Team 2:
Mechanical Menaces
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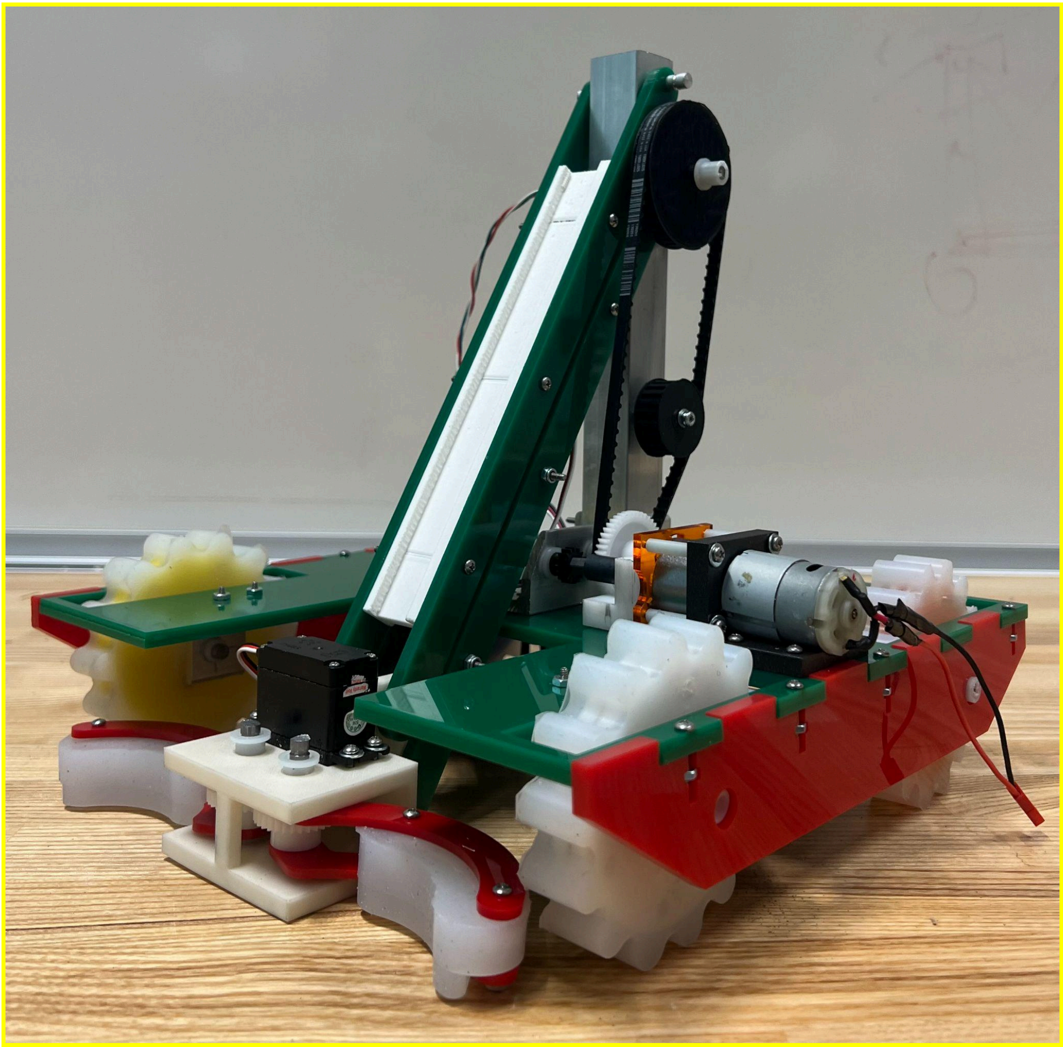


Figure 1: Picture of the final robot

Abstract

This report details the comprehensive design and development process of a competitive robot constructed for the Turf Wars competition, where the primary objective was to score tennis balls and pucks into a designated basket within a challenging arena environment. The project was framed by specific constraints including size limitations, the number of allowable actuators, and the use of predefined materials and manufacturing processes. Our team approached the problem by focusing on optimizing the robot's maneuverability, stability, and precision in object handling. Initial design options were evaluated through a series of dynamic simulations and practical tests, leading to the selection of a robust gripper mechanism suited for precise scoring. The final robot featured a customized drivetrain and an arm mechanism with enhanced grip functionality, designed to operate efficiently across varied terrains and inclines encountered during the competition. Despite facing challenges with terrain navigation and mechanical reliability under competitive stress, the robot achieved commendable performance, underscoring the effectiveness of our engineering solutions and iterative design strategy.

