[REDACTED] Final Design Report

Jason Dao
Christian Castro
Chloe Nguyen
Derek Ko
Shishir Subramanya
Cindy Lu

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Executive Summary

The mission of Team [Redacted] was to create a fast, lightweight, small, structured rover that was functional. We decided to prioritize speed and mobility to give ourselves the best chance at a good time during the course trial.

As a team we approached this goal in a unique way as we opted to use coroplast instead of wood for the weight difference and durability we saw in it. We also chose the 45-tooth gear for the reason of trying to have high speed and so it accumulated in our rover having the foundation to achieve our goal. The small chassis brought challenges such as organizing the electronics into the compact space. Our team at one point took apart a servo and put it back together to allow it to fit in the position we wanted and keep things from touching.

The main issue we faced was setting up the foundation to create the slim, fast rover. Our big problem was that our steering arm broke multiple times. This came from us trying to keep the piece slim which led to the piece not being able to withstand the pressure of the servo. This piece was made of 3D print so our team had to redesign the piece. Through trial and error of making the piece wider twice, the thickness was now able to handle the servo and we were able to compete in the races and avoid disqualification.

Our team also struggled to get the rover to get over the cones due to the gears getting stuck. Our fabrication team worked on making different gear guards to try to counteract this but we were not satisfied with the result. Our team ended up changing our steering last second, expressing our adaptability, and moved the steering to the back. This turned out for the better as with this setup we got top 10 in the preliminary timed race.

Making everything work with a small chassis allowed us to stay true to our goal and maintain a small lightweight build. The vision we had also proved effective with us making the top ten with the rovers. It was a challenge to stay within our parameters but throughout the ten weeks, we learned to make micro adjustments to our design that allowed for our vision to be achieved.

Problem Definition

Introduction

Our challenge was to create a rover that was able to move around and operate with fully-functional steering, as well as be able to drive through obstacles such as cones and ramps. In order to do this, our goal was to balance different priorities such as speed, torque, turn radius, and overall durability of the rover. We also were placed with certain constraints such as size and budget, so we had to maximize our priorities within these constraints.

We went about this project by first designing a CAD model of our rover in solidworks, measuring the size and mass of the various parts as best as we could. After we were satisfied with the way this came out, we then began fabricating the chassis and attached the electronic parts to it. We 3D printed our steering mechanism and attached this to the chassis, the electronics, and the wheels. We then tested our rover on the course, trying to get the best time that we could.

Technical Background

Steering

Our rover used Ackermann steering geometry. As opposed to parallel geometry, in which both wheels turn at the same angle, in Ackermann steering, the two wheels turn at a different angle, with the inside wheel turning at a higher angle. The advantage is that it results in the two wheels rotating around a single converged point, which may reduce sliding when driving.

Torque/Speed

One of the most difficult decisions when using a motor such as the one we used is deciding where to draw the line between torque and speed. Increased torque could improve our ability to overcome the cones and ramps on the course, whereas increased speed would help us get a faster time (at the risk of being unable to complete the obstacles).

We controlled the rover’s torque and speed using our gears. Gears with less teeth have more speed and less torque, whereas gears with more teeth have less speed but more torque. In the end, we used the 45-tooth gear. Though this had less torque, we made conscious design choices (such as using coroplast for the chassis) that would lighten the load of the rover and allow for it to be supported by the torque that we had.

Rover History

One of the contexts in which the word “rover” is used is rovers that travel to Mars. The first and one of the most famous Mars rovers, was named Sojourner and landed on Mars in 1997. It had measurement tools that allowed it to gain information about the environment of Mars. This was later followed by the rovers Spirit, Opportunity, Curiosity, and Perseverance. Similar to the rover that we designed, these rovers contain batteries to power them as well as various electronic parts. However, as their main purpose is gathering information, the specific parts they use may be different.

3D Printing

Our group chose to use 3D printing for steering for its customizability. Being able to print a design in nearly any shape meant that we had a clear idea before starting fabrication of how our steering would look like. This technology works by cutting a 3D model into thin layers which are printed on top of each other until the entire model is created. It is also called additive manufacturing, because it works by adding material to be able to create a shape as opposed to cutting it out.

While the history of 3D printing dates back to 1980, when Hideo Kodama filed a patent for an idea similar to the 3D printing we have today, it is in the past few decades that the technology has become more widespread. Today, there are many different brands of 3D printers in the market that are used for applications such as medical uses, construction, and even personal use.

