Turf Wars Competition Final Report

Team: "Tony Robo"

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Engineering Sciences 51: Computer-Aided Machine Design
Professor Seymur Hasanov

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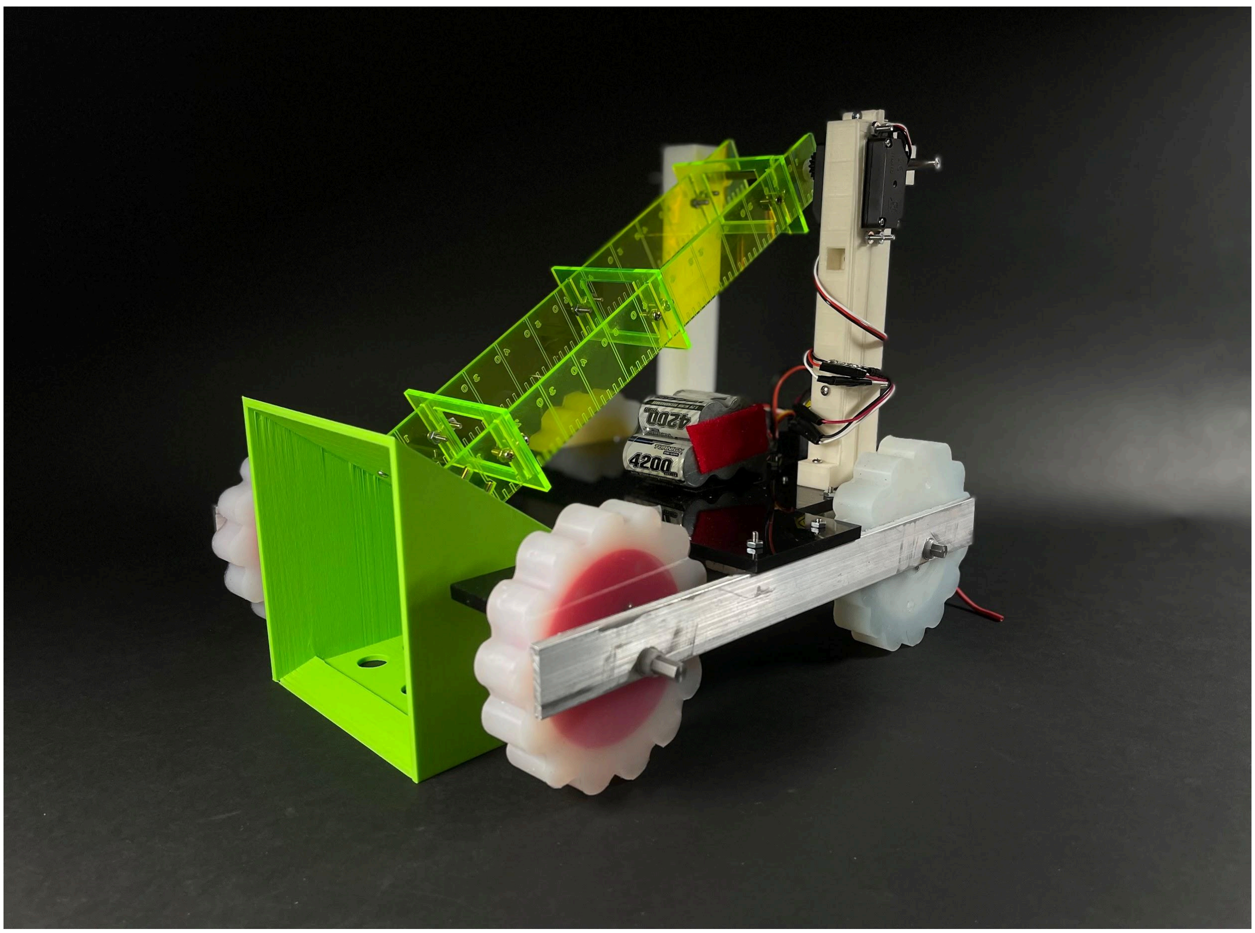


