Milestone 9
Final Design Briefs
Material Mermaids

Ava Mantzouranis, Benjamin Fichter, Nicholas Scozzafava, Maren Iski, Charlotte Grohowski, Ethan Monders, Alfonso Gruss, Michael Baugh

[redacted]

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Section #1:

The base of the OTV is made using a half inch piece of plywood, cut into required dimensions. Four motors are attached to each corner of the base(Figure 1.2), with four regular wheels attached to each motor(Figure 1.5). Two ultrasonics are placed on the inside of the front two wheels (Figure 1.1), while two others are placed in between the front and the back wheels(Figure 1.4). For the scoop/ramp, a thin sheet of plywood is attached to the base of the OTV. Wood is stacked on top of the back side of the plywood until it reaches the height of the OTV. The stack is then glued to the underside of the wood base. The scoop(ours was cut in half so that it was short enough), is then glued to the front of the thin plywood(Figure 1.1). In the space between the base and the scoop, the weight sensor is placed so that the ball will roll up the ramp and land on the scale. To create enough friction, tape over the wheels and add hot glue. All wiring and electronics can be placed on top of the base.

Figure 1.1

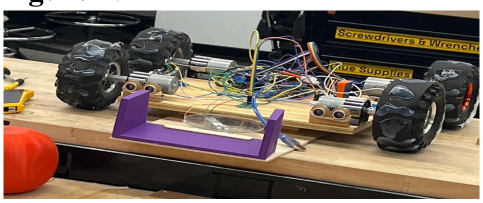


Figure 1.2

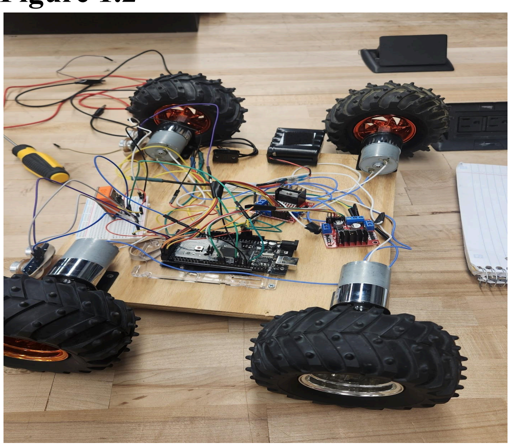


Figure 1.3

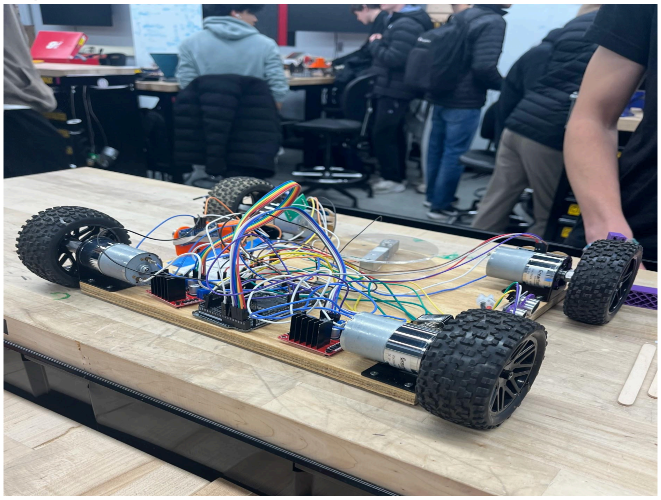


Figure 1.4

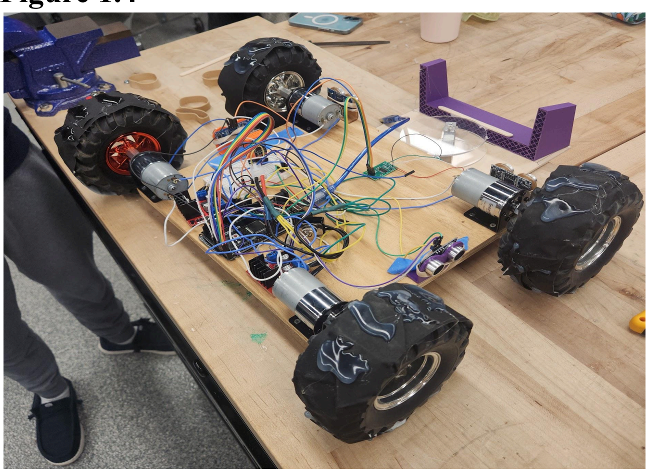


Figure 1.5

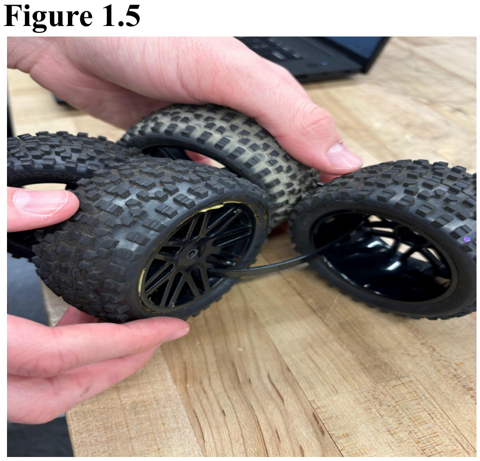
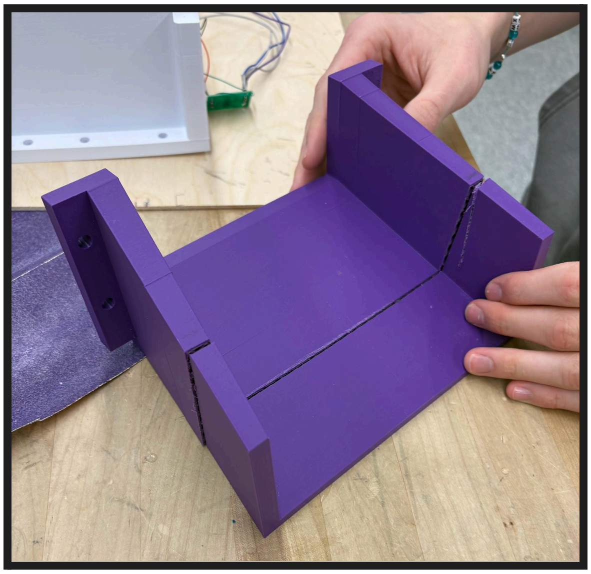


Figure 1.6



Section #2:

The mission objectives for the OTV include the standard objectives shared among all teams, as well as objectives tailored to our material identification goals. The standard objectives include navigating to within 150 millimeters of the mission site. This requires the OTV to start from one of two starting positions, at any orientation, and adjust its orientation to travel 150 kilometers to the other starting position. Another standard objective is the OTV's ability to navigate completely past three obstacles. Starting from either of the two points, at any orientation, the OTV must reorient itself and maneuver past three obstacles, which can be randomly positioned and oriented. The OTV must then reach the non-obstacle zone beyond these obstacles, indicating successful navigation. The final standard objective is for the OTV to navigate completely into the destination zone. After passing the obstacles and entering the designated area, the OTV must travel under the passageway, to the left of the log, indicating successful mission completion.