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Design Requirements

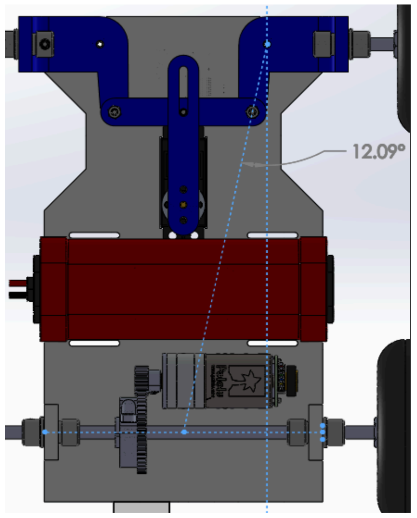
The rover had the following design requirements:

- Structure
    - Width < 10”
    - Length < 16”
    - Team must fabricate rover including steering and chassis
    - 3D printing allowed for steering
    - Raw materials may be purchased with permission from staff
- Power/propulsion
    - Motor provided
    - Easily-accessible power switch
    - Removable battery
- Safety
    - Gear guard to prevent contact with gears
    - No protruding sharp objects/edges
    - Keep wires away from moving parts
    - Wires and connectors insulated
- Cost
    - Total cost of rover (including 3D printed parts) < $300
    - Bill of Materials/parts list must be provided

Design Description

Summary of Design

The main focus of our design is to minimize weight. The material of the chassis is coroplast, one of the lightest available materials, while the chosen gear is the 45-tooth version, allowing the rover to accelerate as quickly as possible. Additionally, the rover was made as small as possible to further minimize mass and maximize the acceleration possible.



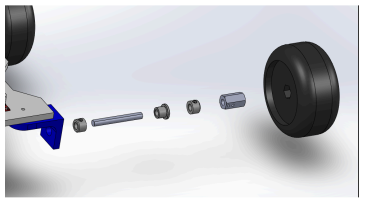
The steering mechanism is designed with Ackermann steering geometry in mind. This steering linkage design allows both steering wheels to have the same axis of rotation, meaning there should be little to no slippage of the wheels.

To achieve Ackermann steering geometry, the axis from the kingpin to the steering pins must meet at the center of the rear axle, as shown in the 3D model to the right.

To rotate the steering mechanism, a slot mechanism was used to attach the servo horn to the rest of the linkage.

One of the design requirements is to have an easily removable battery. This was achieved through velcro straps. Horizontal cuts were made where the battery would be placed to fit velcro and tighten the battery to the chassis.

A major design choice was the use of 85-mm wheels. The obstacle course shown to us involved obstacles that required a higher clearance below the rover, such as the cones and the ramp. The 85-mm wheels would be more effective in allowing the rover to traverse these obstacles as the wheels would increase the height of the rover above the ground.

