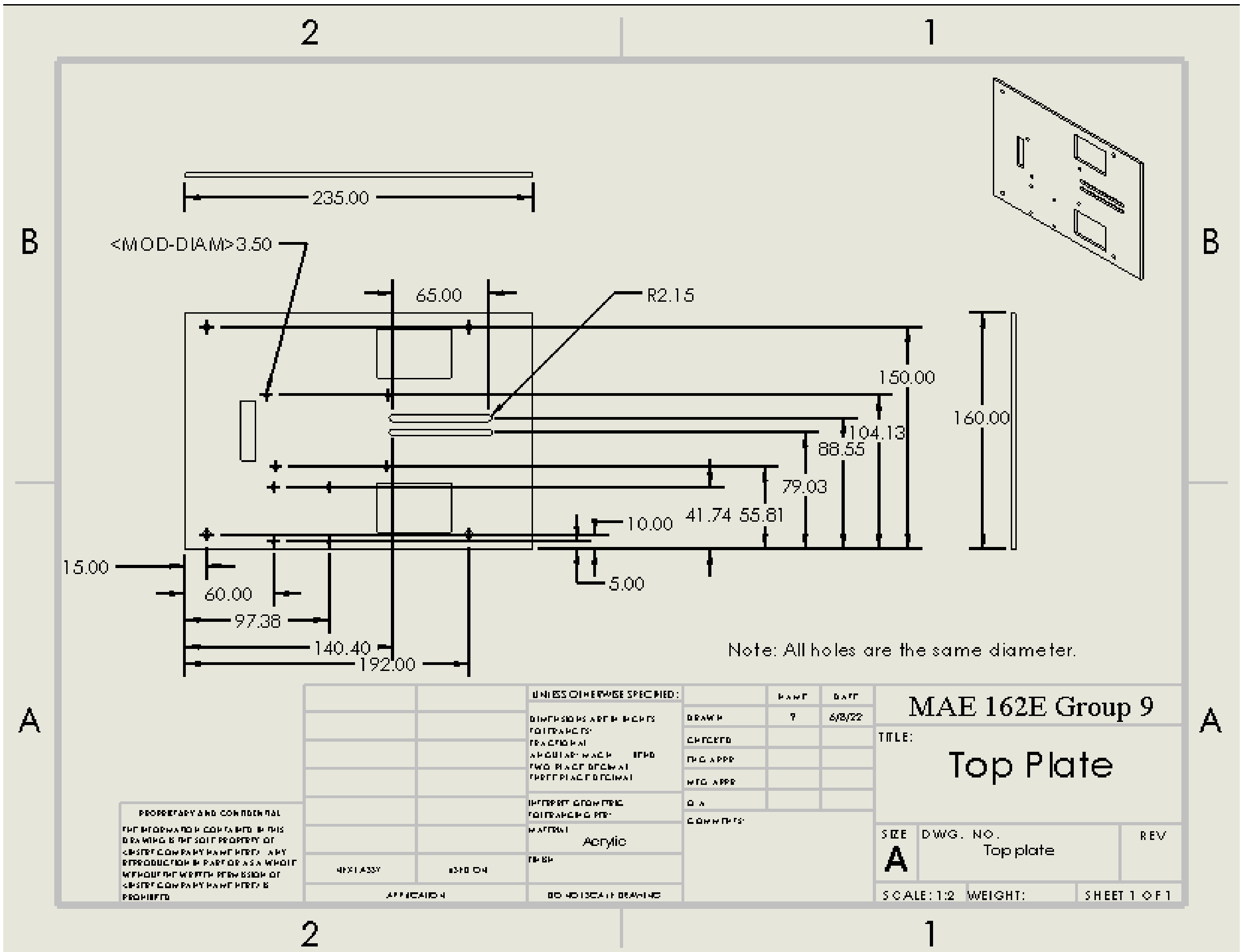


Figure 78: Top Plate Engineering Drawing

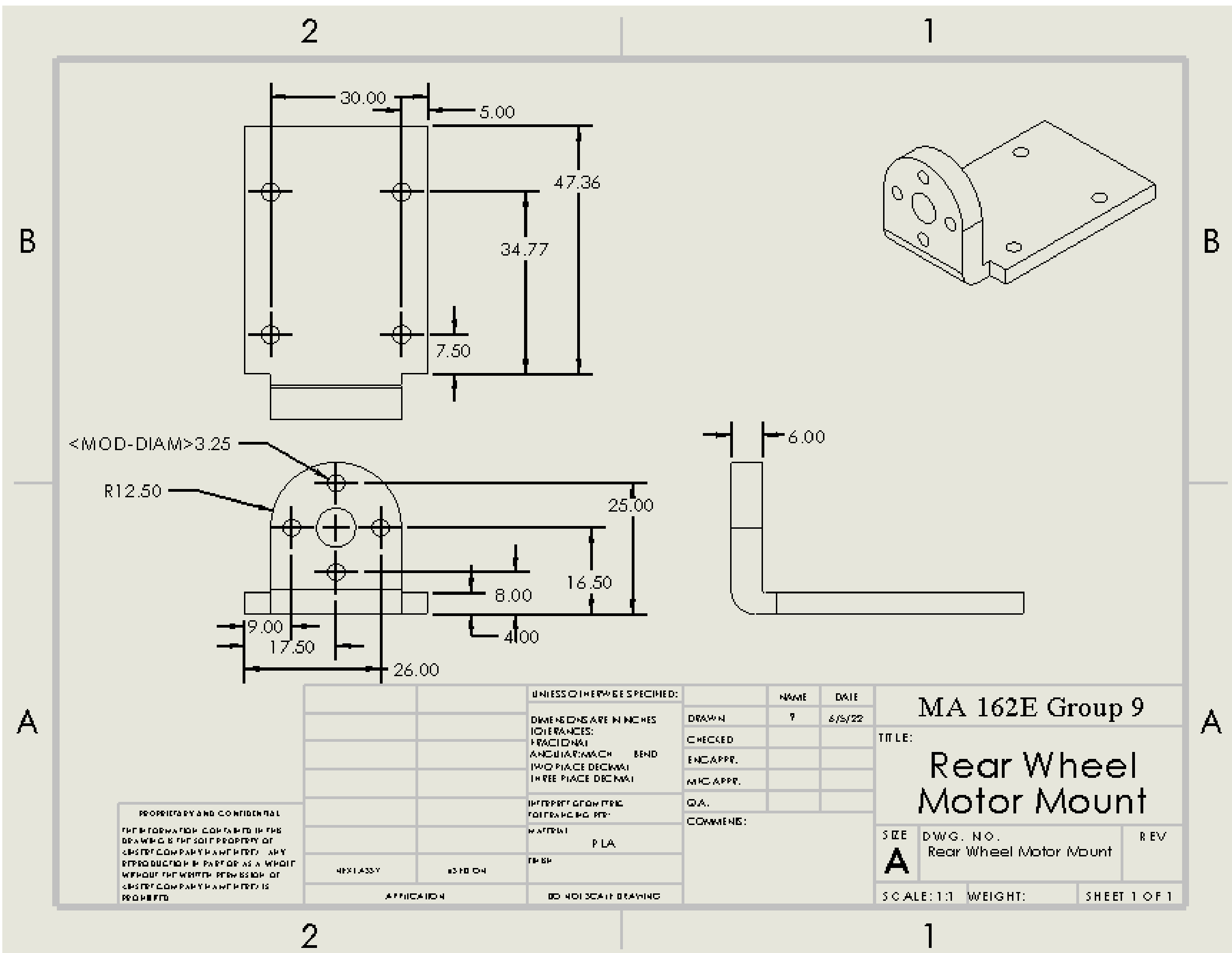


Figure 79: Rear Wheel Motor Mount Drawing

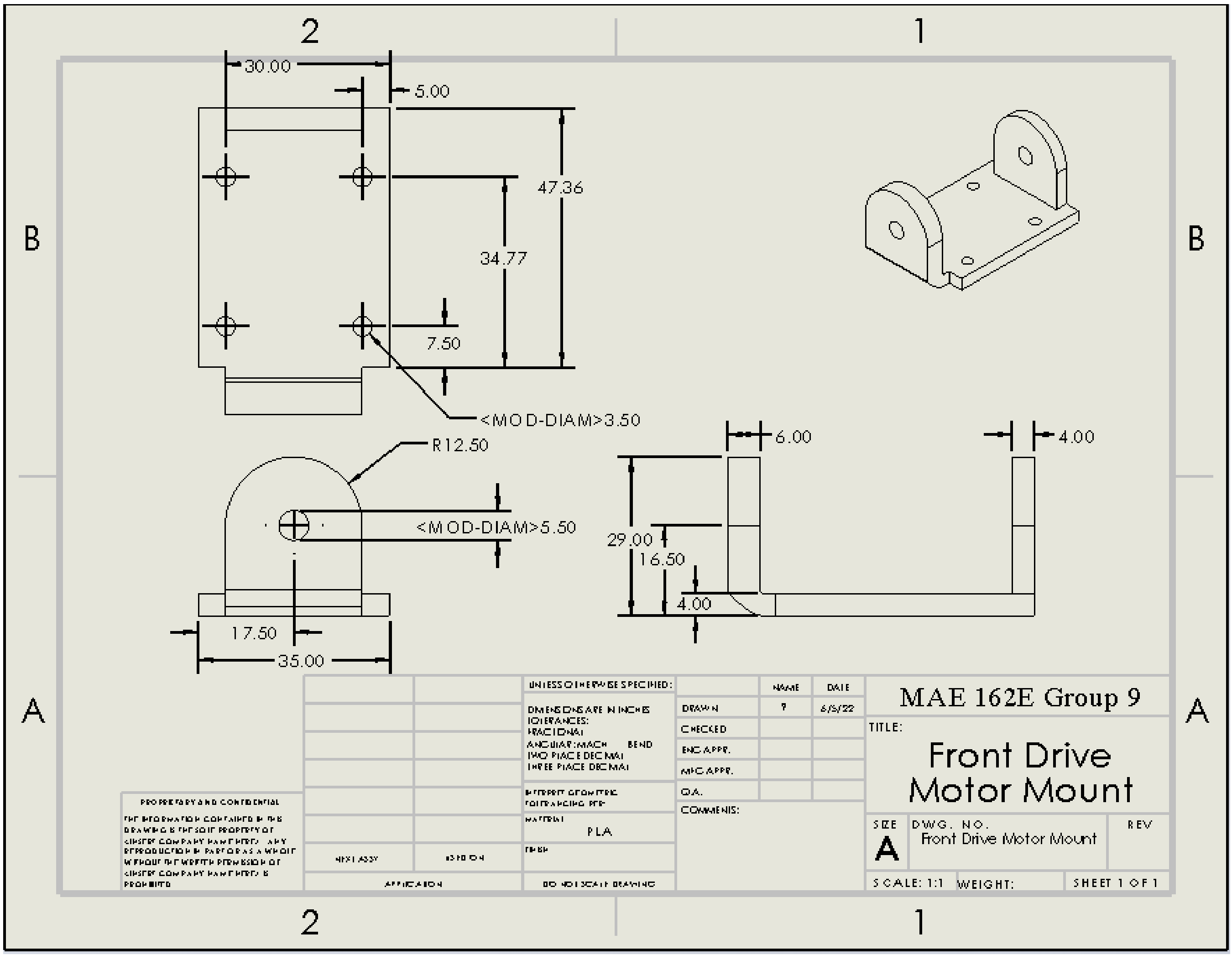


Figure 80: Front Wheel Mount Drawing