Section 1: Abstract

ES-51 highlights the design and execution of a remote-controlled robot built to quickly and efficiently score as many points as possible during the Turf Wars Competition. This year's challenge was to use our robot to secure tennis from the floor or from an elevated surface for extra points. There was a 3-point scoring zone of a vertical board in the middle of the arena where the highest zone earned 3 points, middle zone earned 2 points, and lowest zone earned 1 point. The goal was to score as many points as possible by the robot getting the tennis balls onto the scoring board by any means possible. Using a combination of Solidworks CAD software, physics calculations, prototyping, machining processes including milling, lathing, laser cutting, and more, our five-person team designed and manufactured a robot capable of traversing the field, collecting tennis balls, and placing them on the 3-point zone using our scooper-arm mechanism. The final design uses an elevated arm attached to a scoop which has access to the ground and is formed to fit 2 tennis balls. A servo meshed with a gear on a shaft allows the arm to rotate beyond 180º to discard the balls onto the scoreboard, and the scoop includes a lip that prevents the tennis balls from falling out on the way up. The arm is connected to the drivetrain through two parallel vertical structures providing extra vertical height when discarding balls in order to stay within the box of justice but access the 3-point zone at over 16 inches high. During the competition, the scooper successfully led to 3-point scoring, but was not able to effectively fit 2 balls consistently and there was a tendency for a 2nd to fall out.

Section 2: Concept Development

2.1 Constraints:

Our team was required to use six different manufacturing processes to construct parts critical to the function of the robot: milling, laser cutting, drilling, turning, 3D printing, and molding. Regarding materials, each team was provided two sheets of 12" x 24" x ¼" acrylic and two sheets of 12" x 24" x ⅛" acrylic. The team was also limited to using 15 cubic inches of 3D printed PLA. Additionally, each team was granted use of different dimensioned Delrin, aluminum rods, aluminum brackets, fasteners, gears, and belts supplied by the lab room in unlimited quantities.

Internally, the robot was required to use two distinct servo motors for functionality. Four additional motors were permitted, but only one was allowed to be a screwdriver motor. The rest had to be continuous rotation servos or 90 degree servos. The robot had to use the remote control system provided by the lab, and the motor draw was not allowed to exceed nine amps.

Each robot had to fit into a box of dimensions 12" by 12" by 12". The robot also had to be able to climb a 15º and 30º incline. Each team had exactly two minutes to prepare the robot before the round began, and each round lasted 4 minutes.

2.2 Criteria:

The criteria used to select our design included: weight, manufacturing, consistency/ease, efficiency of ball pickup, and scoring ability. Reducing the weight of the robot was important for mobility especially on inclines and for reducing material costs, which would have been evaluated given a tie with another robot in competition. Each of the categories are scored from a -1 to 1 for each proposed solution and each also is given a weight by the group. The manufacturing criteria is the most heavily weighted category because having a finished product before the competition was essential in order to have time to practice for the competition. A score of -1 reflects a manufacturing requirement exceeding far beyond the time allotted in class, a score of zero reflects a questionable ability to complete it in class, and a score of +1 translates to a confident ability to manufacture this design within class and have additional time to practice. Consistency and ease includes the ability to easily maneuver the robot without foreseeing many complications with the functionality. A -1 translates to unnecessary complexity and +1 translates to reliable. The efficiency of ball pick-up follows the same framing where a +1 is reliable/efficient pickup and -1 is the opposite. Lastly, scoring ability follows the scoring possibility of each design included the time taken to score 3 points consistently and efficiently. The pugh matrix is illustrated in Table 1 below.

Table 1: The Pugh matrix compares the different designs. The Scooper Mechanism proved to be the most effective design.

Criterion	Importance	Baseline	Spinner	Linear Puncher	Scooper
Weight	1	1	-1	0	0.5
Manufacturing	3	1	0	-1	1
Consistency/Ease	3	1	-1	0	1
Efficiency of Ball Pickup	2	-1	-1	0	1
Scoring Ability	2	-1	1	-1	0
Total		**1**	**-2**	**-2**	**3.5**

2.3 Alternate Solutions

The first design devised and considered was the spinner and wheels shown in figure 1 that would allow for a quick process to score points. However, it is very heavy with many pieces and would have difficulty garnering balls from the arena. Ultimately, due to the difficulty of manufacturing and inefficiency in picking up balls, we pivoted away from this idea and sought something less complex. During prototyping, the issue with weight became very apparent.