For material identification objectives, the goals include picking up the ball, weighing the ball, and determining the correct composition and type of the ball. For the first objective, the ball will start at either of the two starting positions, and the OTV must travel to the ball's location and lift it off the ground using various techniques. For the second objective, the OTV must place the ball onto a weighing mechanism to determine whether it is heavy, medium, or light. Finally, the OTV must identify the ball's composition, determine whether it is made of rigid plastic or foam, and accurately display this information on the vision system.

To meet these requirements, our team designed an OTV with capabilities for movement, lifting, weighing, and material identification. These capabilities are described in further detail in the report.

Section #3: Propulsion Modeling:

Configuration, Wheel Size, Motor Selection, Drive Train, and Steering System:

Our OTV uses a four wheel drive train configuration, with each wheel with radius 0.0762 m powered by its own motor. All four wheels are directly driven and are directly coupled to the motor's shaft. Each wheel is driven by a Greartisan 12 V DC geared motor rated at 200 RPM with a 37mm diameter gearbox. These motors were selected for their high torque at low speeds. Steering was achieved through moving wheels on the right and left sides at differing speeds independently.

Figure 3.1 FBD:

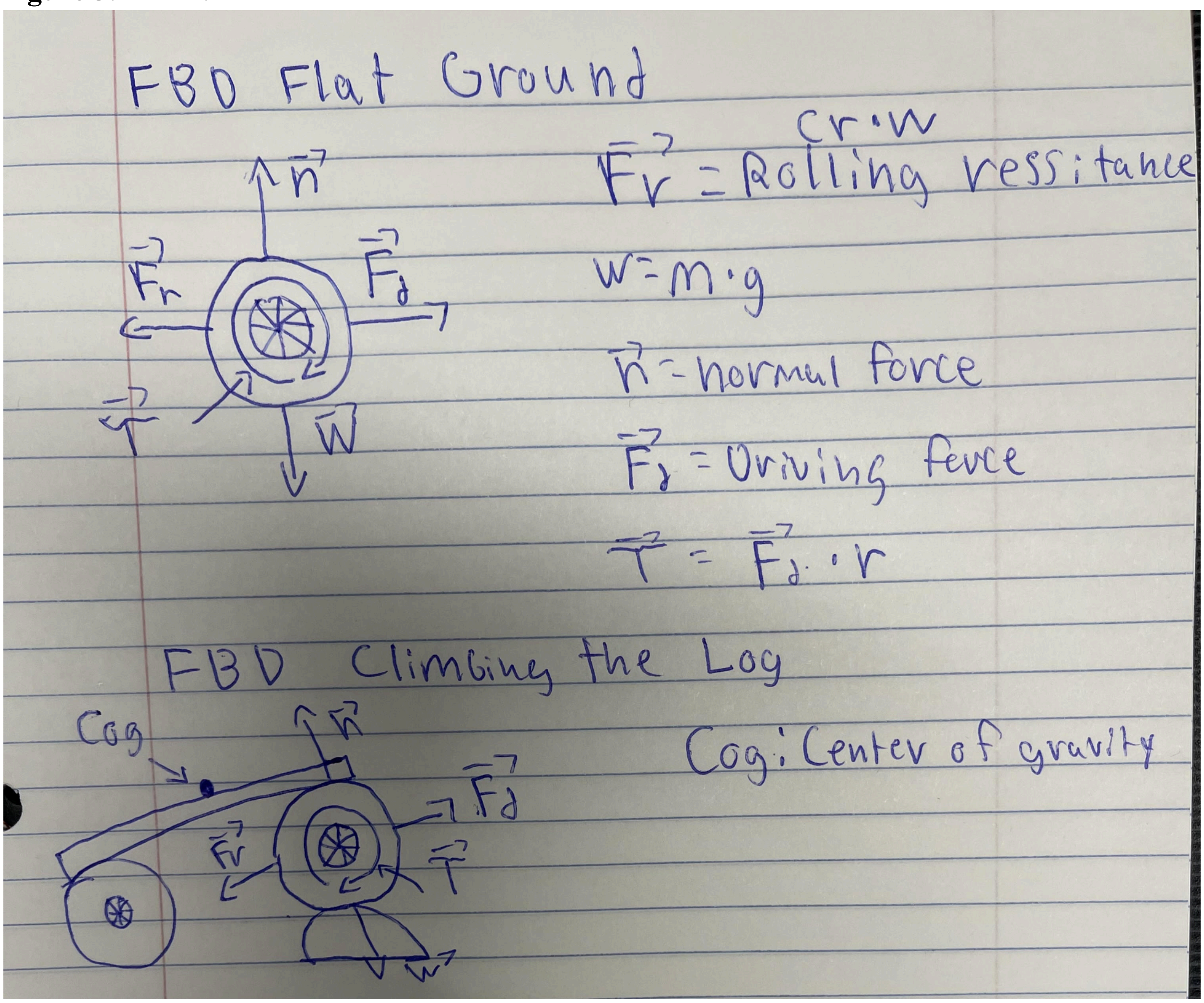


Figure 3.2

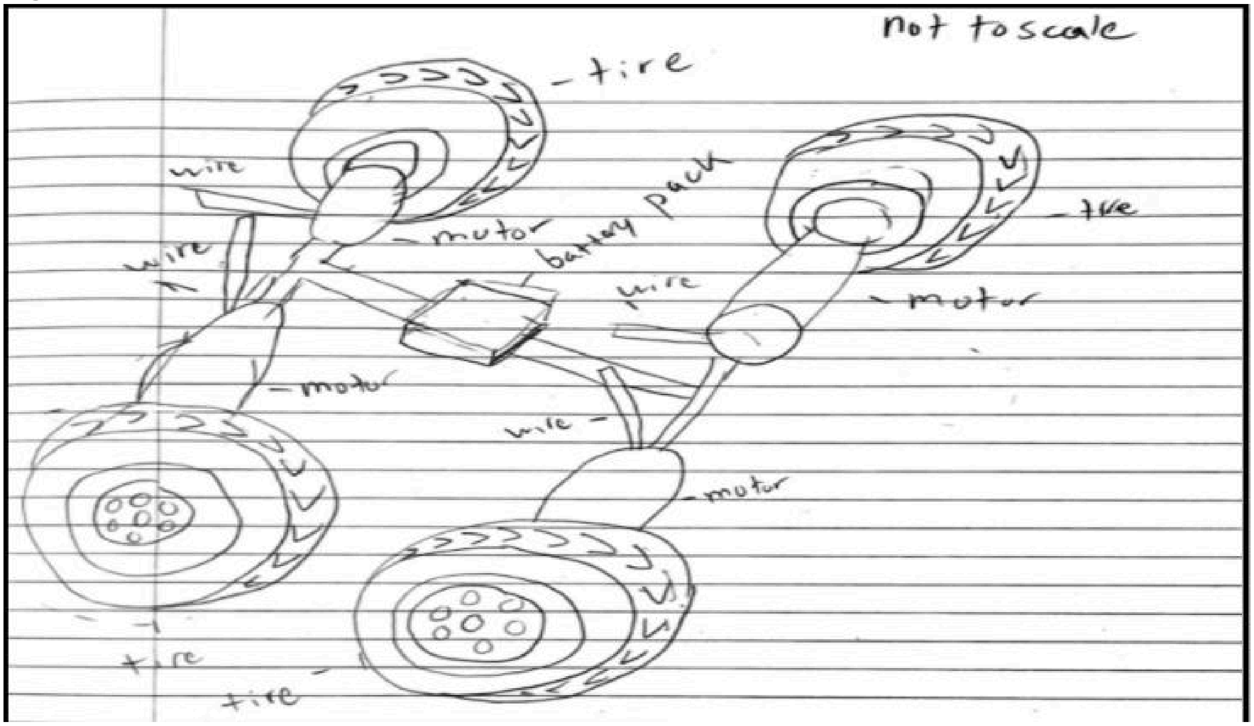
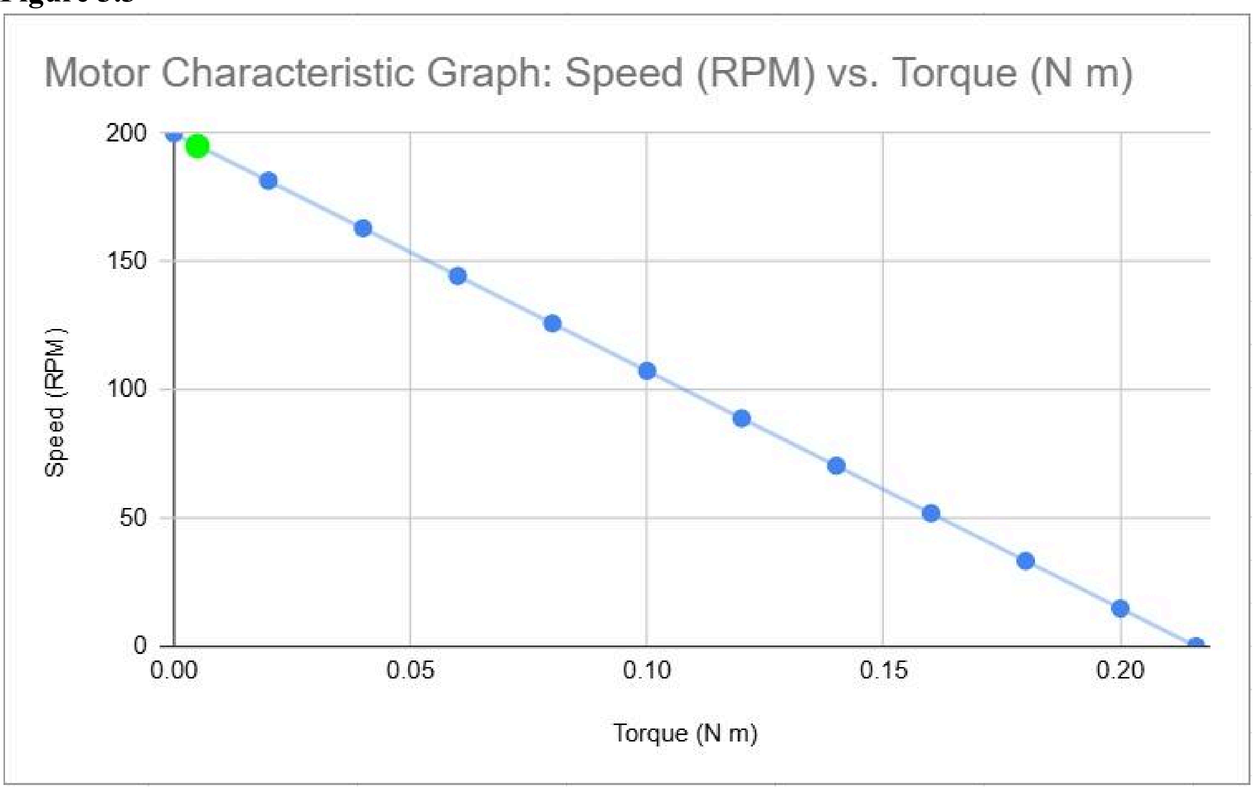


Figure 3.3



As seen in Figure 3.1 the driving force is equal to the rolling resistance. Rolling resistance is also equal to the coefficient of rolling resistance multiplied by the mass of the OTV and gravity. The rolling resistance of our OTV falls between 0.0537 N and 0.403 N. The torque of the wheels can be calculated by multiplying the rolling resistance by the radius of the wheel. The torque of the wheels falls between 0.0041 N m and 0.0307 N m. The torque per motor can be found to be between 0.0010 N m and 0.0077 N m. The green point in Figure 3.3 shows the operating point of the OTV. The torque at this point is 0.005 N m and the angular speed is 195 RPM. The target linear speed for the OTV was selected to allow for timely completion of the mission and to maintain control when navigating obstacles. The target linear speed for our OTV was 1.0 m/s. The OTV's operating linear speed is 1.56 m/s showing that the motors were too powerful for the size of the OTV. The operating current for one of the motors is 0.5 A, so with four motors on the OTV the operating current is 2.0 A.