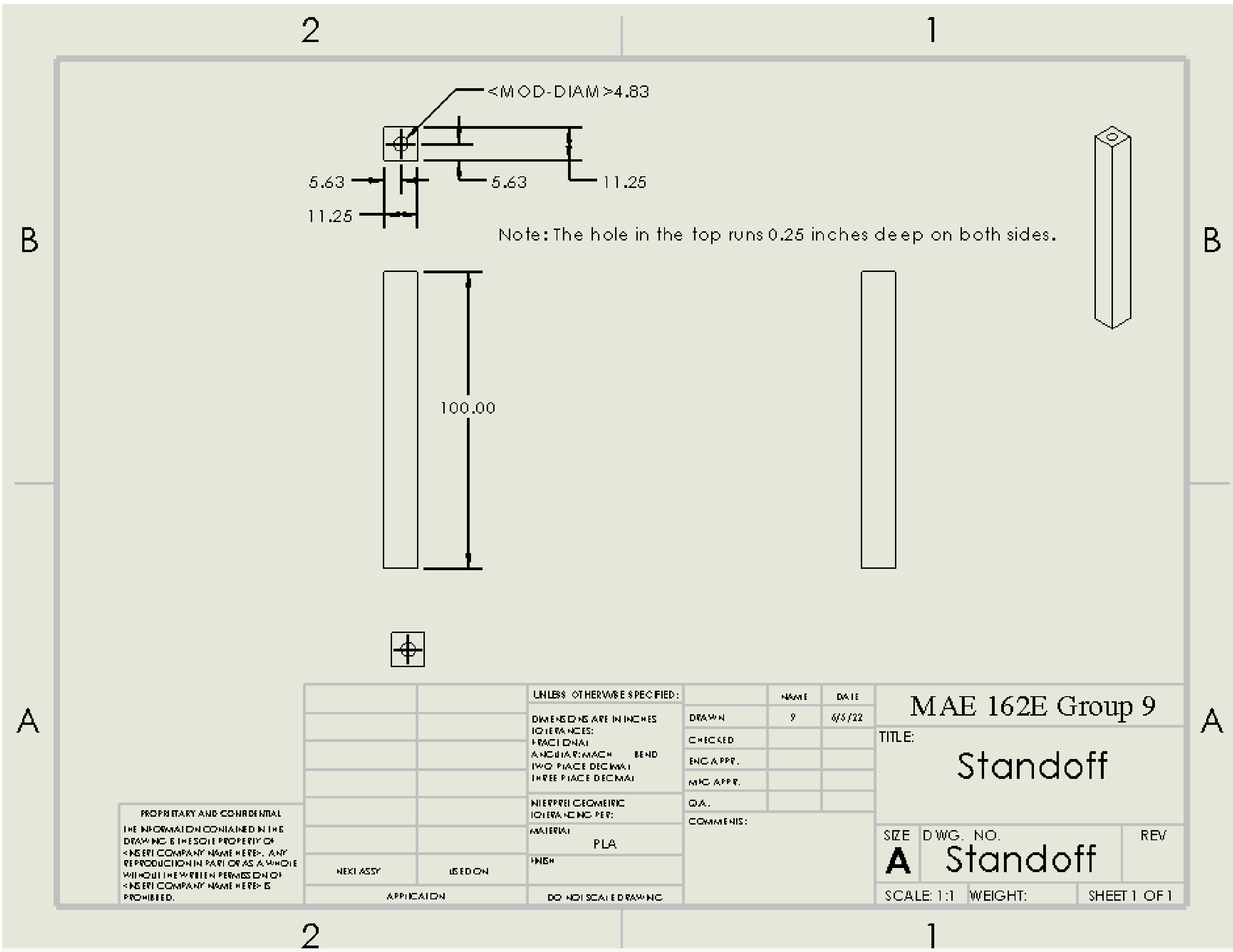


Figure 81: Standoff Drawing

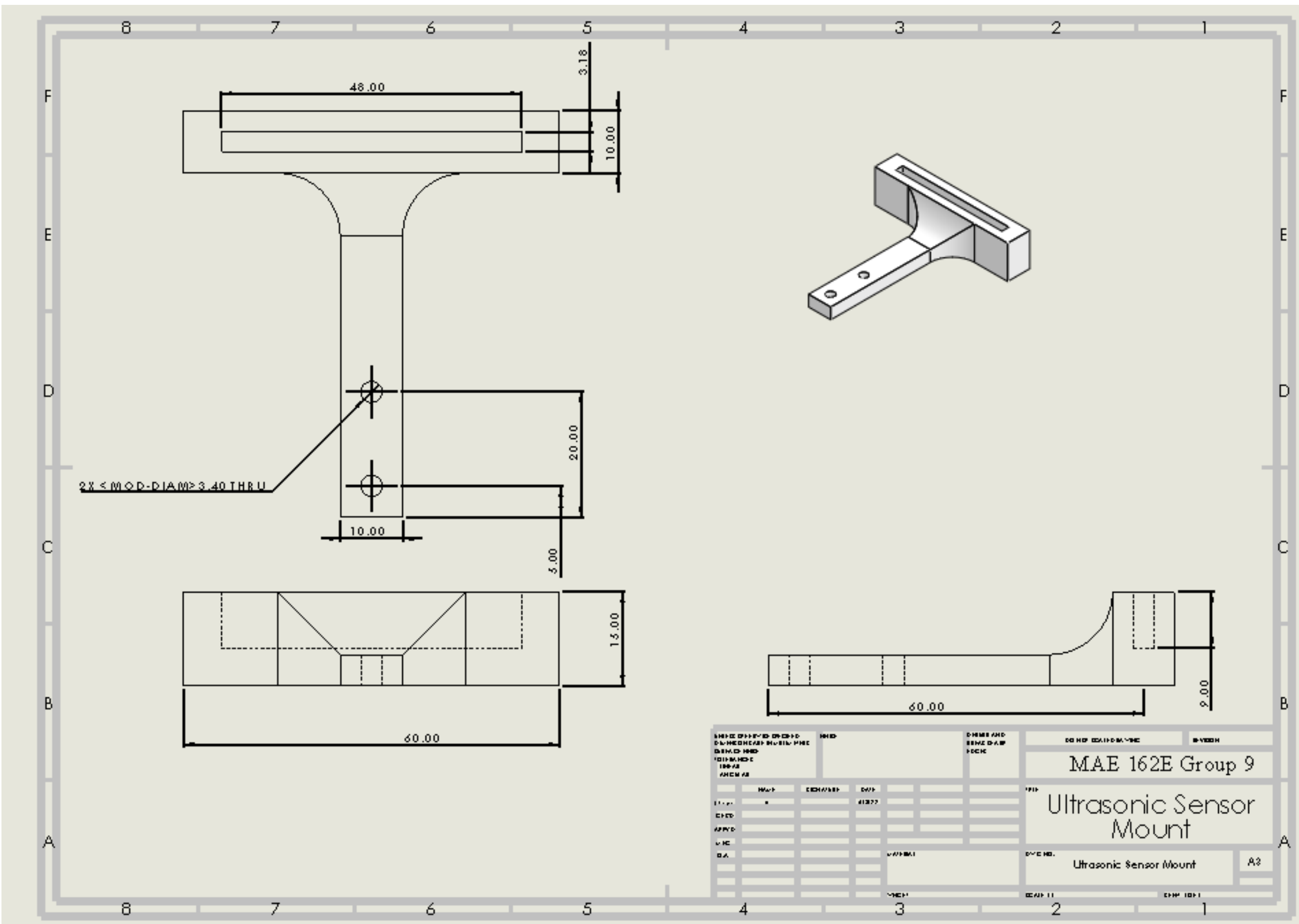


Figure 82: Ultrasonic Sensor Mount Drawing

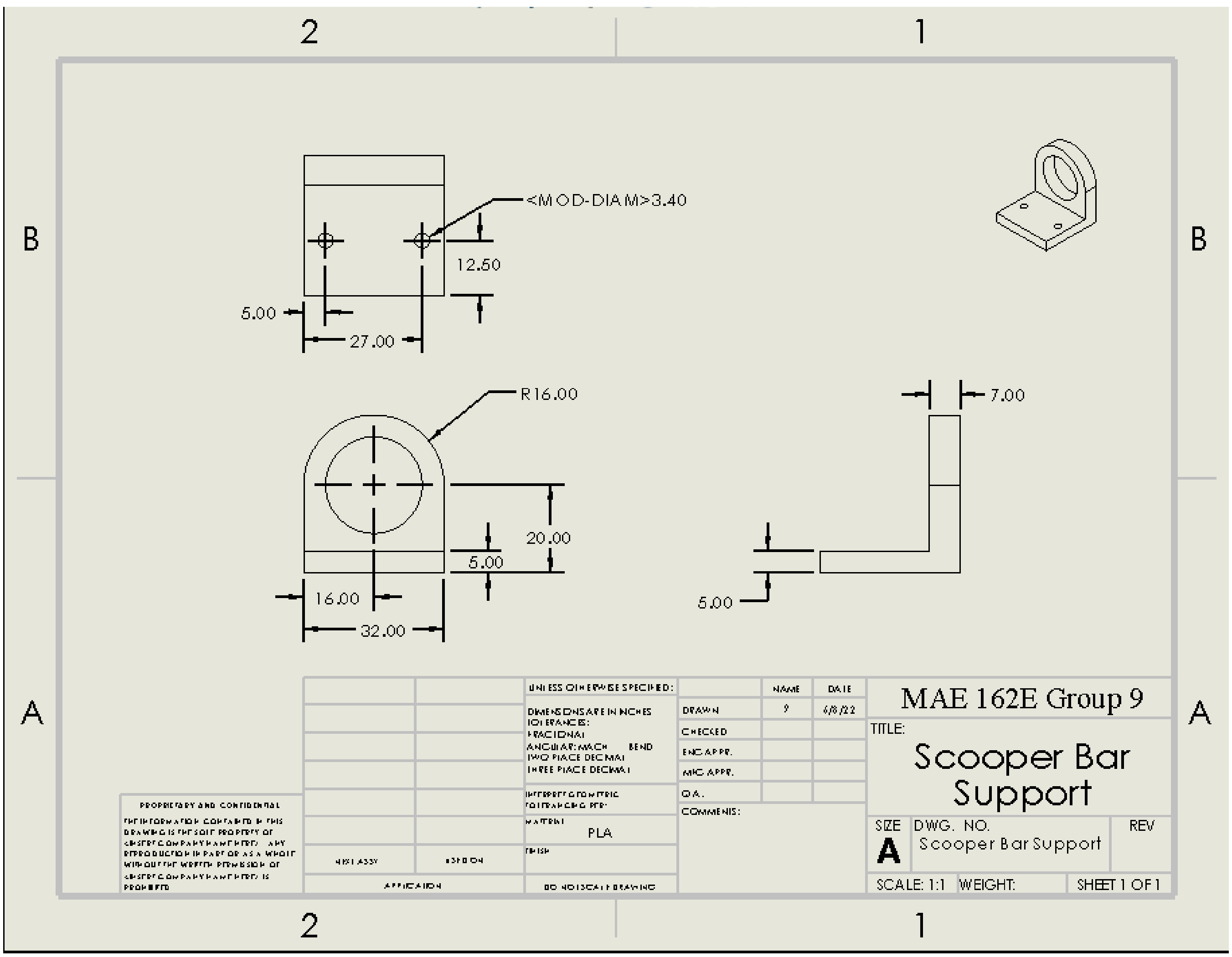


Figure 83: Scooping Mechanism Support Drawing

18.1.3 Stateflow Charts