The linear puncher was the next contender (shown in figure 2) and is something we presented during design review 1 as our chosen design. However, there were questions about the ability to generate the necessary velocity to eject the ball with enough force and velocity to reach the 3-point range on the scoreboard consistently. The proposed mechanism included a structure that would tilt to the necessary angle that would reach the scoreboard with a structure in the back of the robot that would launch the balls onto the scoreboard. As stated, the difficulty in the punching mechanism eventually led us to pivot to the scooper method, but linear punchers are a strategy that have proven successful in similar situations with different supplies based on previous research.

Lastly, the scooper mechanism (shown in figure 3) is the strategy that was executed and led to success as we achieved 3rd place in the turf wars competition and were able to beat some tough opponents. This was not the most complex design, but allowed us to secure balls efficiently without adding extra complexity in transition the balls from the pick-up mechanism to the scoring mechanism. Rather, they are the same process and led to smooth manufacturing while still allowing us to be competitive in the competition.

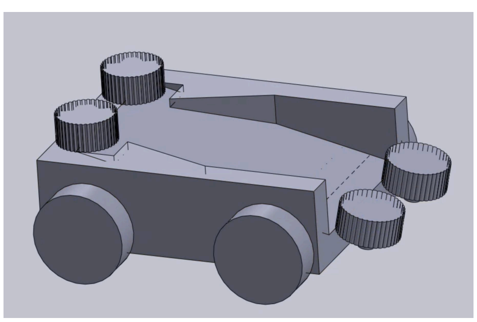


Fig. 1: Alt Design: Spinner & Wheels

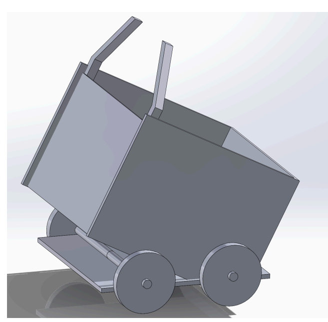


Fig. 2: Alt Design: Linear Puncher

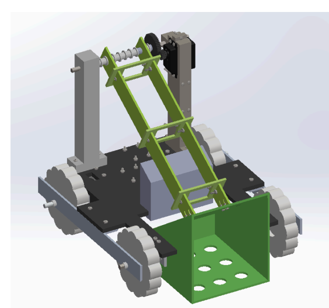


Fig. 3: Alt Design: Scooper

Section 3: Analysis

In order to proceed toward our final solution, our team worked together to scientifically assess our ideas and design propositions. To describe our analysis and simulations to resolve these issues, it is imperative that we first introduce our conceptual design that we analyzed and developed. We were thinking of essentially a robot that would scoop balls in via an arm and then using a servo motor would rotate to place the balls onto the velcro wall to score points. The first part of our analysis included the drivetrain calculations to indicate what gear ratio/torque was needed in order to ascend the 15 and 30 degree inclines. The calculations are shown in figure 4:

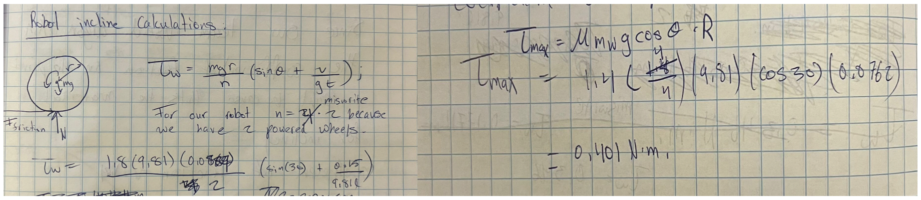


Figure 4: Calculations for drivetrain

Our calculations showed that our wheels will not slip because the torque on the wheels is less than the maximum torque when taking into consideration friction; since we used Dragonskin as the silicone for our wheels our coefficient for friction was 1.4.