1. Concept Development

1. Constraints:

The project's objective is to design and construct a functional remote-controlled robot capable of competing in the Turf Wars competition. This competition involves scoring tennis balls and pucks into a basket within a designated arena, as depicted in Figure(2).The robot must adhere to the competition's scoring rules and restrictions.

Figure 2: The Turf Wars Competition Arena

Design and Construction Constraints:

1.1: Materials and Components:

1.1.1: Manufacturing Processes: The robot must be constructed using at least six different manufacturing processes, including milling, laser cutting, drilling, turning, 3D printing, and molding.

1.1.2: Material Allotment: The team is provided with:

Two sheets of 12” x 24” x ¼” acrylic

Two sheets of 12” x 24” x ⅛” acrylic

15 cubic inches of 3D printed PLA

1.1.3: Additional Supplies: Unlimited quantities of Delrin, aluminum rods, aluminum brackets, fasteners, gears, and belts are available. Glue and tape are not permitted.

1.2: Mechanical and Electrical Specifications:

1.2.1: Actuators: A maximum of six actuators are allowed, with 2 to 3 being screwdriver motors and the rest being continuous or 90-degree servo motors.

Power Limitations: The maximum current draw is restricted to 9 Amps.

Physical and Performance Requirements:

1.2.2: Size Constraints: The robot must fit within the "box of justice," which has internal dimensions of 12”x12”x12”.
Mobility: The robot is required to climb two ramps; one with a 15º incline and another with a 30º incline.

1.3: Operational Constraints:

1.3.1: Preparation Time: Each team has exactly two minutes to prepare the robot before each round.
1.3.2: Duration of Each Round: Each competition round lasts four minutes.
These guidelines ensure that the robot not only meets specific design and performance criteria but also adheres to the constraints and challenges posed by the competition's unique environment.

2. Criteria:

Prior to finalizing the design criteria, the team engaged in discussions to define what an ideal robot would entail for the Turf Wars competition. The core aim of the robot is to efficiently score points by depositing balls (worth 1 point each) and pucks (worth 2 points each) into a hoop, while also proficiently navigating the competition field.

2.1: Design Considerations:

Objective: The primary focus is on scoring both balls and pucks and moving up and down the two ramps in the arena.
Weight and Center of Gravity: Special attention is required for the robot’s weight distribution and center of gravity to enable it to successfully ascend 15° and 30° inclines.
Maneuverability and Precision: Initially, the team considered a multi-ball/puck shooting mechanism. However, to avoid complications with the robot's center of mass, especially on inclines, a decision was made to prioritize maneuverability and precision over the capability to shoot multiple objects simultaneously.

2.2: Additional Design Criteria:

Mobility: Effective movement across flat surfaces and inclines.
Collection and Deployment: Efficient collection of balls and speed of deployment with precise targeting.
Stability and Durability: Ensuring the robot remains stable and durable under competition conditions.
Ease of Assembly and Fabrication: The robot should be straightforward to assemble and fabricate with the available resources.
Driving Ease: The robot must be easy to control and drive during the competition.
Shooting Accuracy: Precision in shooting, particularly for scoring in the Turf Wars.

2.3: Prototype Development:

Three initial prototypes were conceptualized to explore different strategies:

The Dumper: Designed to quickly unload balls and pucks.
The Collector: Focused on efficiently gathering more balls and pucks from the field at a time.
The Gripper: Aimed at securely holding and precisely deploying balls and pucks.

Each prototype's functionalities and their suitability for the competition's demands were analyzed, and further details alongside preliminary sketches of these solutions are provided in Figure (?).

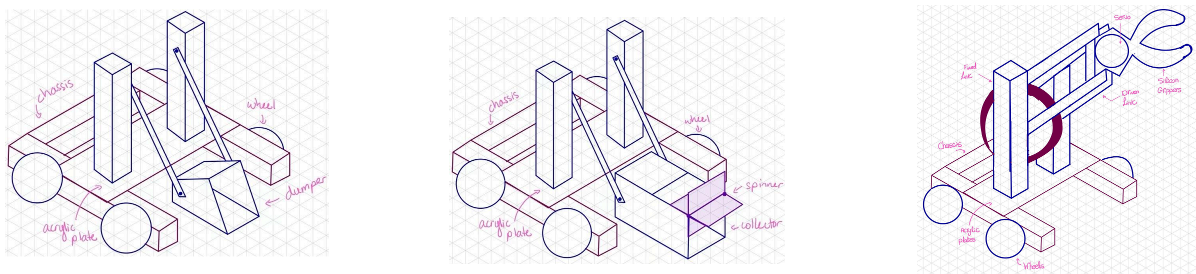


Figure 3: sketches of the initial design solutions

This structured approach allowed the team to critically assess each design's potential effectiveness within the stringent competition parameters. The following Pugh Matrix was used to assess each design.