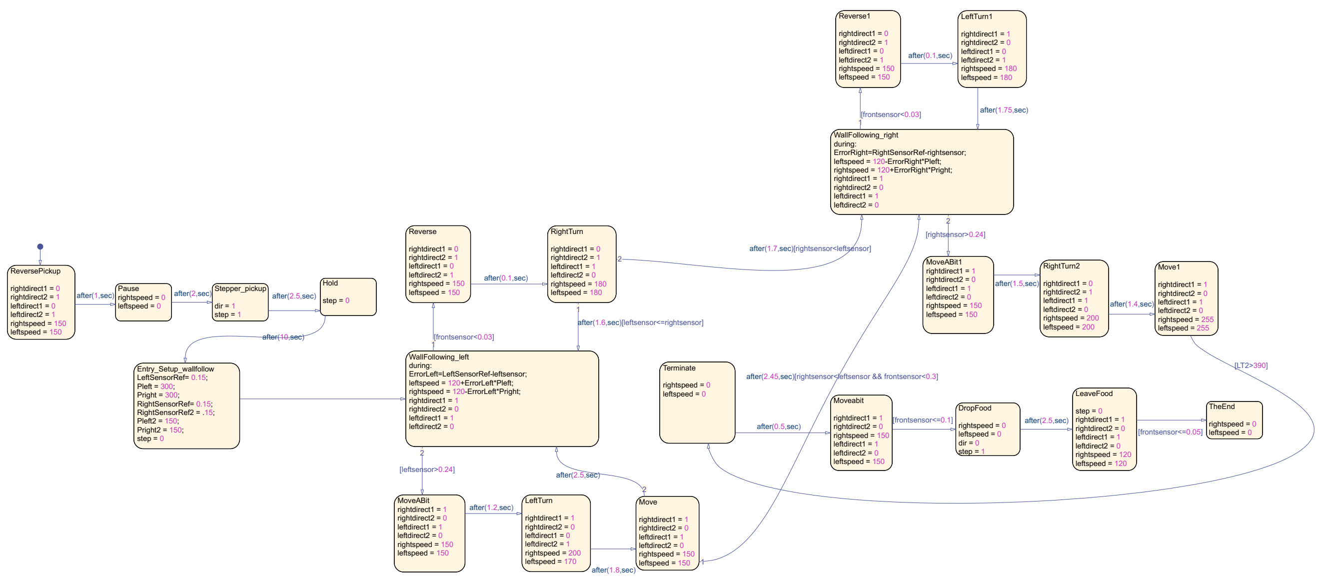


Figure 84: Overall Stateflow Chart

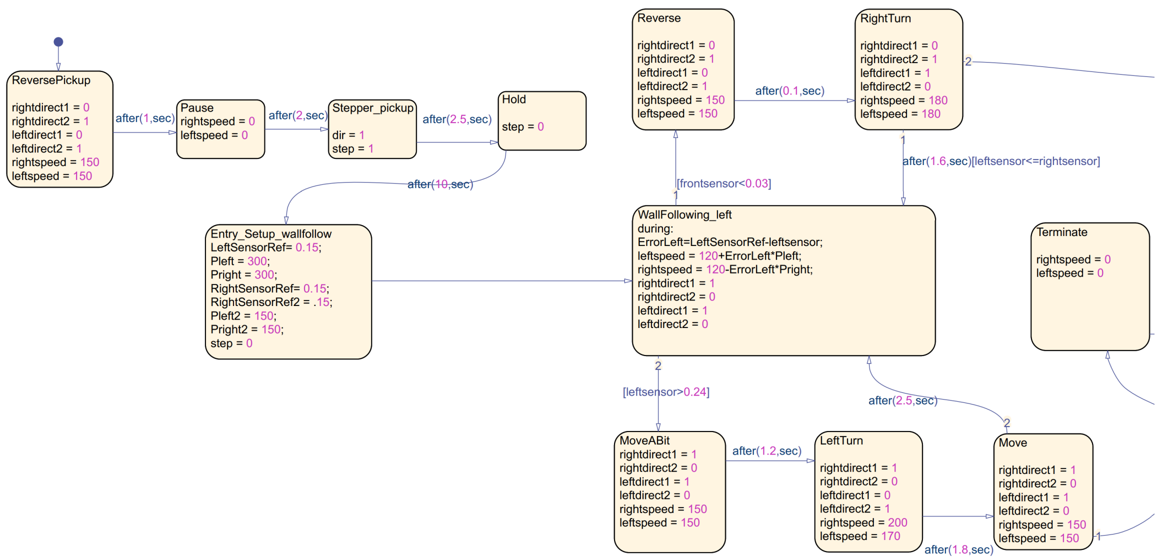


Figure 85: Left side of Stateflow Chart, zoomed in for increased legibility

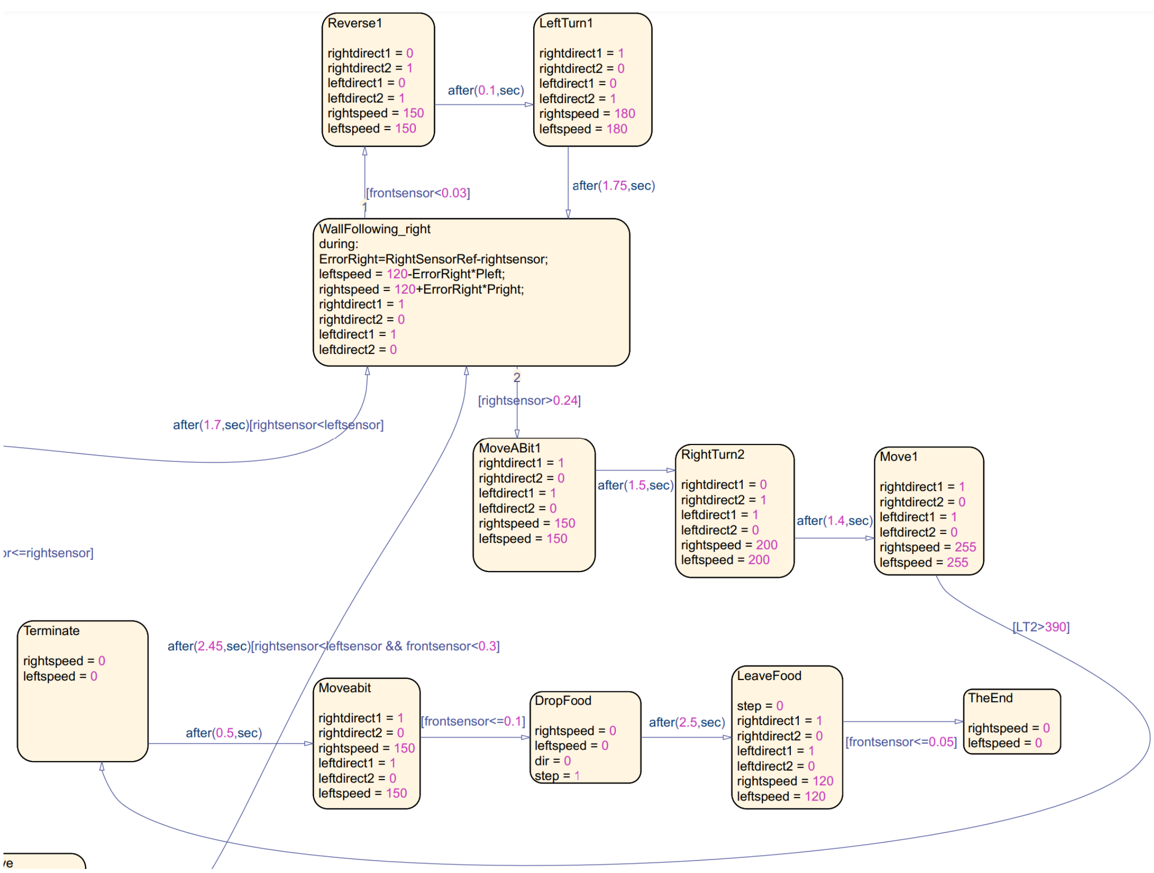