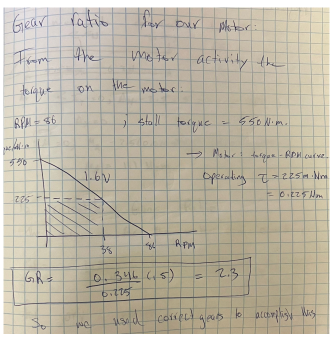


Figure 5: Calculations for Motor Gear Ratio

Despite our calculations showing that our wheels won't slip, we also had to take into consideration how much torque is provided by our motors, and how much torque should be provided at the wheels to go up the 30 degree incline. For that reason we did some gear calculations to figure out what gear ratio is suitable for our robot. In addition to this, we know that energy conservation is never perfect (there is no 100% efficiency), and so we added a safety factor of 1.5 into our calculations. The calculations for our gear ratio is shown in figure 5. Our calculations essentially indicated that we need a gear ratio of 2.3. This value makes sense when we take into consideration that we powered our robot with only two wheels. Our system didn't take advantage of a belt that made all four wheels powered. Based on this we used the correctly sized gear for our robot motors.

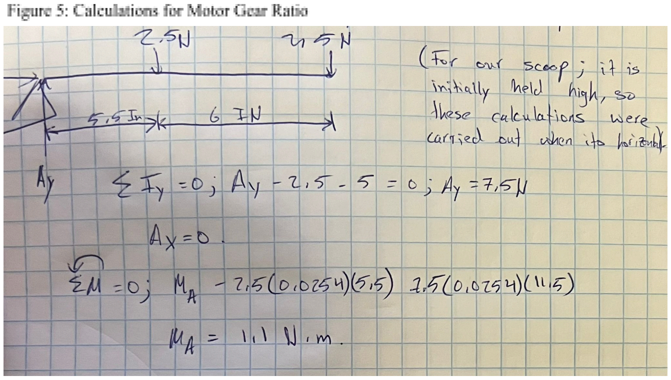


Figure 6: Calculations for scooper arm

After we figured out our drivetrain, we tested it to make sure it can incline the 30 and 15 degree inclines with comfort - it succeeded in doing so. Moving on we had to start thinking about our mechanism that will take balls off the ground onto the scoreboard. Since we were thinking of a scooper, where we would pick up balls by driving them against the wall, and then using the servo motor to roll the balls onto the board. For that reason we had to start analyzing this mechanism. Figure 6 shows the calculations we carried out to figure out the necessary torque that needs to be exerted by the servo motor in order to carry the balls onto the score board.

Our calculations showed that we need a servo motor that can accomplish at least 1.1 Newton meters of torque. We compared this value to the nominal value of torque from a servo motor which is about 0.51 Newton Meters of torque (we used the S4303R servo motor). From there, simple gear ratio calculations (taking the factor of safety into consideration) told us that we will need a gear ratio of 3.

One important simulation for our robot involved our scooper. When we first placed it we realized it wasn't placed very firmly and so we decided that we had to rethink our design to allow for more contact between the acrylic arms and the scooper. This was worked out in Solidworks and we ended up with two symmetrically placed holes for screws and nuts and one rectangular hole in which the acrylic arm would friction-fit into the scooper. A picture for the CAD is shown to the right.

These steps of analysis were necessary for the completion of our robot.

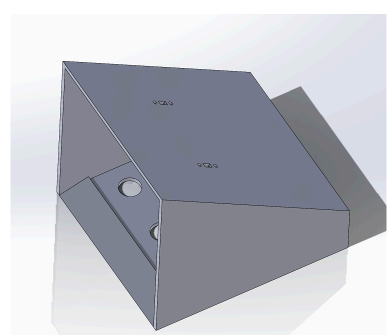


Figure 7: Better scoop design

Section 4: Final Solution

4.1 Functionality:

The final design of our robot showcases a specially engineered scooper mechanism meticulously crafted to optimize tennis ball storage without compromising functionality. Our custom-built scooper is designed for optimal ball collection, facilitating the retrieval of balls from the ground while skillfully releasing them onto the Velcro wall with one motion. The underlying concept of this design is that the scooper remains flush to the ground during ball pickup, utilizing the wall as an assistant to guide the ball into the scoop. As the robot ascends the ramp backwards, the arm will be slightly elevated to prevent collision with the incline and to keep the ball from rolling out. Upon reaching the scoreboard, the robot will lift the arm and gently roll the balls out of the scooper onto the board.