Table 1: The pugh matrix for the three design solutions

Criteria	Concept A: Dumper	Concept B: Gripper	Concept C: Collector
Mobility on flat surfaces	0	0	0
Mobility on 30-degree incline	0	0	0
Ball Collection Speed	0	+	+
Ball Deployment Precision	+	+	+
Stability	0	+	-
Durability	-	+	-
Ease of Assembly	+	+	+
Ease of Driving (in Turf Wars)	0	+	0
Precision of Shooting	+	+	0
Rank	**2**	**1**	**3**

Note that the final decisions are based on a ranking system, with the Gripper design being the 1st place out of the three designs.

3. Alternative Solutions:

3.1: Design 1: The Dumper

The Dumper is designed to scoop up a single ball, ascend ramps in reverse, and swing its arm over 180° to deposit the ball. (Referenced in Figure 4)

Pros:

- Easy to engineer, featuring a simple mechanical design.
- Straightforward construction with minimal moving parts.

Cons:

- Challenging to control, especially on inclines.
- Limited precision in ball deployment.
- Potential for instability during arm swing.
- Restricted to handling one ball at a time.

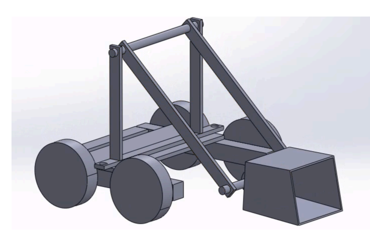


Figure 4: CAD design of the dumper

3.2: Design 2: The Collector

The Collector uses a spinning mechanism to gather balls, which can be reversed to release them. The spinning parts are considered to be made from either rubber bands or silicone pieces. (Referenced in Figure 5)

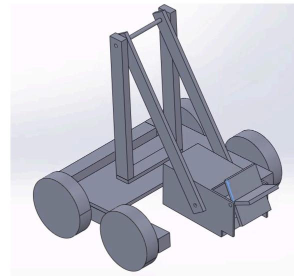


Figure 5: CAD design of the collector

Pros:

- Relatively easy to engineer.
- Capable of picking up multiple balls simultaneously (currently up to two).

Cons:

- Requires precision in operation to efficiently collect and release balls.
- The front-heavy design might lead to balance issues, adding complexity to maneuverability.

3.3: Design 3: The Gripper:

The Gripper employs a claw mechanism to grip a ball, lifts the arm while maintaining its parallel orientation to the ground, and opens the claw to release the ball. (Referenced in Figure 6)

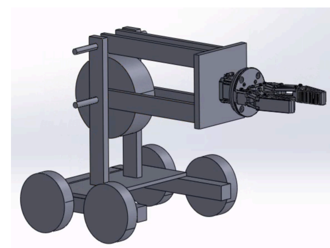


Figure 6: CAD design of the gripper

Pros:

- Easy to engineer with a sturdy and robust design.
- Simplifies driving as the control and movement are more predictable.
- Provides a reliable mechanism for precise ball handling.

Cons:

- Limited to picking up one ball at a time.

3.4: Selected Design: The Gripper

The Gripper was selected as the optimal design solution after evaluating it through the Pugh matrix, a tool used to compare multiple design options against a set of criteria, using a baseline for comparison. The following reasons contributed to its selection: the Gripper's design offers a robust construction that is less prone to mechanical failures during the competition. This reliability is crucial in high-stress environments where precise movements and operations are necessary. Compared to the other designs, The Gripper provides a more predictable and stable driving experience, crucial for navigating through the varied terrain of the competition arena, including inclines. While it handles only one ball at a time, similar to The Dumper, The Gripper's design allows for more precise placement of the ball, crucial for maximizing scoring opportunities under competition conditions. The simplicity of The Gripper's design makes it more adaptable for modifications and improvements. Its basic mechanism allows for future enhancements, such as increasing the gripping capacity or refining the arm's movement for faster operation.

By focusing on these key strengths, The Gripper design aligns well with the competition's demands and the team's capabilities, making it the most suitable choice among the alternatives.