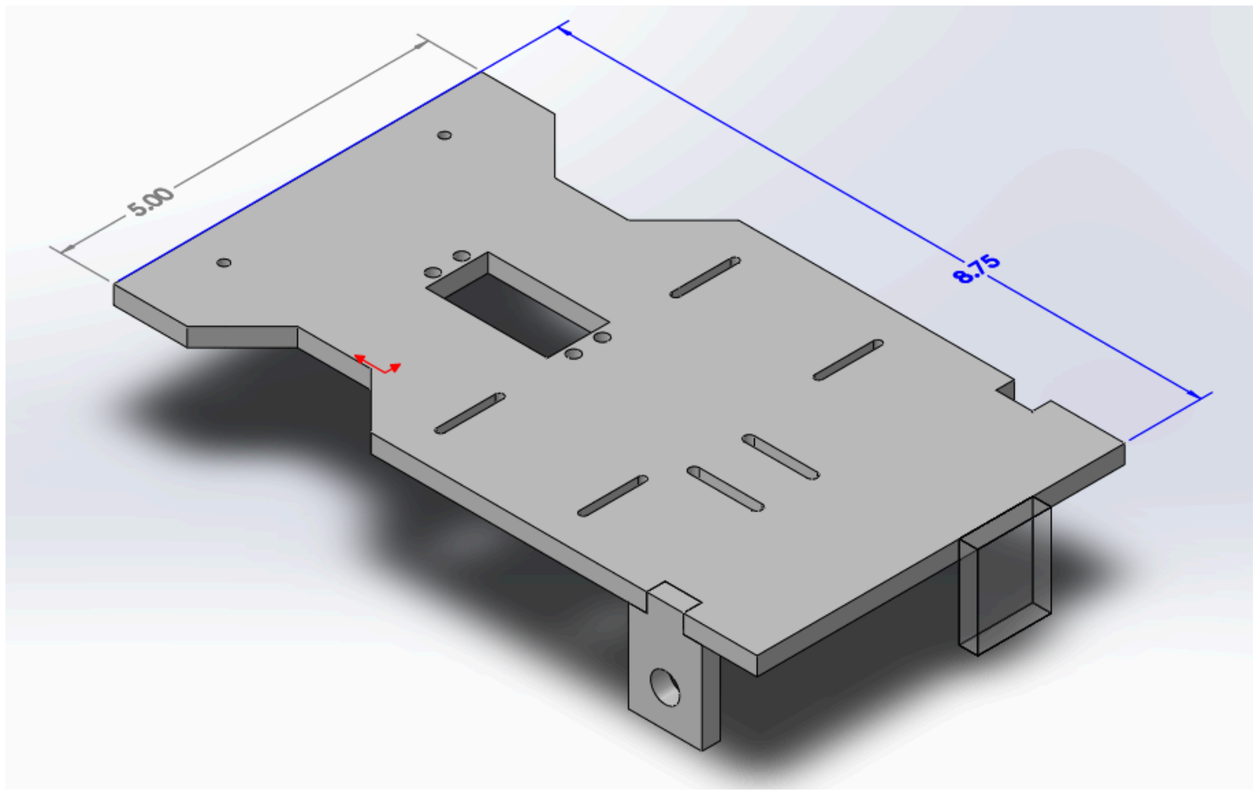


Exploded view of back wheel

The steering/axle parts were assembled in the following order: sleeve bearing, axle, shaft collar, wheel adapter, wheel. 3D-printed parts were attached to the chassis using 16-mm screws and lock nuts. The 3D parts were printed with holes 0.5 mm larger than the size of the screw to allow free rotation around the fastener. The rear axle mounts were glued onto the rover using gorilla glue. Slots were cut into the chassis to allow proper nucleation between the axle mounts and the chassis.

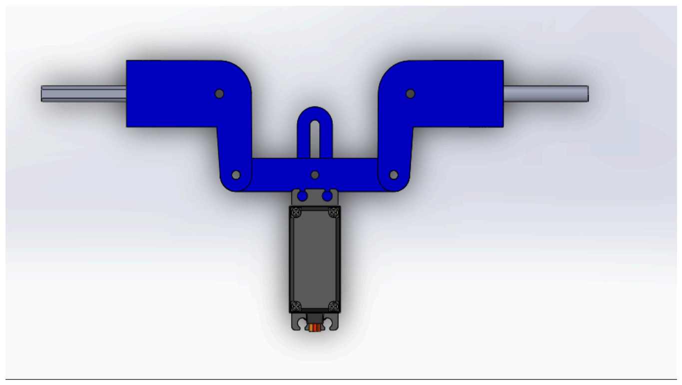
Design Details

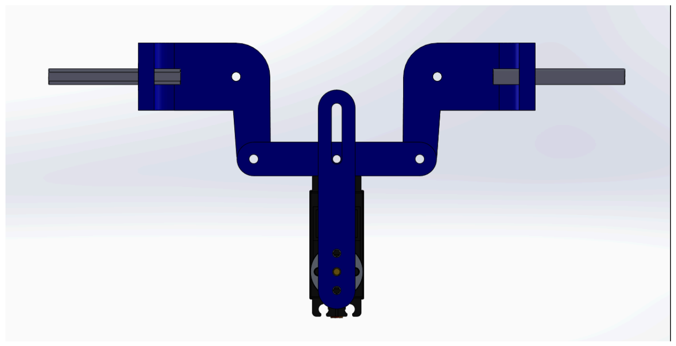
The main chassis is composed of a single flat sheet of quarter-inch thick coroplast that is overall 8.75x5 inches in length and width. The rear axle mounts are perpendicular to the chassis and made of the same material. The attachment was designed in a way that would allow the height of the wheels to be easily adjusted in the event that there was not enough clearance below the rover. The final height of the rear axle mount below the rover was 1.25 inches. Additionally, a 1x1.25 inch gear guard was glued on the rear of the rover.