The uniqueness of our design lies in the distinctive scooper we crafted. This design features a skillfully angled back wall on the scoop, facilitating the seamless and controlled release of balls at a specific inclination. To enhance secure containment, we incorporated a lip on the inside of the scooper, preventing any unintended rolling out of balls.

The open side of the scooper is thoughtfully designed with a chamfer, ensuring a flush alignment with the ground and facilitating the smooth pick up of balls. The attachment arm that connects the scoop to our robot begins at a 30-degree angle, optimizing swift ball retrieval. Upon reaching the scoring board, it ascends to an angle surpassing 90 degrees, ensuring an effective and precise release of the balls.

During the competition, our robot delivered a performance that exceeded our initial expectations. In the days leading up to the competition, we encountered an unexpected challenge with the breakage of the robot's arms, prompting us to implement last-minute adjustments. Fortunately, the day before the competition, we successfully addressed potential arm snapping issues by crafting a sturdy arm supporter in the lab. This strategic move enabled us to score points effectively and secure a spot in the semi-finals.

Regrettably, just before the commencement of the semi-finals, a setback occurred as the pin securing one of the gears to the wheel shaft broke. Consequently, one of our two wheels ceased to spin with the motor, leaving our robot handicapped and capable of only circular movements. This limitation prevented us from scoring any additional points and ultimately led to our defeat. Despite this challenge, we secured 3rd place in the competition, underscoring the overall success of our robot.

Our final robot iteration successfully met the team's criteria by demonstrating the capability to collect and release the tennis balls with one mechanism. This achievement has been significant from the beginning of our design brainstorming because we wanted to keep our design as simple as possible to mitigate any type of battery overload or possible issues. Our primary objectives were twofold: firstly, to impede the opposing team's point accumulation as much as possible, and secondly, to swiftly achieve points ourselves. Attaining these goals was extremely important to our team.

Additionally, we overcame challenges related to size, ensuring that our balls could be released at the highest possible height for maximum scoring potential while still staying within the justice box limitations. This aspect was equally crucial to our set criteria. We successfully achieved all of our predetermined goals and navigated through the specified constraints.

To optimize our performance within the time constraints of the arena, our primary focus was enhancing our robot's ability to collect and release balls efficiently. The robot excelled in ball collection, thanks to an optimal scooper design. However, challenges arose when navigating the ramp, as it was not able to climb the 30-degree including, hindering its abilities to quickly ascend.

Despite the scooper's proficiency in single-ball retrieval, difficulties emerged when attempting to lift two balls simultaneously. While our motor possessed sufficient torque for the task, unforeseen gear slippage during arm elevation prevented the successful release of both balls, despite the available space and design capabilities of the scooper. Nonetheless, we managed to overcome these challenges and successfully collect the tennis balls.

Given more time, transitioning from a two-wheel drive to a belted four-wheel drive would likely have improved our scoring capabilities, facilitating smoother ascension of the 30-degree incline compared to navigating around to the 15-degree incline. Additionally, incorporating a belt system into the servo arm gear would have enhanced stability, mitigating gear slippage issues and enabling the release of both collected balls.

Although there are things that could be improved, our overall design was not only sufficient, but also successful. We were able to build and run a fully functional robot that was able to accomplish the tasks it was given.

Section 5: Final Design Specifications

The table below shows our final design specifications including mass, dimensions, undercarriage clearance, turning radius, drivetrain gear ratio(s), and other miscellaneous specifications.