The OTV's actual linear speed was 0.625 m/s which is much lower than the calculated operating linear speed. This is because the operating speed was too fast for the vision system, so the OTV needed to move slower to accomplish the mission objectives. The actual angular speed was 78.3 RPM which is also much slower than the calculated angular speed. The actual operating torque of 0.131 N m is much higher than the predicted operating torque. These numbers vary because of the friction between the wheels and the ground and uneven load distribution between the four wheels. Even with the addition of the hot glue to the bottom of the wheels the wheels of the OTV still slipped and did not fully grip the surface. The OTV also had a tilt toward one side which resulted in an uneven load distribution. These two factors resulted in a loss of linear speed and a large difference between the predicted torque and the actual torque value.

Calculations:

Rolling Resistance Force

$$F_r = \mu_r m g$$

$$F_{r,min} = 0.002 \cdot 2.7407 \cdot 9.81 = 0.0537\,N$$

$$F_{r,max} = 0.015 \cdot 2.7407 \cdot 9.81 = 0.403\,N$$

$$\sum F_x = 0$$

$$F_{\{Drive\}} = F_r$$

Total Torque Required at Wheels

$$T_{\{Total\}} = F_r r$$

$$T_{\{Total\}, min} = 0.0537 \cdot 0.0762 = 0.0041\, N \cdot m$$

$$T_{\{Total\}, max} = 0.403 \cdot 0.0762 = 0.0307\, N \cdot m$$

Torque Required per Motor

$$T_{\{Motor\}} = \frac{\{T_{\{Total\}}\}}{\{4\}}$$

$$T_{\{Motor\}, min} = \frac{0.0041}{\{4\}} = 0.0010\, N \cdot m$$

$$T_{\{Motor\}, max} = \frac{0.0307}{\{4\}} = 0.0077\, N \cdot m$$

Goal Angular Speed of the wheel

$$\omega_{goal} = \frac{v_{goal}}{r}$$

$$\omega_{goal} = \frac{1}{0.0762} = 13.12\, rad/s$$

Convert Angular Speed to RPM

$$RPM_{goal} = \frac{\omega_{goal}\, 60}{2\pi}$$

$$RPM_{goal} = \frac{13.12 \cdot 60}{2\pi} = 125.3\, RPM$$

DC Motor Torque-Speed Relationship

$$\omega = \omega_{no\ load}\left(1 - \frac{T}{T_{Stall}}\right)$$

$$\omega_{min\ load} = \omega_{no\ load}\left(1 - \frac{0.001}{0.216}\right) = 199.1\, RPM$$

$$\omega_{max\ load} = \omega_{no\ load}\left(1 - \frac{0.0077}{0.216}\right) = 192.9\, RPM$$