Analysis

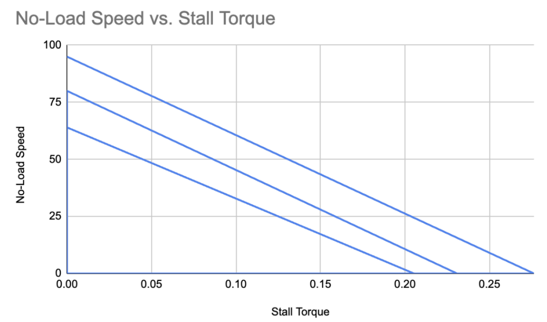
In the development of our robot for the Turf Wars competition, we conducted several critical analyses to ensure the robot's design met both functional and competitive standards. These included dynamic simulations, load analyses, and experimental validations.

4.1: Motor Calculations:

	1.2 Volts	1.4 Volts	1.6 Volts
τ_{stall}	0.2053	.2308	.2763
τ_{max}	0.1549	0.1609	0.1728
$\omega_{no\ load}$ (rad/s)	6.702	8.376	10.053
$\omega_{no\ load}$ (RPM)	64	80	96
ω_{max} (RPM)	3.351	4.188	5.026
Efficiency	31.0%	23.3%	25.9%

Table 2: Motor Specifications

Graph 1: The no load speed-stall torque graph for the motor



- K_T= 0.0596 Nm/A
- K_V= 0.167 V/(rad/s)

These motor performance calculations were essential for selecting the appropriate motors and gearing systems. By accurately sizing the motors, we ensured that the robot could achieve and maintain the required speeds and torques without overloading the electrical system, thus maximizing efficiency and reliability in competitive scenarios. The calculations helped confirm that the robot could operate within the strict limits of power consumption, which is crucial for compliance with competition rules and for preventing electrical failures during matches. Additionally, ensuring that the motors could deliver the required torque directly influenced the robot's ability to navigate different terrains and manipulate objects, directly impacting its scoring ability in the competition.

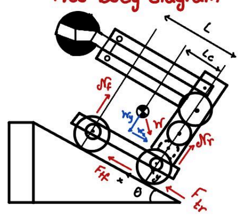
4.2: Center of Mass Calculations (Dynamic Stability Analysis):

To prevent the robot from tipping over while climbing inclines or during rapid maneuvering, we analyzed the robot's stability.
Assumptions: Uniform weight distribution; ability to climb the ramp.

- **These are the variables for the following calculations:**

W: weight of the robot
N_f: Normal Force on the front wheels , N_r : Normal Force on the rear wheels
F_{tf} : Tractional force on the front wheels, due to static friction
F_{tr} : Tractional force on the rear wheels, due to static friction
L: the distance between the center of the two wheels
L_c: the distance between the rear wheel and the center of mass

"Free body diagram"



- The weight of the robot is 5.69 lbs
- The distance between the front and the rear wheel is
- Using Solidworks, we know the center of mass is:

$\bar{X} = 5.023$, $\bar{Y} = 2.287$, $\bar{Z} = 2.619$

- The ramp angles are 15° and 30°.
- The radius of the wheel is 3 in.
- The robot is a rear-wheel-drive robot, the torque provided by the motor $\tau_{motor} = 3.582$ lb.in.
- The gear ratio from gearbox is 3: 1.

To find the friction acting on the rear wheels:

$T_{output} = \tau_{motor} \times GR = 10.746$ lb.in

$F_{tr} = \frac{\tau\omega}{r} = \frac{10.746}{3} = 3.582$ lbf

This is the force responsible for the robot moving on both sides of the ramp.

Driving up the 15° ramp:

pivot at the rear wheel center:

$\circlearrowleft M: \quad 0 = W_y L_c - N_r L$

$0 = 5.69 \cos 15 \times 5.023 - N_r \times 6.405$

$0 = 27.61 - 6.405 N_r$

$N_r = 4.31$ lbf

$\Sigma F_y: 0 = N_f + N_r - W_y$

$0 = N_f + N_r - W \cos 15$

$0 = 4.31 + N_f - 5.69 \cos 15$

$N_f = 5.69 \cos 15 - 4.31$

$N_f = 1.186$ lbf

These results make senese since the normal force on the rear wheel (N_r) is expected to be greater than that on the front wheels (N_f) → because it is a rear-wheel drive.

$\circlearrowleft M = -W_x h + W_y L_c$

$0 = -5.69 \sin 15 \times h_{max} + 5.69 \cos 15 \times 5.023$

$h_{max} = \frac{5.69 \cos 15 \times 5.023}{5.69 \sin 15} = 18.746$ in

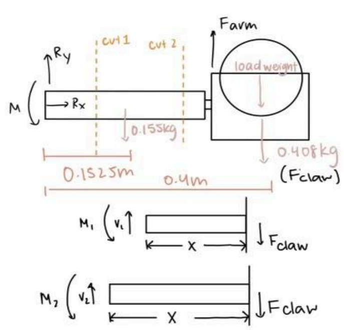
In theory, this is the maximum height the robot could reach without toppling.