Specification	**Value**	**Requirement**	**Justification**
Movement	Must be able to rotate 360 degrees	Want robot to move freely	Needs to be able to collect balls around field
Mobility	Must be able to climb 15 and 30 degree slopes	Want robot to be mobile and get atop the ramp	Don't want robot to flip over/needs to remain upright
Retrieving	Scooper must be able to collect 2-3 balls and store them in robot	The robot should have storage for balls to score more points.	Necessary to collect balls to shoot them and score points
Dimensions	Must fit within 12x12x12 inch box	Want robot to be small enough to fit the justice box	Needs to meet requirements for project
Drivetrain Gear ratios	There should be a gear ratio of at least 3 for the arm's servo motor and a gear ratio of at least 2 for the drivetrain motors	The robot should be able to incline the 30 degree incline with ease and the scooper should be able to lift balls comfortably	We want the robot to score us points by going up the incline and placing balls onto the scoreboard.
Turning Radius	Our robot should be able to rotate around itself in position - a turning radius of 0. This is accomplished because the different sets of wheels (left and right) are controlled separately and so while one wheel goes forward the other can go backward and thus the robot rotates around its own axis.	This should be accomplished in order for us to correctly position our robot on the ramp	When we rotate the scoop onto the scoreboard the balls fall in the correct place.
Mass	The mass of our robot should be less than 4 kilograms	We want the ramp to be light enough so that our motors can take it up the inclines	The lighter the robot the less power requirements on the wheels which would mean better battery life while turfing.
Undercarriage Clearance	There should be a minimum of 1.5inch undercarriage clearance	We need our robot to have a sufficient ground clearance so as to smoothly go up the ramps.	Having little undercarriage clearance would cause us obstacles going up the ramp and hinder our mobility.

Section 6: Appendix

6.1 Bill of Materials

Item Number	Part Number (in SolidWorks)	Description	Qty	Material	Construction
1	Aluminum Shaft Support for Front Wheels	Connects Front Wheels to Base Plate	2	6061 Aluminum	Horizontal Band Saw, Vertical Band Saw, & Drill Press
2	Inch - Spur Gear 32DP 16T 20PA 0.25FW – S16N3.0H2.0L0.25N	16-Tooth, 32-Pitch Gear Connecting Servo to Shovel Arm	1	Acetal	
3	Linkage Right	Right Support Outside Wheels	1	6061 Aluminum	Horizontal Band Saw, Vertical Band Saw, &l Drill Press
4	Linkage Left	Left Support Outside Wheels	1	6061 Aluminum	Horizontal & Vertical Band Saw, & Drill Press
5	Shaft for Drivetrain	Hex Shaft Connecting Motor to Back Wheels	2	316 Steel	Lathe
6	Wheel	Wheels	4	400g Dragon Skin 10 Silicone, Acrylic Wheel Inserts	CNC for Wax Mold, Silicone Casting
7	Hex Shaft for Front Wheel	Hex Shaft for Front Wheels	2	316 Steel	Lathe
8	Nylon Bushing Hex Cut	Hex Nylon Bushings for Wheels and Shovel Arm	7	Nylon	
9	Nylon Bushing	Bushing Used as Spacers for Wheels and Shovel Arm	2	Nylon	
10	Servo Assembly	RC Rev1 Servo that Drives Shovel Arm	1	Assorted	
11	Hex for Arm	Hex Shaft to Support Shovel Arm	1	316 Steel	Lathe
12	Inch – Spur Gear 32DP 48T 20PA .25FW – S48N3.0H2.0L0.25N	48-Tooth, 32-Pitch Gear on Shovel Arm	1	Acetal	
13	Delrin Arm Motor Support	Delrin Support for Shovel Arm	1	Delrin	CNC, Vertical Drill Press
14	Baseplate for Model	Chassis for Robot	1	¼” Acrylic	Laser Cutter

15	91772A110	Pan Head Machine Screw, 4-40 Thread, 0.5” Length	37	Stainless Steel	
16	92010A022	M2.5 x 12 mm Flat Head Screw	4	Stainless Steel	
17	91772A108	Pan Head Machine Screw, 4-40 Thread, ⅜” Length	13	Stainless Steel	
18	91772A108	Pan Head Machine Screw, 4-40 Thread, ⅜” Length	8	Stainless Steel	
19	Mobile Arms	Arms to Support Shovel	2	⅛” Acrylic	Laser Cutter
20	Scooper	Shovel to Collect Balls	1	2.25in^2 PC ABS	3-D Printer
21	Nut for Robot	MSHXNUT 0.112-40-S-N Nut for Screw Ends	54	Stainless Steel	
22	95606A120	Nylon Washer 0.25” D	14	Nylon	
23	Bracket for Arms	Support Spacers for Shovel Arm	3	⅛” Acrylic	Laser Cutter
24	91772A108	Pan Head Machine Screw, 4-40 Thread, ⅜” Length	6	Stainless Steel	
25	Arm Support	Support for Shovel Arm on Servo-Side	1	2in^2 PC ABS	3-D Printer
26	Arm Rest	Prevents Shovel from Rotating Below Wheels	1	2in^2 PC ABS	3-D Printer
27	RC Controller	Controller for Robot	1	Assorted	
28	RC Receiver	Receiver for Robot	1	Assorted	
29	Battery	Battery Pack for Robot	1	Assorted	
30	Delrin Shaft Support	Delrin Shaft Support	2	Delrin	CNC Mill
31	97431A300	E-Clip 0.25" ID	2	Steel	
32	Washer Small	Washer 0.41" ID, 0.54" OD from Screwdriver	2	Steel	
33	Motor	Motor from Screwdriver	2	Assorted	
34	Planetary Gearbox	Planetary Gearbox from Screwdriver	2	Assorted	
35	Metal Circle	Metal Circle with 6 Notches from Screwdriver	1	Steel	
36	Hex Drive Shaft	Hex Drive Shaft from Screwdriver	2	301 Steel	