Predicted Linear Speed from Motor RPM

$\omega = \frac{(2\pi \cdot 195)}{60} = 20.43\ rad/s$

$v = r\omega$

$v = 0.0762 \cdot 20.43 = 1.56\ m/s$

Operating Current

$I_{total} = 4\, I_{motor}$

$I_{total} = 4(0.5) = 2\ A$

Measure Actual Linear Speed

$v_{actual} = \frac{distance}{time} = \frac{1m}{1.6\ s} = 0.625$ m/s

Actual Angular Speed

$\omega_{actual} = \frac{v_{actual}}{r} = \frac{0.625}{0.0762} = 8.20\ rad/s$

$RPM_{actual} = \frac{\omega_{actual} \cdot 60}{2\pi} = \frac{8.20 \cdot 60}{6.2832} = 78.3\ RPM$

Actual Operating Torque

$T_{actual} = T_{stall}(1 - \frac{\omega_{actual}}{\omega_{no\ load}}) = 0.216(1 - \frac{78.3}{200}) = 0.131\ N \cdot m$

Section #4: Electronics:

Component	Quantity	Current (mA) per Unit	Total Current (mA)
DC Motors (via 2× L298N)	4	500	2000
HC-SR04 Ultrasonic Sensors	4	15	60
WiFi Module	1	80	80
FSR402 (Force Sensor)	1	1	1
HX711 (with load cell)	1	1.5	1.5

Total Current Draw	—	—	**2142.5 mA (2.14 A)**

Battery Capacity	Total Current	Estimated Runtime
2000 mAh	2142.5 mA	0.93 hours (~56 min)

Battery details

- Battery type: Tenergy NiMH pack
- Voltage: 12 V
- Capacity: 2000 mAh (2.0 Ah)
- Maximum recommended continuous discharge rate: 2 A (≈1C)

Power modulation plan (propulsion + mission actuators):

Propulsion (4 DC motors via 2 L298N)

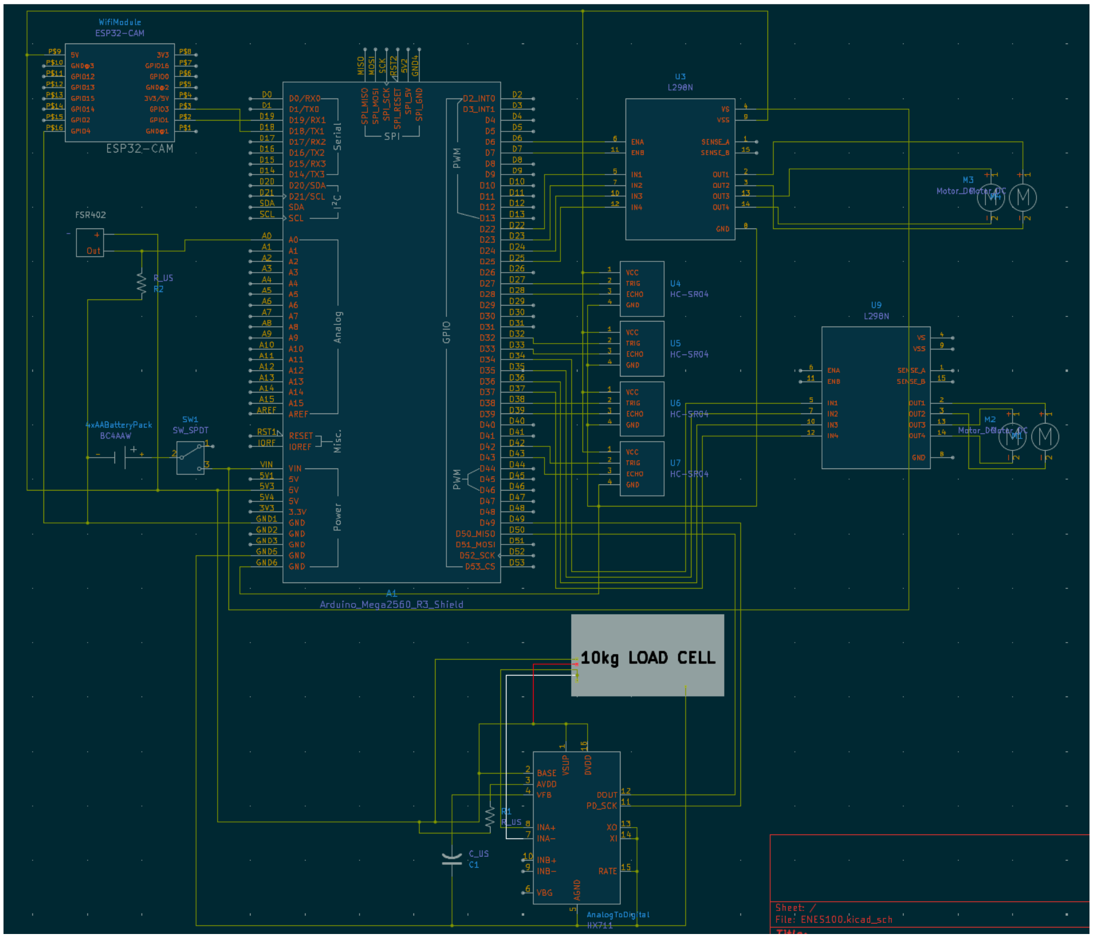
- PWM control on L298N enables pins to modulate motor speed; direction pins set forward/reverse.
- We should have gradually increased PWM to reduce slipping, however we did not have the time to and had to focus on other code priorities.
- Cap max PWM (e.g., 70–85%) to reduce average draw toward the battery's 2 A recommended continuous limit. This also increases the runtime!

Mission actuator (just 1 servo)

- Drive the servo with standard servo PWM, but avoid holding high torque unnecessarily:
    - Move to position, then reduce servo holding time if the mechanism allows (don't keep it straining).
- Power-wise: servo draws spikes, so ensure that the motors are off while it is in use.

Note that we did not actually implement this in our OTV, rather this was the plan.