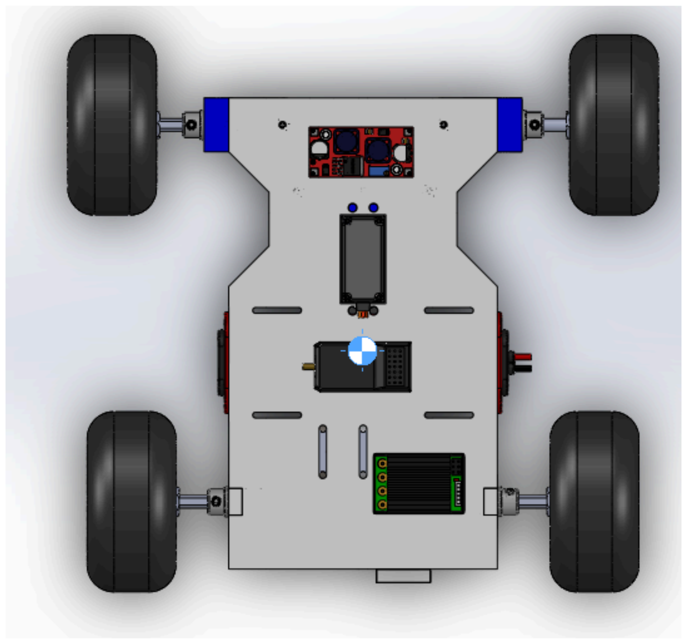
All parts of the rover made using coroplast

The steering of the rover consisted almost entirely of 3D-printed parts. This was chosen because, despite the relative weakness of these parts, it would allow us to create more precise parts that would better achieve the low slippage of Ackermann steering geometry.

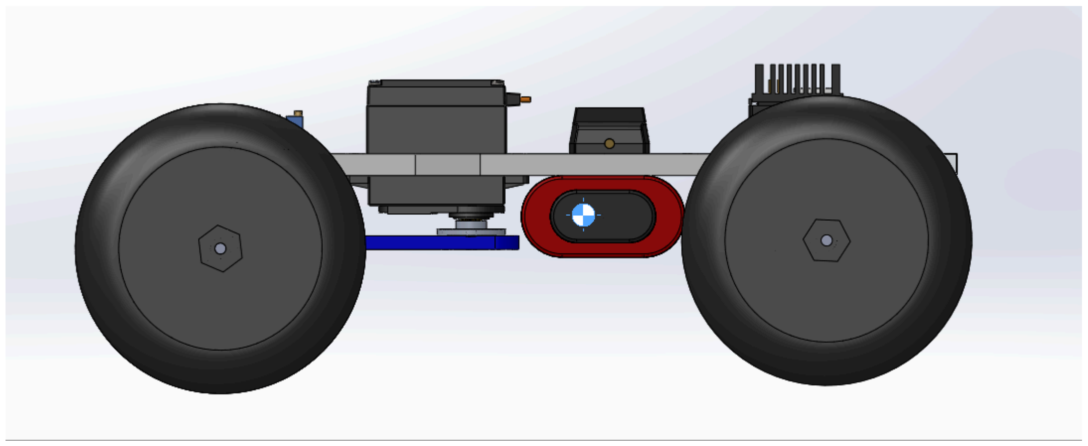




We aimed to make the center of mass relatively low to avoid the possibility of the rover flipping. This meant that careful placement of the battery, the heaviest component, was necessary, since the rest of the rover was very lightweight and the center of mass would be easily influenced by the battery’s location.