37	Washer Large	Washer 0.39" ID, 0.77" OD from Screwdriver	2	Steel	
38	92010A022	M2.5 x 12 mm Flat Head Screw	4	Stainless Steel	
39	Laser Cut Front Plate	Front Plate for Motor	2	⅛" Acrylic	Laser Cutter
40	91772A116	Pan Head Machine Screw 4-40 Thread 1.25"	8	Stainless Steel	
41	94639A662	Unthreaded Spacers, 3/16" OD, 11/16" Length	8	Nylon	
42	90126A505	Washer for Number 4 Screw Size, 0.125" ID, 0.312" OD	12	Steel	
43	Retaining Ring	External Retaining Ring for 10mm Shaft Diameter	2	Steel	
44	Nylon Bushing	Nylon Flange Bushing, ID 1/4" OD 3/8"	4	Nylon	
45	A 1M 2-TA32016	Acetal Plastic Gear, 16 Teeth, 32 Pitch	2	Acetal	
46	Round Shaft	Round Shaft	2	Steel	
47	A 1M 2-TA32048	Acetal Plastic Gear, 48 Teeth, 32 Pitch	2	Acetal	
48	92373A113	Slotted Spring Pin, 1/16" Diameter, 3/4" Long	2	Steel	
49	Motor Mount	3-D Printed Motor Mount	2	PC ABS	3-D Printer
50	Al Shaft Support	Aluminum Shaft Support	2	6061 Aluminum	

6.2: Assembly Drawing of Final Robot

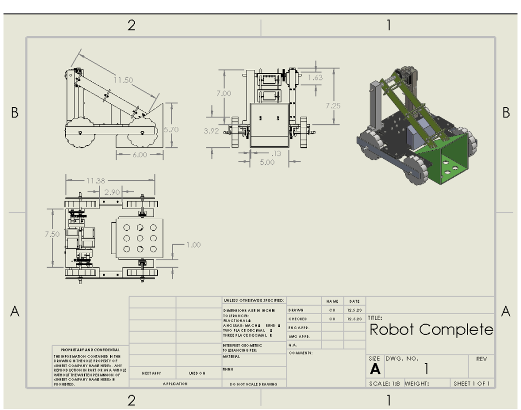


Fig. 8: Robot Drawing

6.3: Exploded View of Robot

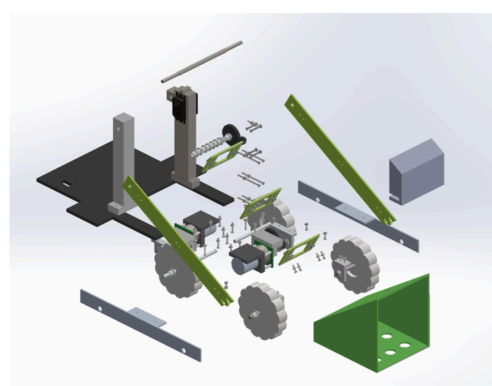
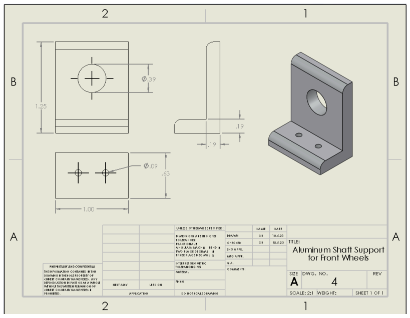
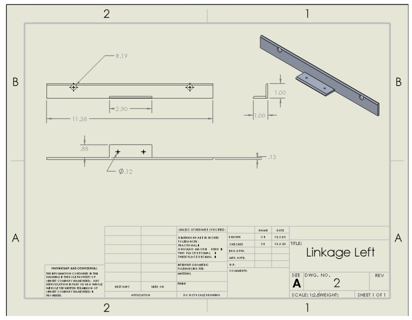