Figure 86: Right side of Stateflow Chart, zoomed in for increased legibility

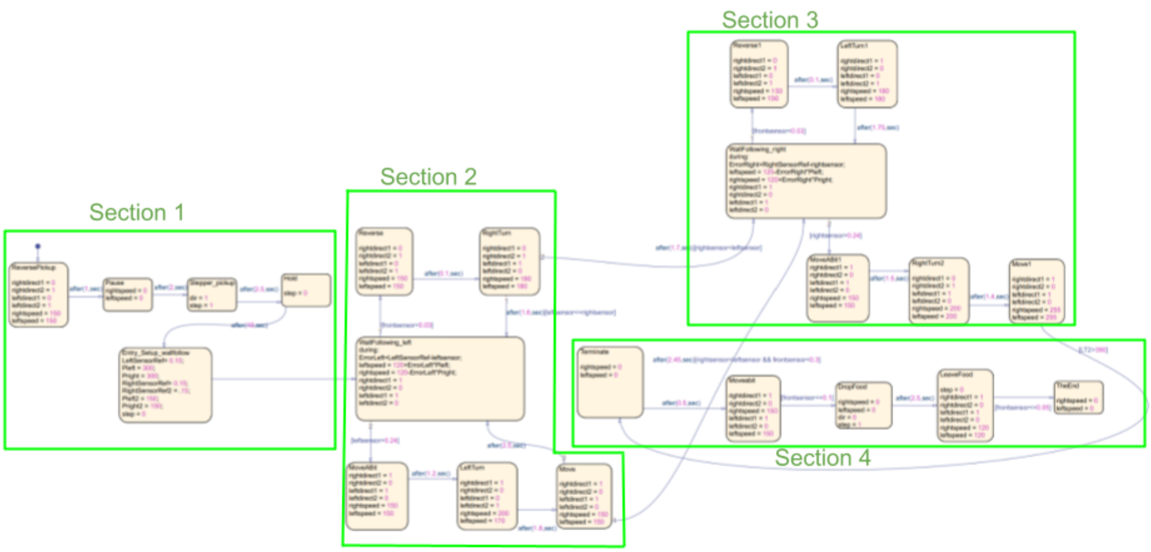


Figure 87: Overall Stateflow Chart with main sections labeled

18.1.4 Simulink Code

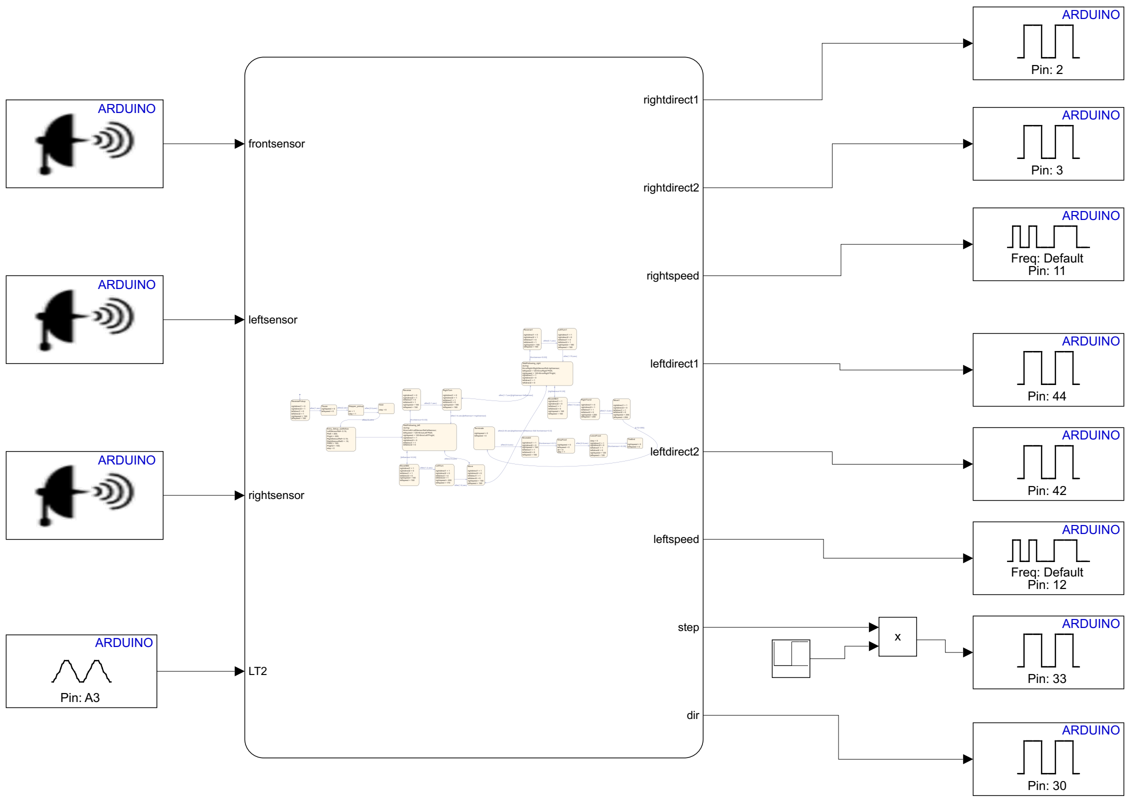


Figure 88: Overall Simulink Code