Figure 7: The center of mass calculations

This analysis ensured that our robot's design would maintain a low center of gravity and a wide base, crucial for preventing rollovers on ramps and during abrupt movements. The theoretical maximum calculated height would work perfectly with the ramp provided in the competition since the max height it needs to reach is around 7.5 in, making sure that the robot will not topple over while climbing up.

4.3: Arm Calculations:

The robotic arm's performance is critical for scoring by precisely handling balls and pucks. The analysis ensures that the arm can operate efficiently, sustain the loads during operation, and accurately position objects.



$V_1 = F_{claw} = 3.998$ N

$M_1 = F_{claw} \cdot x = 3.998x$ Nm

$V_2 = 1.519 + 3.998 = 5.517$ N

$M_2 = (1.519)(0.1525) + 3.998x + 1.519x$

$= 5.517x + 0.232$ Nm

each link of four-bar linkage:

1.7272 x 0.635 cm cross-section

$M = 5.517(0.406)/4 = 0.619$ Nm

$\text{max stress} = \frac{My}{I} = \frac{(0.619)(0.0086)}{\frac{(0.00635)(0.0173)^3}{12}} = 1.94$ mPa

tensile strength of acrylic is 65 mPa so arm will not break

Figure 8: The arm calculations

Ensuring the arm can lift and maneuver objects without exceeding the structural limits of its materials prevents mechanical failures during critical moments of the competition. Proper stress calculations directly affect the robot's ability to score effectively by reliably picking up, transporting, and releasing objects in the designated scoring zones. It also ensures the longevity and durability of the arm mechanism, reducing the risk of in-field failures and maintenance issues.

Final Solution

The final robot had several features that optimized it for the competition. For example, it features a four-bar linkage, which ensured that the claw stayed level to the ground no matter how the arm moved. The arm linkage was tensioned by a pulley attached to its post. The robot's claw had soft silicone grips, which provided the traction necessary to pick up both balls and pucks. The robot's drivetrain was rear-wheel drive with dragonskin silicone wheels.

The robot placed fourth overall in the competition. It was able to score some points in some rounds, but overall did not score as many points as we hoped. The main issues with the robot were its inability to navigate through uneven terrain or onto steep slopes. The robot was reliable when it came to gripping the balls and pucks without dropping them.

In relation to the team constraints, the robot fits within the box of justice easily. It was also possible for us to prepare the robot in two minutes before the competition started, as there were very few moving parts. Finally, according to the material constraints, we did not exceed limits on acrylic, 3D printing PLA, or motors. In regards to the team criteria, the robot succeeded most at accuracy. The claw design made it so that it could be positioned exactly over the hoop before dropping its cargo. The center of gravity was also considered in the fact that much of the weight was at the bottom of the robot. When going up the ramp, the claw could be lowered to reduce the chance of tipping backward. When it came to maneuverability, however, the robot's final performance did not quite meet our standards. Overall, the advantages of the robot were its accuracy and adaptability to different situations, whereas its disadvantages lay in the reliability of its driving.

If given more time, we would make a number of improvements to our robot. To improve the driveability, using a belt to connect the wheels and effectively give the robot all-wheel drive would greatly improve its performance on an uneven stage or steep hills. The meshing of the gears in the gearboxes was also slightly unreliable, so we would spend more time constructing those accurately. The last improvement we could make to the drivetrain is the wheels themselves – using a softer silicone and a wheel shape that maintains more contact with the ground could greatly improve the maneuverability. The claw feature also could be improved. One thing that proved unreliable in the competition was the belt tensioner, as it didn't always stay as tight as we wanted. This could be improved by constructing a stronger attachment to the post that didn't allow the tensioner to slip. Another possible consideration would be having a claw that was able to score forwards or backwards (i.e able to go over the top) so the bot can avoid unnecessary movement.