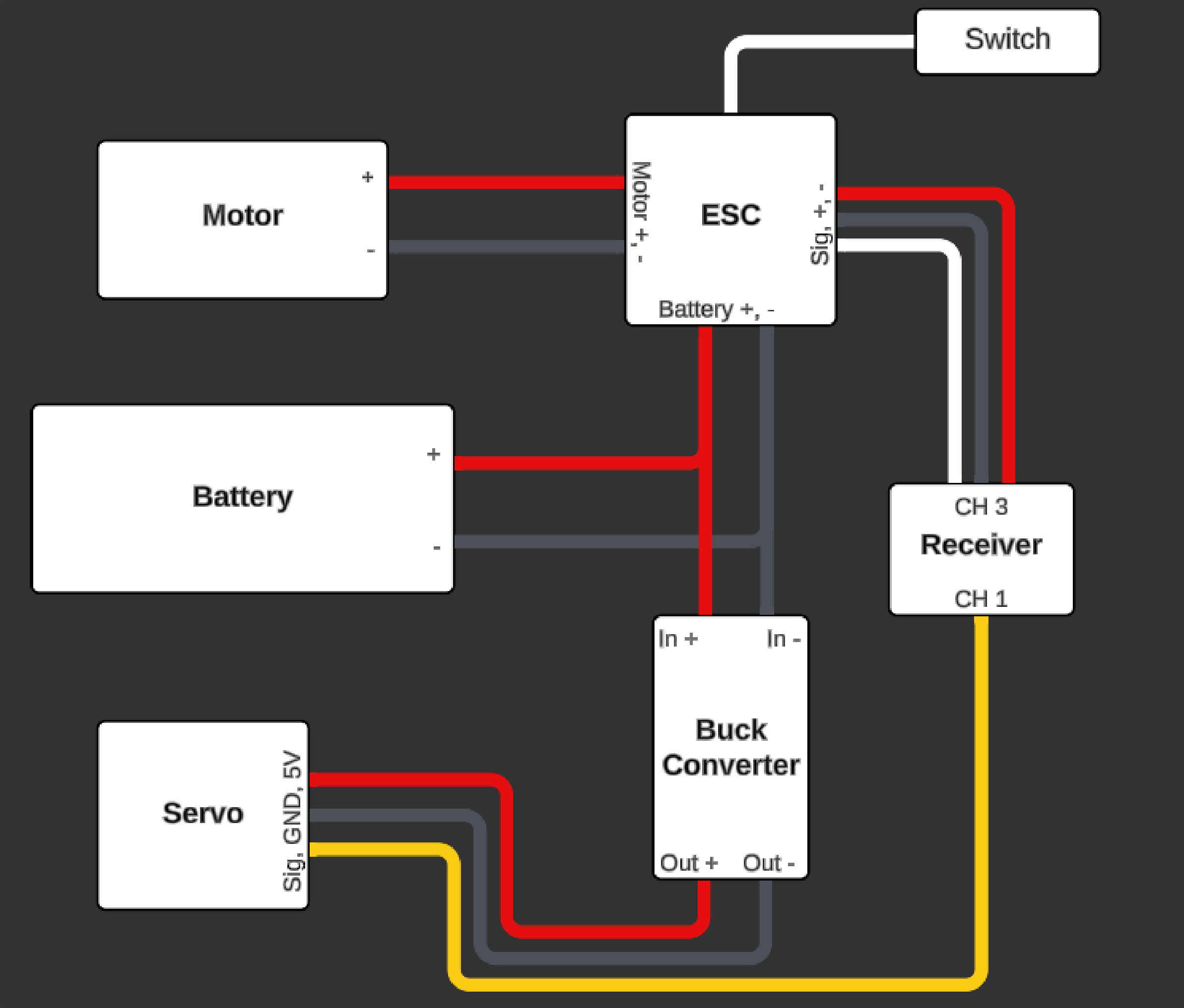


Location of COM from above



Location of COM from side

Wiring Diagram



The ESC is the central component of the circuit, and cuts the amount of voltage that is sent to the rest of the circuit from the battery. It also has a switch that turns on and off the entire circuit. The battery is the power source of the entire circuit, and is connected to the ESC. The motor is what powers the back wheels, and is connected to the ESC as well. The buck converter is attached to the ESC and the servo, and it increases the current sent to the servo by decreasing the inputted voltage. The receiver receives signals that are sent by the transmitter, and sends signals to the servo via Channel 1 to control the steering. It also sends signals to the ESC via Channel 3 to control the motor speed. Finally, the servo controls the steering, and is thus connected to both the buck converter and the receiver.

Action Item Report

Task Assignment

a. Task Assignment:

i. The different teams and what they did:

Captains: Christian and Jason - Captains work on overview and making sure the initial vision of the light weight rover comes to fruition.

CAD Design: Jason and Shishir - The CAD work on solid works set up the foundation and foundation for fabrication to create the team's envisioned rover. The team also set up Ackermann steering and created the pieces to be 3d printed for the final design.

Electronics: Cindy and Chloe - The electronics team worked on the wire work and placement for the rover to be functional. They set up the servo and all the connections needed to make the rover functional.