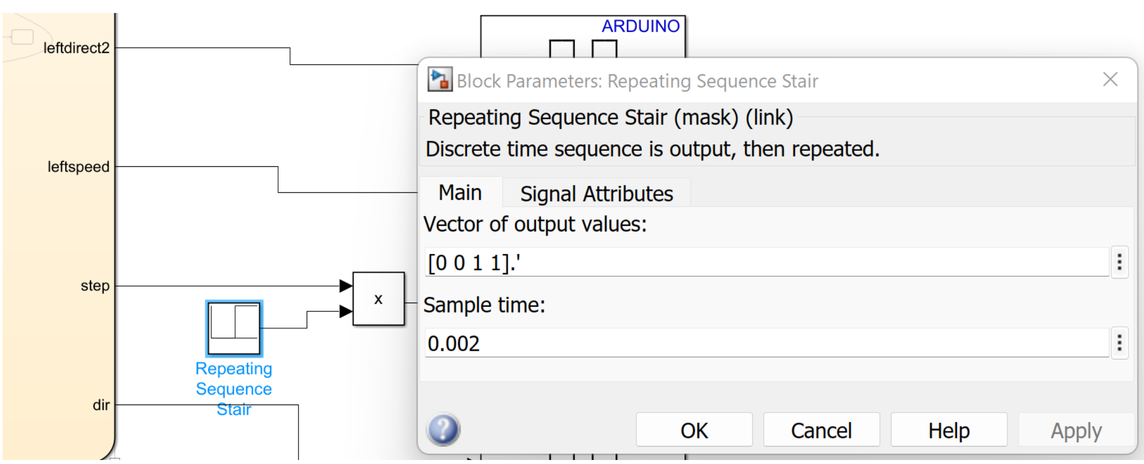
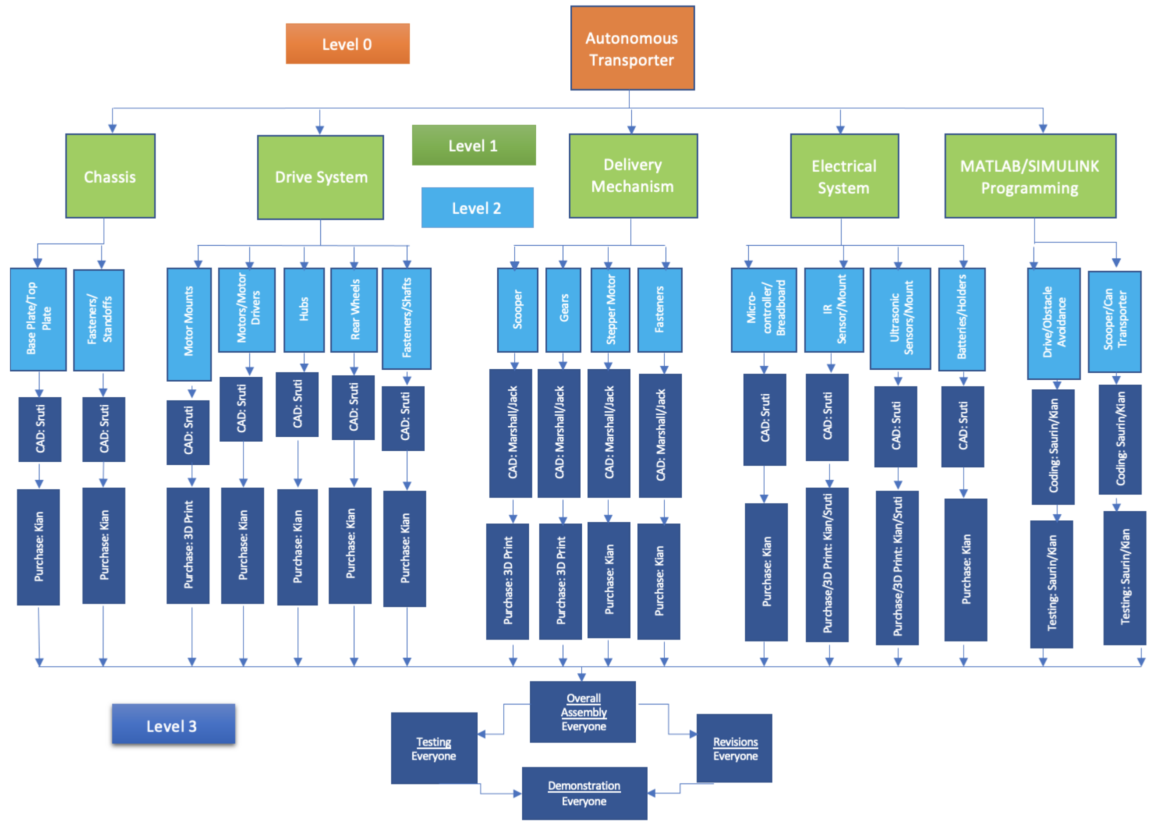


Figure 89: Simulink code with the repeating sequence stair for the stepper motor shown

18.1.5 Work Breakdown Schedule



18.1.6 Packing Slips and Receipts

Salesorder 1J476302

Order by: customer 0J198287	Ship To:	Bill To: customer
KIAN MOHSENI CAPSTONE SHAEFER 420 WESTWOOD PLZ ENG IV TAN/SHAEFER LOS ANGELES, CA 90095-8357 USA 3108256580 maesuppt@seas.ucla.edu	Same as order	AMANDA GORDILLO UCLA MAE 420 Westwood Plaza Engineering Bldg IV Los Angeles, CA 90095 USA 3106866834 MAESUPPT@SEAS.UCLA.EDU

Order date	Customer Purchase Order	Other Reference Numbers	Customer Tax ID	Payment Terms
26 Apr 2022		Web order #943976		PayPal

Ship Via USPS Priority Mail **Shipping Terms** Included in invoice **Sales Rep** N/A; web order