Final Design Specifications

Table 3: final design specifications

Design	Specification
Baseplate Dimensions	11.5”x11”
Robot Mass	5.69 lbs
Robot Height	11.5”
Undercarriage Clearance	2.5”
Turning Radius	12”
Drivetrain Gear Ratio	3
Maximum Arm Height	18”
Maximum Claw Width	7.5”

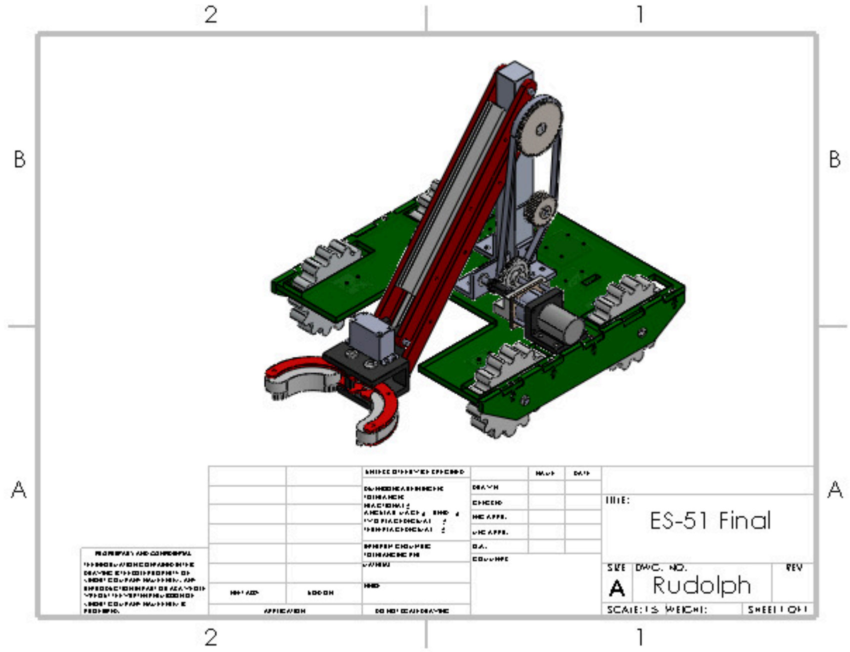
Appendix

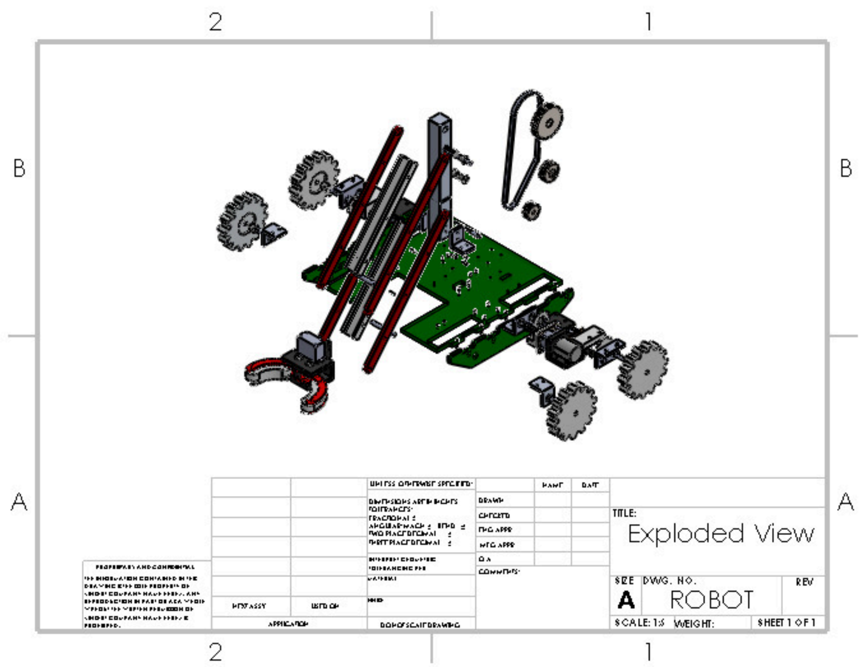
Table 4: Bill of Materials

Part No.	Name	Description	Quantity
Main Body			
1	Baseplate	¼” acrylic, laser cut	1
2	Side plates	¼” acrylic, laser cut	2
3	Wheels	Dragonskin silicone	4
4	Wheel inserts	Acrylic	4
5	Wheel axles	6061 Aluminium hex rod	4
6	Bearings	¼” Nylon bearings, broached to hex	8
7	L brackets	6061 Aluminum Angle brackets, band saw	4
8	Screws	¾” pan head phillips 4-40	8
Arm			
9	Servo		1
10	Gears	32 DP, 24 teeth, 20˚ pressure angle	2
11	Hex rods	Aluminum hex rods, lathe	2
12	Grip Supports	⅛” acrylic, laser-cut	4
13	Grip	Ecoflex-30	2