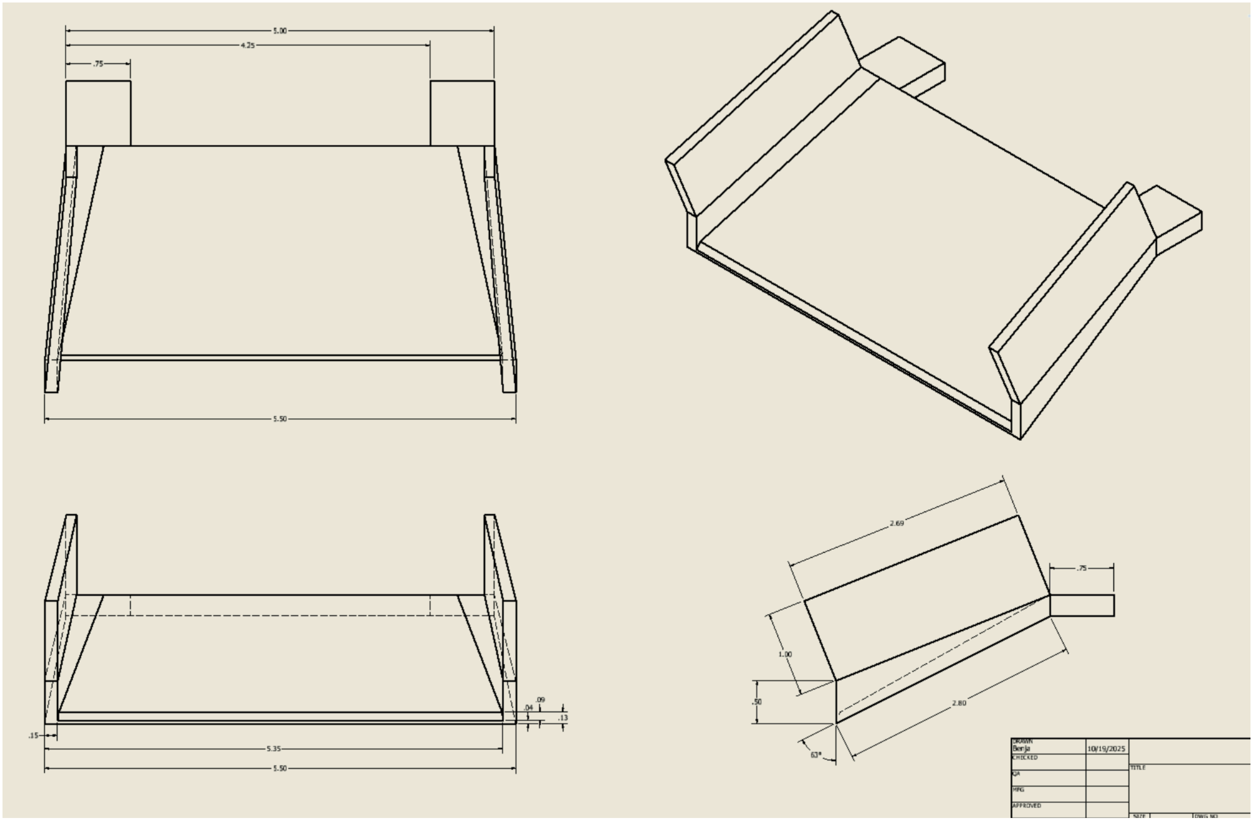
Electronic Wiring:

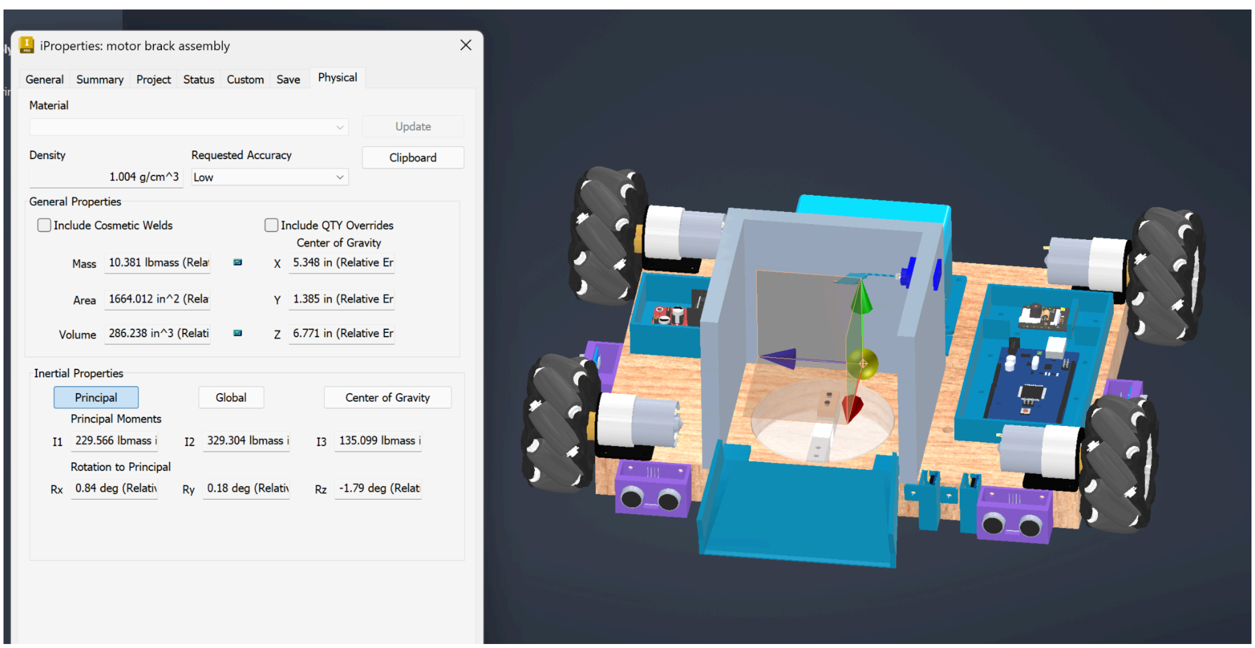


Pin Assignments:

Module	Pins	Type
2x H-Bridge L298N	D22-25,34-37 direct to 12V	Digital, direct power
4x HC-SR04	D27,28,32,33,38,39,42,43	Digital
HX711	D49,D50	Digital
Wifi Module	D18,D19	TX/RX
FSR402	A0	Analog
12V Battery	VIN	VIN (Direct Power)

Section #5: Compiled Set of Engineering Drawings:


5.90
4.25
.75
5.50
.15
5.35
5.50
.09
.04
.13
2.69
.75
1.00
.50
2.80
63°
10/19/2025


iProperties: motor brack assembly
General
Summary
Project
Status
Custom
Save
Physical
Material
Update
Density
Requested Accuracy
Clipboard
1.004 g/cm^3
Low
General Properties
Include Cosmetic Welds
Include QTY Overrides
Center of Gravity
Mass
10.381 lbmass (Rela
X
5.348 in (Relative Er
Area
1664.012 in^2 (Rela
Y
1.385 in (Relative Er
Volume
286.238 in^3 (Relati
Z
6.771 in (Relative Er
Inertial Properties
Principal
Global
Center of Gravity
Principal Moments
I1
229.566 lbmass i
I2
329.304 lbmass i
I3
135.099 lbmass i
Rotation to Principal
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0.84 deg (Relativ
Ry
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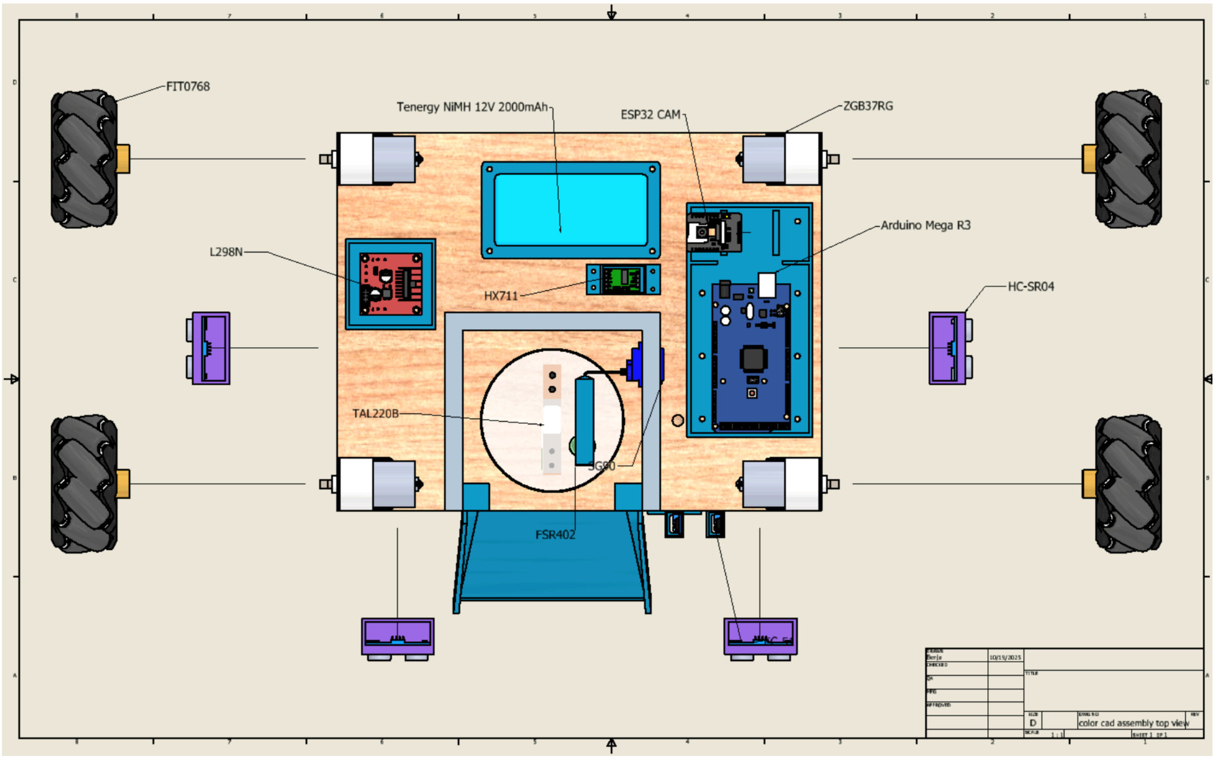
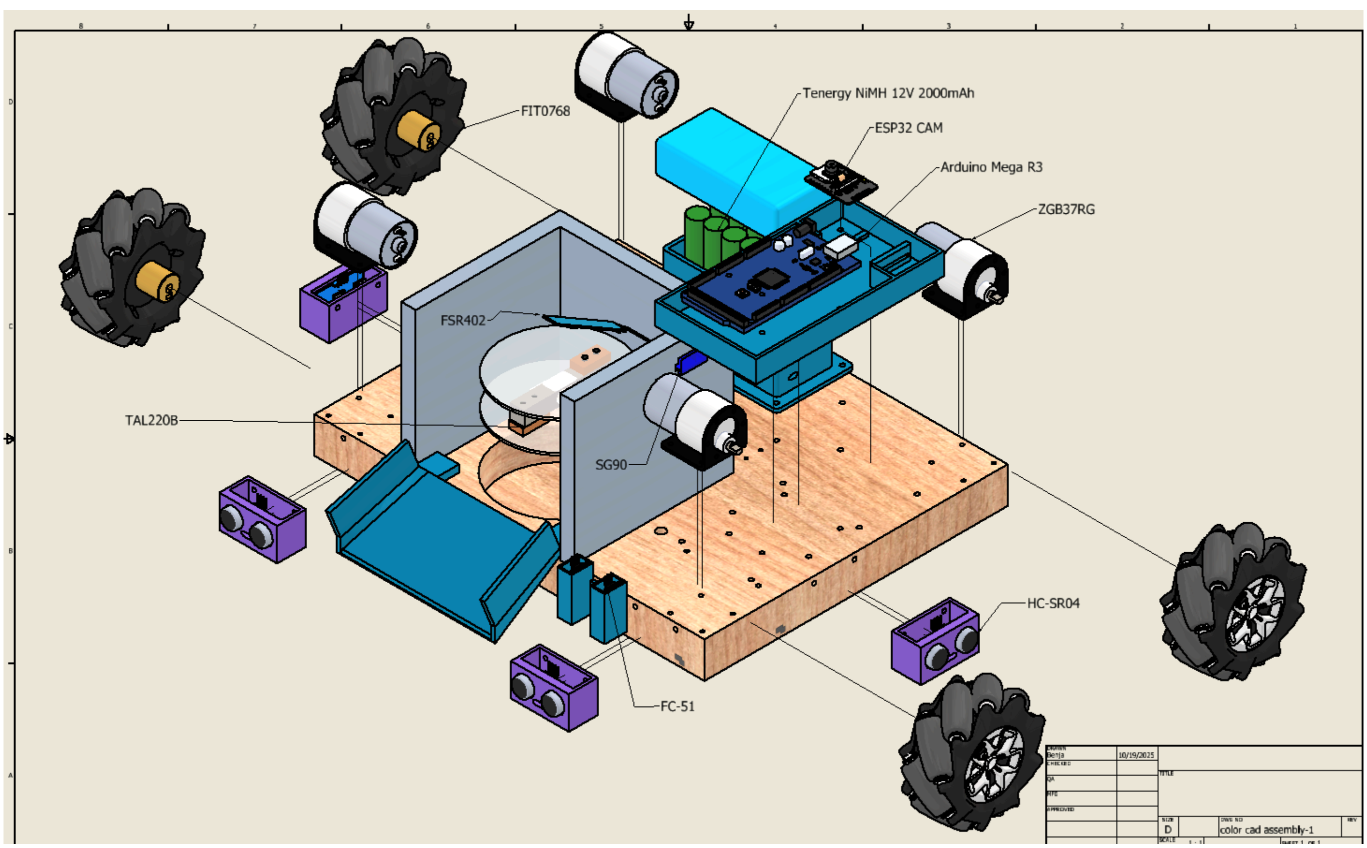
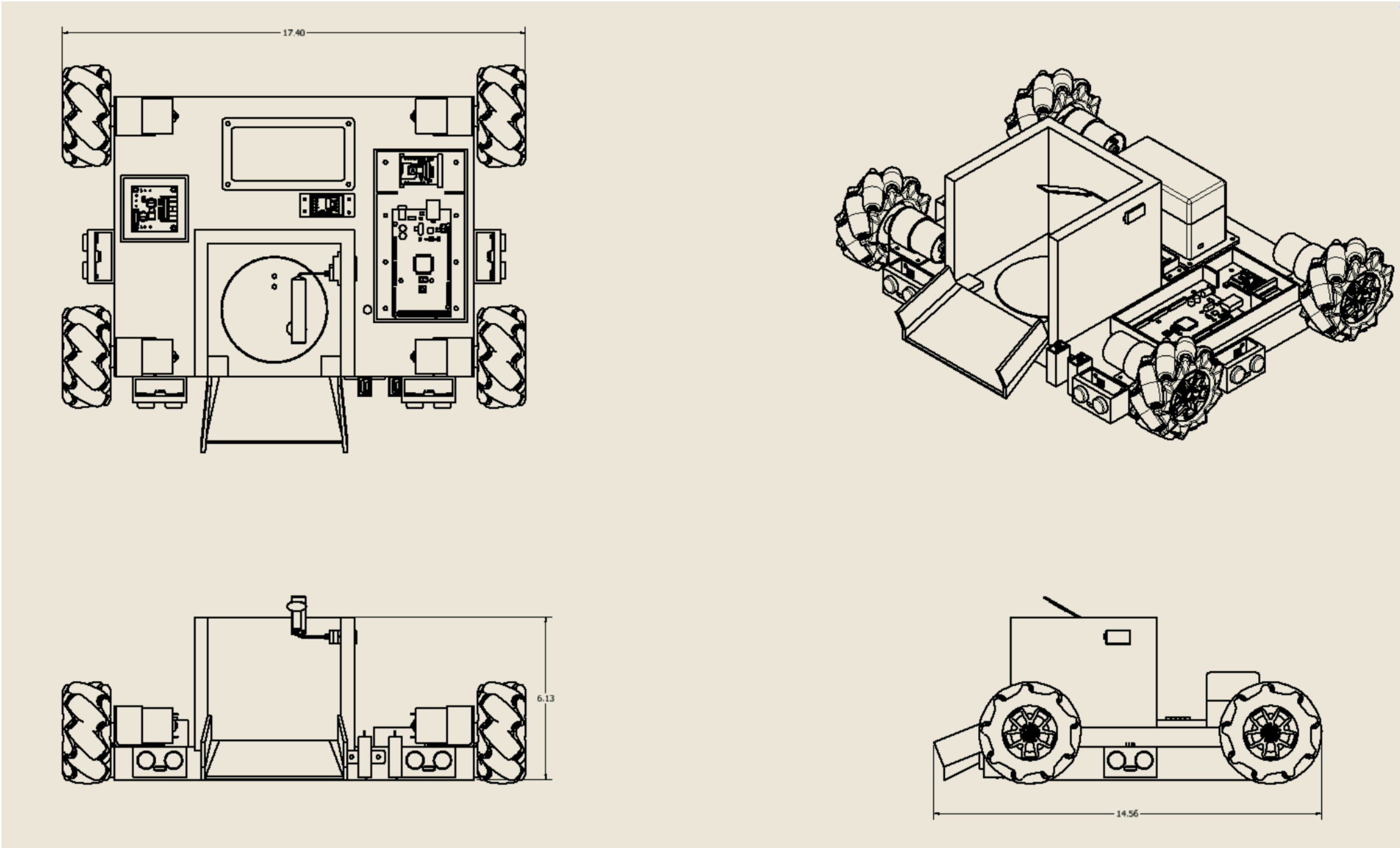
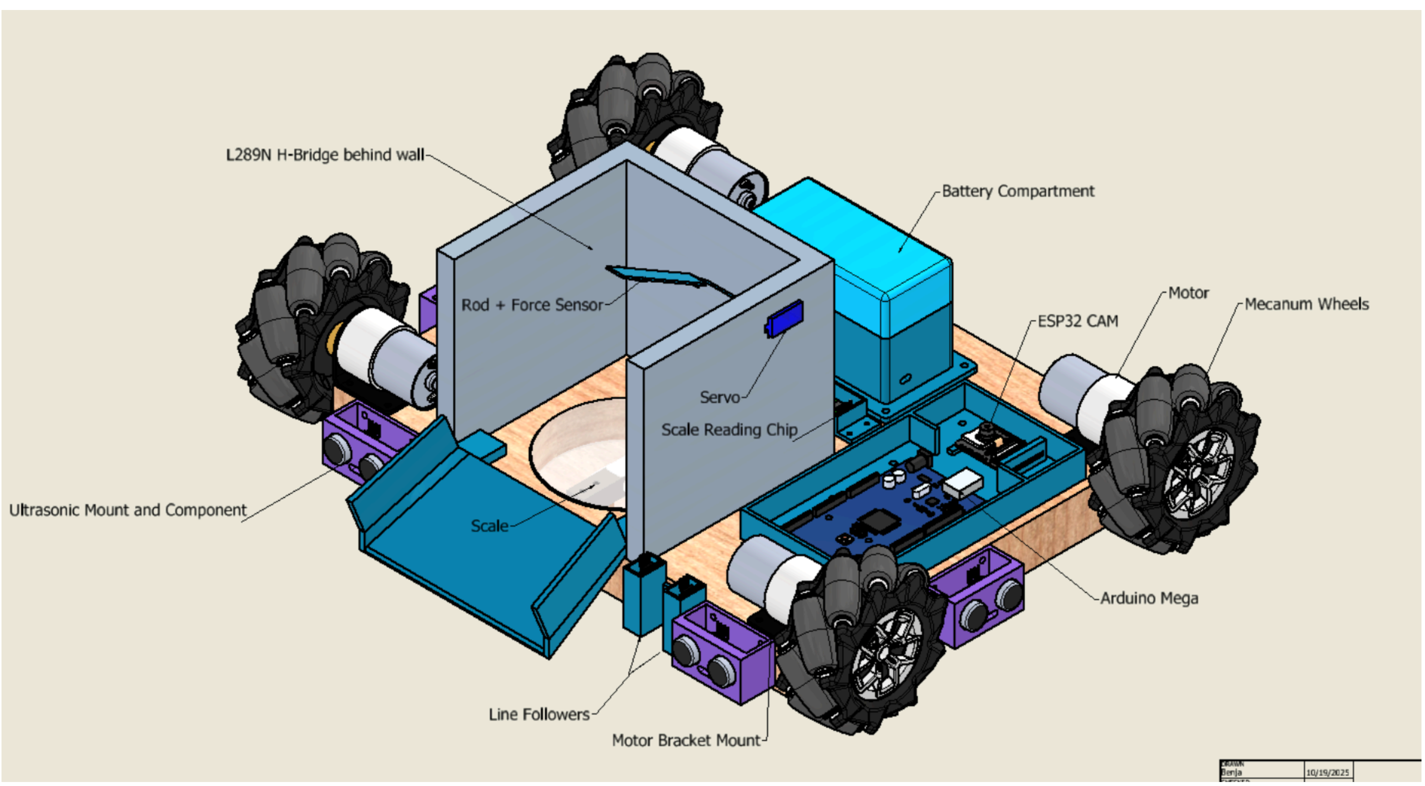
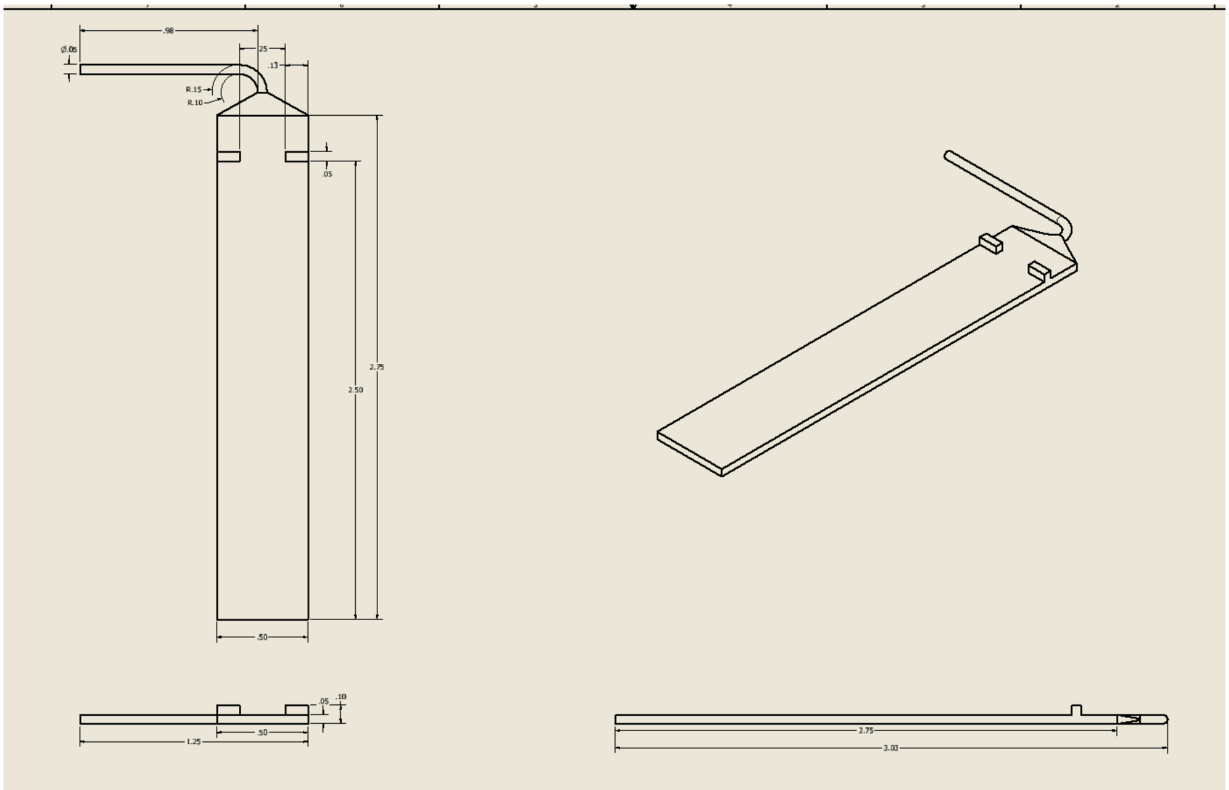
Rz
-1.79 deg (Relat