Order Line	Ordered	Canceled	Item Number	Item Description	Shipped	Back Order	Unit Price US$	Extended Price
1	2	0	4869	227:1 Metal Gearmotor 25Dx71L mm MP 12V with 48 CPR Encoder	0	0	45.95	91.90
2	1	0	2267	Stepper Motor: Bipolar, 200 Steps/Rev, 42×38mm, 2.8V, 1.7 A/Phase	0	0	21.95	21.95
3	4	0	1421	Pololu Wheel 60×8mm Pair - Red	0	0	5.75	23.00
4	4	0	1997	Pololu Universal Aluminum Mounting Hub for 4mm Shaft, M3 Holes (2-Pack)	0	0	8.49	33.96
5	1	0	2266	Pololu Stamped Aluminum L-Bracket for NEMA 17 Stepper Motors	0	0	3.95	3.95
6	1	0	1075	Machine Screw: M3, 5mm Length, Phillips (25-pack)	0	0	0.99	0.99

Subtotal:	175.75
S & H:	8.07
Tax:	17.46
Total:	**$201.28**
Amount paid:	**$201.28**

McMASTER-CARR

Order Confirmation

562-692-5911
562-695-2323 (fax)
la.sales@mcmaster.com

Ship to

University of California Los Angeles
U C L A Mech & Aerospace Engr
Engr IV Bldg
420 Westwood Plz
Los Angeles CA 90095

Attention Kian Capstone Shaefer
Receiving Dept

Purchase Order	Order Date
0205NZD22900	4/26/22
Ordered By	**McMaster-Carr Number**
Mae Support	8115609

Line		Product	Ordered	Delivers	Price	Total
1	2900A278	Hardened Undersized High-Speed M2 Tool Steel Rod, 4 mm Diameter, 3-1/4" Long	2 each	Apr 27	3.48 each	6.96
2	6056N12	Carbon Steel Set Screw Collar for 4 mm Shaft Diameter, DIN 705	2 each	Apr 27	1.77 each	3.54
3	91800A057	18-8 Stainless Steel Narrow Cheese Head Slotted Screws, M1 x 0.25mm Thread, 5mm Long, packs of 5	1 pack	Apr 27	7.46 per pack	7.46
4	91292A113	18-8 Stainless Steel Socket Head Screw, M3 x 0.5 mm Thread, 10 mm Long, packs of 100	1 pack	Apr 27	6.00 per pack	6.00
5	90591A311	Zinc-Plated Steel Hex Nut, Low-Strength, M1 x 0.25 mm Thread, packs of 10	1 pack	Apr 27	4.47 per pack	4.47
6	90576A102	Medium-Strength Steel Nylon-Insert Locknut, Class 8, Zinc Plated, M3 x 0.5 mm Thread, 4 mm High, packs of 100	1 pack	Apr 27	4.65 per pack	4.65

Merchandise	33.08
Shipping	15.43
Tax	3.14
Total	$51.65

Thank you!

Your order has been placed!

Your Order Confirmation is: #C2204S0616

Shipping Information

MAE CAPSTONE
KIAN MOHSENI
420 WESTWOOD PLAZA
ENG IV, 18-117
LOS ANGELES, CA 900095

Billing Information

XXXX0452
05 /2024
XXX
UCLA MAE
420 Westwood Plaza
Los Angeles,CA 90095

Order Details

Catalog Number	Unit Price	Qty	Subtotal
A 6R 3M038060 TIMING BELT 5.08P	$5.89	1	$5.89

Sub Total:	$5.89
Shipping:	$13.18
Tax:	$0.00
Total:	**$29.07**

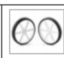
My Account »

Salesorder 1J477910

Order by: customer 0J198287	Ship To:	Bill To: customer 0J198287
KIAN MOHSENI PROF SHAEFER 420 WESTWOOD PLZ ENG IV PROF SHAEFER CAPSTONE LOS ANGELES, CA 90095-8357 USA 3108256580 maesuppt@seas.ucla.edu	Same as order	AMANDA GORDILLO UCLA MAE 420 Westwood Plaza Engineering Bldg IV Los Angeles, CA 90095 USA 3106866834 maesuppt@seas.ucla.edu

Order date	Customer Purchase Order	Other Reference Numbers	Customer Tax ID	Payment Terms
18 May 2022		Web order #946902		Visa ending in 0452

Ship Via USPS Priority Mail **Shipping Terms** Included in invoice **Sales Rep** N/A; web order

Order Line	Ordered	Item Number	Item Description	Shipped	Back Order	Unit Price US$	Extended Price
1	4	1439	 Pololu Wheel 90×10mm Pair - White	4	0	7.95	31.80
2	1	2134	 DRV8834 Low-Voltage Stepper Motor Driver Carrier	1	0	9.95	9.95

Subtotal:	41.75
S & H:	8.45
Tax:	4.77
Total:	**$54.97**
Amount paid:	**$54.97**

McMASTER-CARR

Order Confirmation

562-692-5911
562-695-2323 (fax)
la.sales@mcmaster.com

Ship to

University of California Los Angeles
U C L A Mech & Aerospace Engr
Engr IV Bldg
420 Westwood Plz
Los Angeles CA 90095

Attention Kian Mohseni - Tan: 18-117 E4
Receiving Dept

Purchase Order	Order Date
0205NZD48500	5/13/22
Ordered By	**McMaster-Carr Number**
Mae Support	1037829

Line		Product	Ordered	Delivers	Price	Total
1	5972K91	Ball Bearing, Open, Trade Number 608, for 8 mm Shaft Diameter	2 each	May 16	4.82 each	9.64
2	92005A124	Steel Pan Head Phillips Screw, M3 x 0.5 mm Thread, 14 mm Long, packs of 100	1 pack	May 16	5.79 per pack	5.79
3	2705T114	Light Duty Dry-Running Flanged Sleeve Bearing, Thermoplastic-Blend, for 4 mm Shaft Diameter, 6 mm Long	4 each	May 16	1.38 each	5.52

Merchandise	20.95
Shipping	7.73
Tax	1.99
Total	$30.67