14	Grip inserts	PLA 3D printed **Vol: 0.19 cubic inches**	2
15	Grip housing	PLA 3D printed **Vol: 3.17 cubic inches**	1
16	Linkages	¼” acrylic, laser-cut	4
17	Screws	2” Pan head phillips 4-40	6
18	Locknut	Locknut 4-40	6
19	Bearings	¼” Nylon bearing	4
20	Arm supports	PLA 3D printed **Vol: 2.92 cubic inches**	2
Motors (3 total)			
21	Motor	From screwdriver	3
22	Shaft supports	Delrin, milled	3
23	Gearbox support plate	⅛” acrylic, laser cut	3
24	Round shaft	Aluminum ¼” shaft	3
25	Hex shafts	Aluminum hex shaft	3
26	Screws	½” pan head phillips 4-40	18
27	Screws	1” pan head phillips 4-40	12
28	Screws	¾” flat head phillips 4-40	6
29	Gear	32 DP, 16 teeth, 20˚ pressure angle	3
30	Gear	32 DP, 48 teeth, 20˚ pressure angle	3
31	Bearings	¼” Nylon bearing	6
32	Motor mount	3D printed **Vol: 0.73 cubic inches**	3
33	Spring pin	1/16” dia., ½”	3
Other			
34	Wheel mold	Milled, polyurethane	1
35	Gripper mold	Milled, polyurethane	1
36	Timing belt	Timing belt, .200” pitch, 18” outer circle	1
37	Pulley Gear	3D printed, 1” dia. **Vol: 0.19 cubic inches**	1
38	Pulley Gear	3D printed, 1.25” dia. **Vol: 0.531 cubic inches**	2
39	Pulley Gear	3D printed, 2.5” dia. **Vol: 1.42 cubic inches**	3