Fabrication: Derek and Christian - Fabrication had to bring the plans from the CAD team to life. The team had to adapt and learn through the process and even after when testing went wrong.

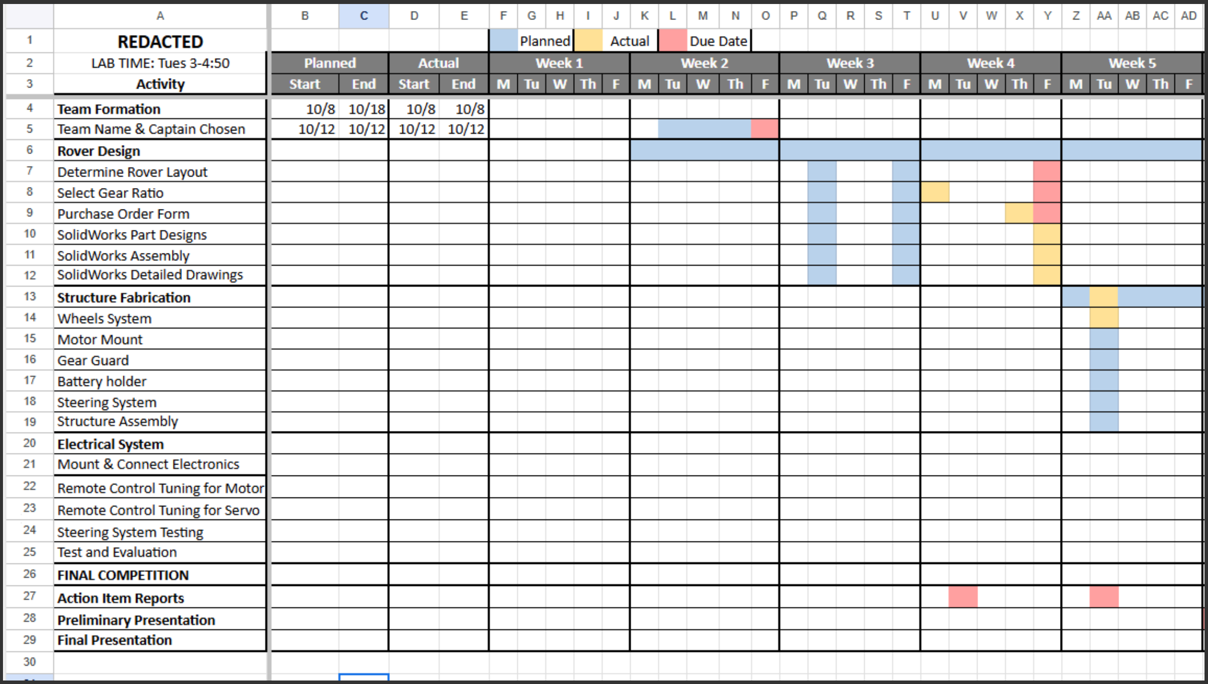
Research/Testing: Derek and Shishir - The research team tested the rover as well as being the starting foundation to the ideas that ended up creating our team's final rover. The test group was there to try to find the points where the rover lacked so that the fabrication team could fix the rover before the final race.

b. Task Management:

i. The Buddy System

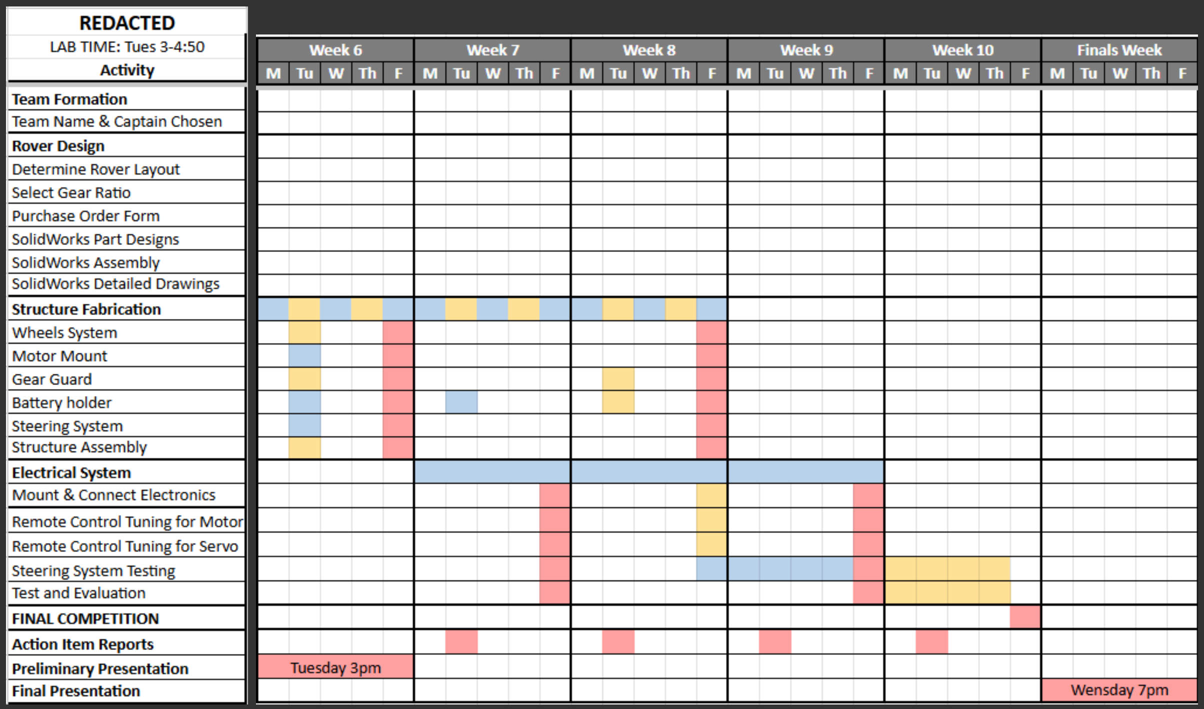
The buddy system was the foundation of our team's communication, it served as a way to keep each member accountable for their work. The way it worked was that the team was separated into groups of two where their partner in their group was the main person to check in on them, each week they would briefly overview what they did. If a person was behind they would need to talk with their partner to resolve it, and if a big issue would arise, that's when captains were informed. This form of communication allowed for each group member to both be responsible for their work as well as the process of the rover as a whole, this system also made weekend meetings with the whole group more efficient as each group already discussed with each other before presenting a weekly update. This system also allowed for more leniency on time for the members as it was more probable to get two members to meet at once rather than everyone, overall our buddy system worked for our method of communication and allowed our team to stay on track throughout the ten weeks.

Gantt Chart



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD
1	**REDACTED**					🟦	Planned		🟨	Actual		🟥	Due Date																	
2	LAB TIME: Tues 3-4:50	Planned		Actual		Week 1					Week 2					Week 3					Week 4					Week 5				
3	**Activity**	Start	End	Start	End	M	Tu	W	Th	F	M	Tu	W	Th	F	M	Tu	W	Th	F	M	Tu	W	Th	F	M	Tu	W	Th	F
4	**Team Formation**	10/8	10/18	10/8	10/8																									
5	Team Name & Captain Chosen	10/12	10/12	10/12	10/12							🟦	🟦	🟦	🟥															
6	**Rover Design**										🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
7	Determine Rover Layout																🟦			🟦					🟥					
8	Select Gear Ratio																🟦			🟦	🟨				🟥					
9	Purchase Order Form																🟦			🟦				🟨	🟥					
10	SolidWorks Part Designs																🟦			🟦					🟨					
11	SolidWorks Assembly																🟦			🟦					🟨					
12	SolidWorks Detailed Drawings																🟦			🟦					🟨					
13	**Structure Fabrication**																									🟦	🟨	🟦	🟦	🟦
14	Wheels System																										🟨			
15	Motor Mount																										🟦			
16	Gear Guard																										🟦			
17	Battery holder																										🟦			
18	Steering System																										🟦			
19	Structure Assembly																										🟦			
20	**Electrical System**																													
21	Mount & Connect Electronics																													
22	Remote Control Tuning for Motor																													
23	Remote Control Tuning for Servo																													
24	Steering System Testing																													
25	Test and Evaluation																													
26	**FINAL COMPETITION**																													
27	**Action Item Reports**																					🟥					🟥			
28	**Preliminary Presentation**																													
29	**Final Presentation**																													
30																														

This project was planned using the Gantt chart above. The chart contained deadlines as well as planned work days. This planning system allowed for us to deal with mistakes as well as necessary shifts to adapt our rover to become efficient for the races. The first five weeks was the foundation and planning time where we selected our gear ratio and decided to commit to using chloroplast. By the end of this brainstorming phase we had our finalized designs that allowed us to start the fabrication process.