Fig. 9: Exploded View of Robot

6.4: Drawings of Non-Standard Parts





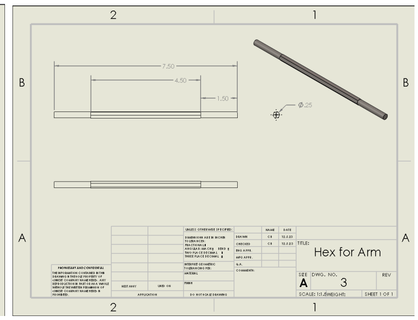


Fig. 10: Hex for Arm   *Fig. 11: Left Linkage*   *Fig. 12: Front Wheel Shaft Support*

6.5: Pictures of Final Robot

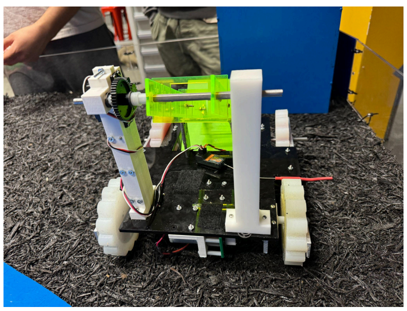


Figure 13: Back View

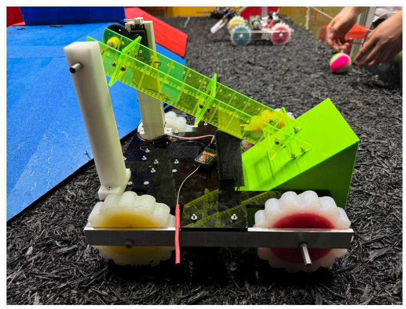


Figure 14: Left Side View

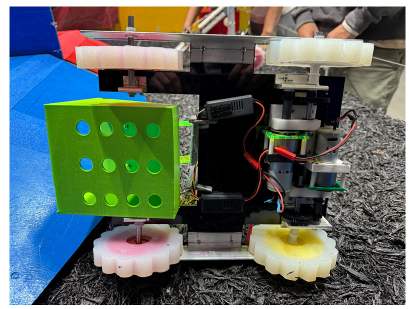


Figure 15: Bottom View

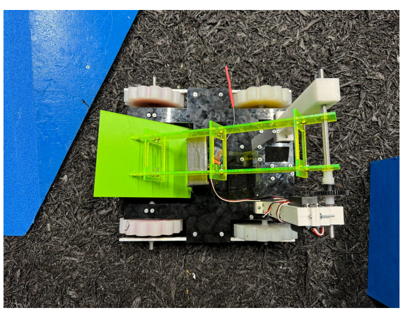


Figure 16: Top View

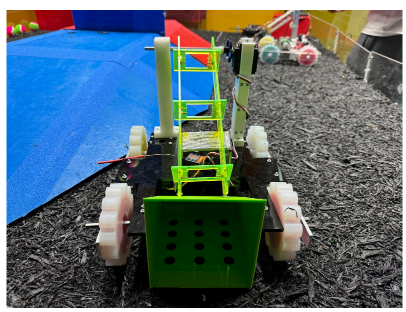


Figure 17: Front View

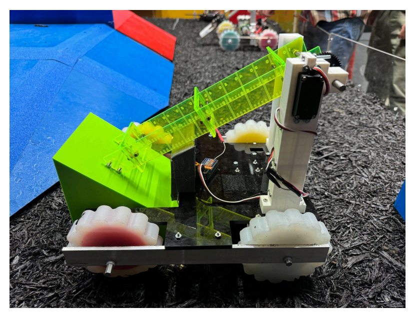


Figure 18: Right Side View