Figure 9: Final Robot





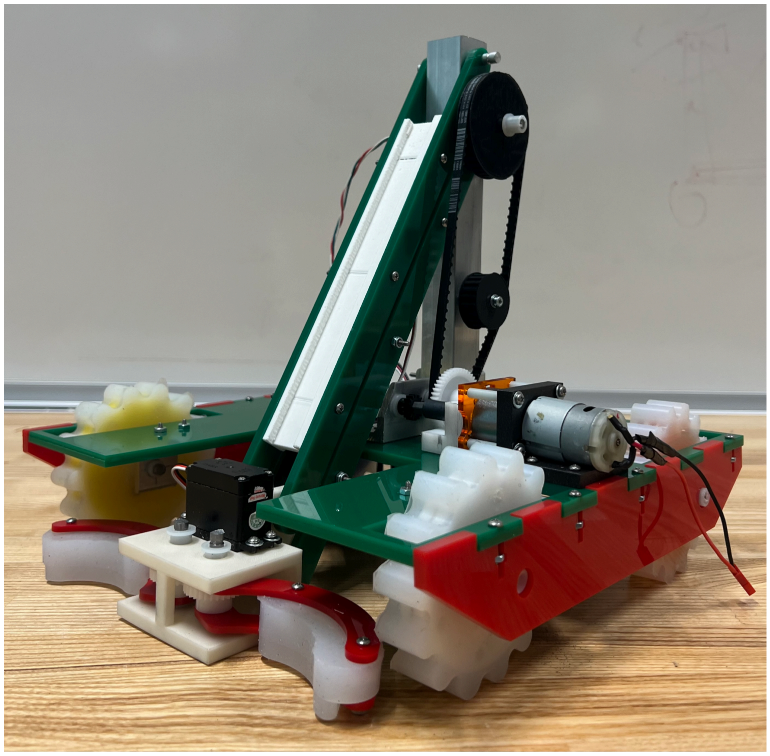
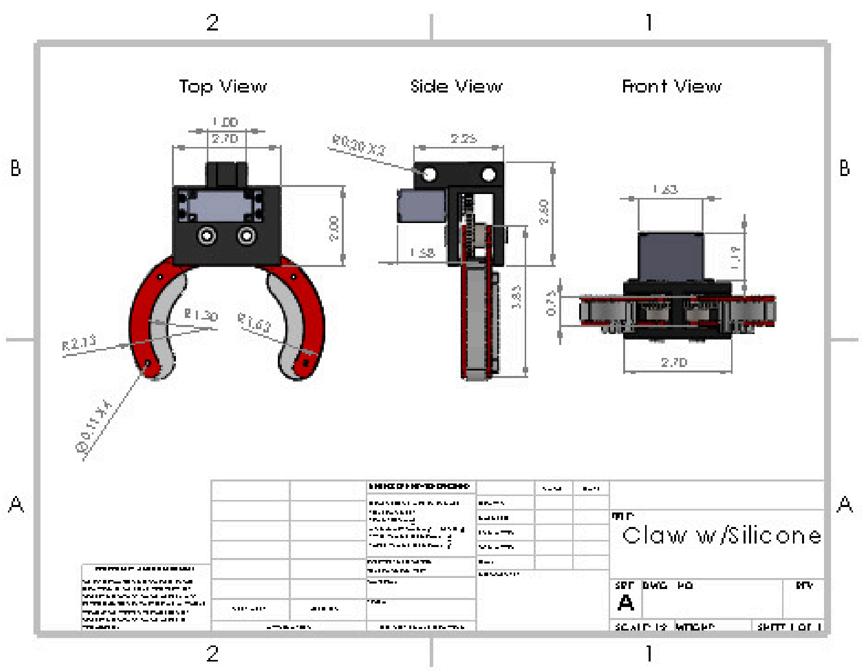
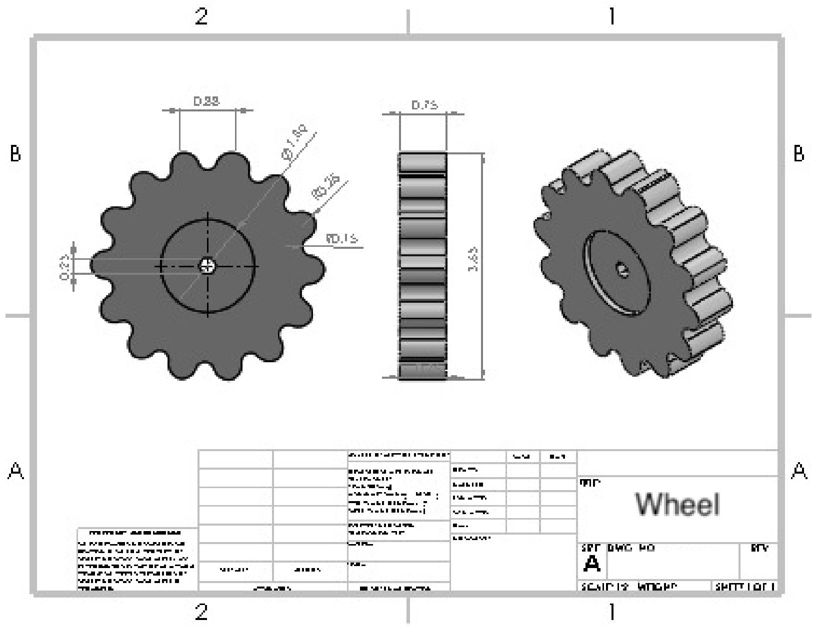


Figure 10: Part Drawings

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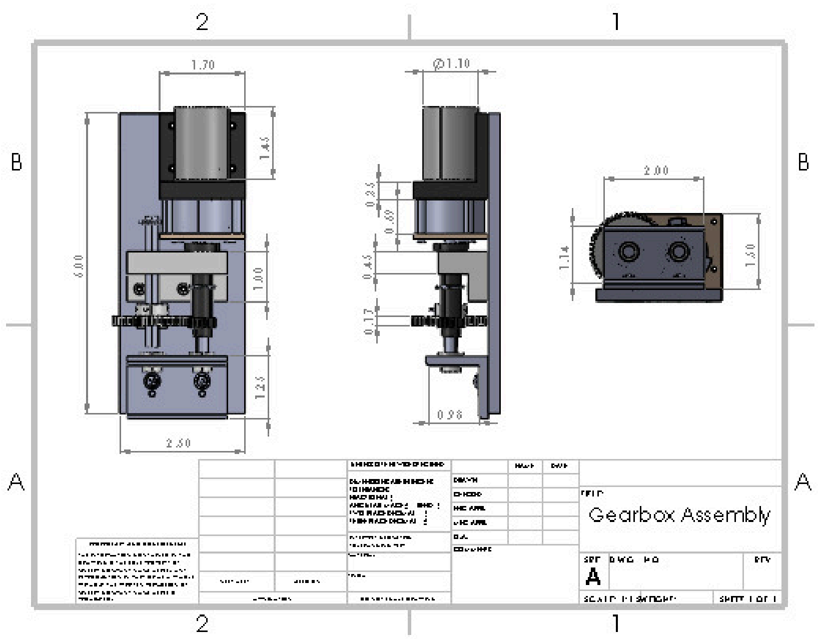
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