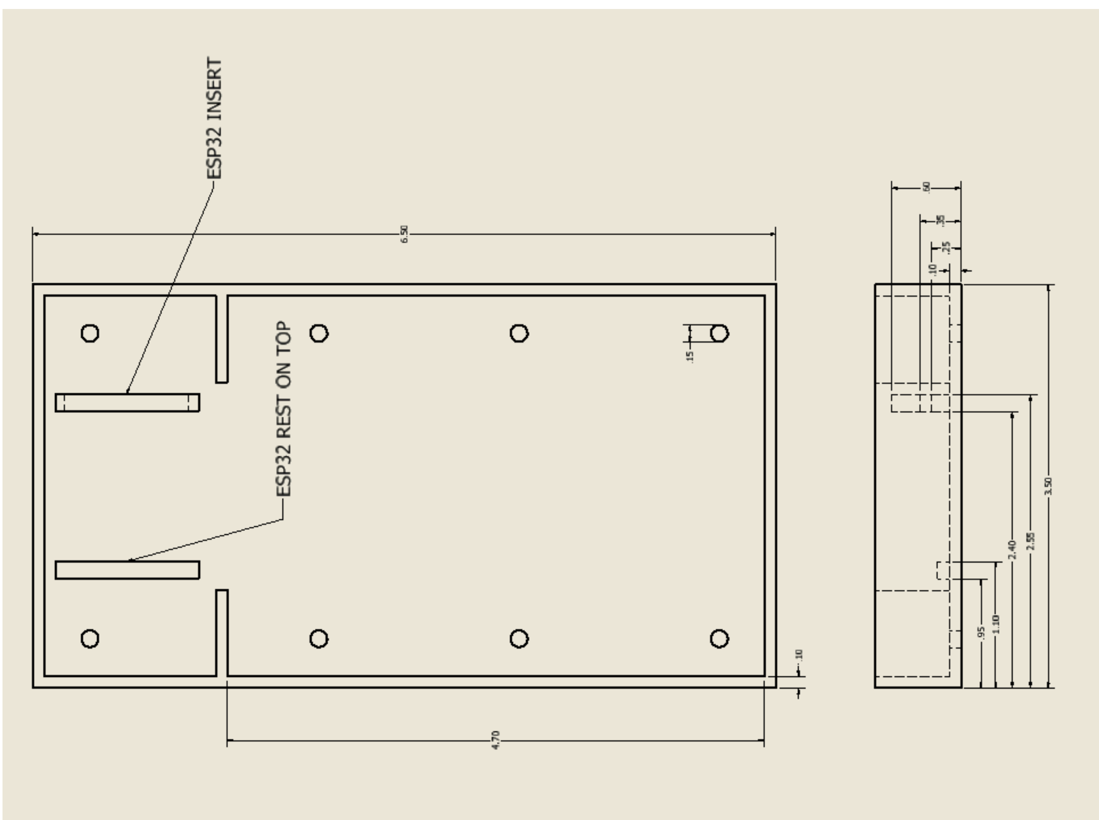

FIT0768
Tenergy NiMH 12V 2000mAh
ESP32 CAM
ZGB37RG
Arduino Mega R3
L298N
HX711
HC-SR04
TAL220B
SG90
FSR402
color cad assembly top view


FIT0768
Tenergy NiMH 12V 2000mAh
ESP32 CAM
Arduino Mega R3
ZGB37RG
FSR402
TAL220B
SG90
HC-SR04
FC-51
color cad assembly-1


17.40
6.13
14.56


L289N H-Bridge behind wall
Battery Compartment
Rod + Force Sensor
Motor
Mecanum Wheels
ESP32 CAM
Servo
Scale Reading Chip
Ultrasonic Mount and Component
Scale
Arduino Mega
Line Followers
Motor Bracket Mount




ESP32 INSERT
ESP32 REST ON TOP

Section #6: Sustainability:

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