REDACTED LAB TIME: Tues 3-4:50	Week 6					Week 7					Week 8					Week 9					Week 10					Finals Week				
Activity	M	Tu	W	Th	F	M	Tu	W	Th	F	M	Tu	W	Th	F	M	Tu	W	Th	F	M	Tu	W	Th	F	M	Tu	W	Th	F
Team Formation																														
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SolidWorks Part Designs																														
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SolidWorks Detailed Drawings																														
Structure Fabrication	🟦	🟨	🟦	🟨	🟦	🟦	🟨	🟦	🟨	🟦	🟦	🟨	🟦	🟨	🟦															
Wheels System		🟨			🟥										🟥															
Motor Mount		🟦			🟥										🟥															
Gear Guard		🟨			🟥							🟨			🟥															
Battery holder		🟦			🟥		🟦					🟨			🟥															
Steering System		🟦			🟥										🟥															
Structure Assembly		🟨			🟥										🟥															
Electrical System						🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦										
Mount & Connect Electronics										🟥					🟨					🟥										
Remote Control Tuning for Motor										🟥					🟨					🟥										
Remote Control Tuning for Servo										🟥					🟨					🟥										
Steering System Testing										🟥					🟦	🟦	🟦	🟦	🟦	🟥	🟨	🟨	🟨	🟨						
Test and Evaluation										🟥										🟥	🟨	🟨	🟨	🟨						
FINAL COMPETITION																									🟥					
Action Item Reports							🟥					🟥					🟥					🟥								
Preliminary Presentation	Tuesday 3pm																													
Final Presentation																										Wensday 7pm				

From weeks six through ten we finished fabrication as well as tested our rover and had to adapt many times throughout the process. Week 8-9 was the main finalization stage where we found errors in our planned testing that allowed us to make minor changes so that during week 10 we can primarily focus on having our driver (Shishir) improve at handling the rover.

Evaluation

Calculations

1. Weight of the Rover:

$$Mass\ of\ Rover\ \times Gravity\ Acceleration\ =\ Weight$$

$$1.03\ kg\ \times\ 9.8\ m/s^2\ =\ 10.094\ N$$

2. Predicted Drive Time:
   - Battery Capacity: 3600 mAh = 3.6 Ah
   - Total Current = motor + servo motor
     - Motor Current: $\frac{12\ V}{5A} = \frac{7.2V}{x} \Rightarrow 3A$
     - Servo Current = 3A (from spec sheet)
     - Total Current = 3A + 3A = 6A

$$Run\ Time\ = \frac{3.6[Ah]}{Total\ Current\ [A]} = \frac{3.6[Ah]}{6[A]}\ =\ 0.6\ hours\ =\ 36\ minutes$$

3. Turning Radius:
   - Angle of the rover’s turn = 35.05°
   - Wheel Base = 7 inches

$$Turning\ Radius\ =\ 12.189\ inches$$

4. Velocity:
   a. Theoretical:
      - Train Ratio = 3
      - Wheel Diameter = 85 mm = 0.085m

$$Train\ Ratio\ = \frac{\omega_{In}}{\omega_{Out}} \Rightarrow \omega_{Out}\ = \frac{\omega_{In}}{Train\ Ratio}\ = \frac{1490\ rpm}{3}\ =\ 496.66\ rpm$$

$$v\ = \frac{496.66\ rpm}{1} \times \frac{1\ min}{60\ sec} \times \frac{(0.085m)\pi}{1\ rev} =\ 2.21\ m/s$$

   b. Experimental:

$$v\ = \frac{\Delta x}{\Delta t} = \frac{2ft - 1ft}{1.05s - 0.88s} = 5.88ft/s\ =\ 1.79\ m/s$$

c. Difference in Theoretical vs. Experimental Velocity:

   i. There is about a 0.42 difference between our theoretical and experimental velocities. A major factor that could explain this difference is the theoretical calculation's lack of accounting for friction between the wheels and the track, which would have occurred during the experimental calculation.

5. Experimental Acceleration:
   - $v_0 = 1.79\,m/s$
   - $v_f = \frac{10ft - 9ft}{2.53s - 2.34s} = 5.26ft/s = 1.60\,m/s$

$$a = \frac{\Delta v}{\Delta t} = \frac{1.60m/s - 1.79m/s}{2.34s - 0.88s} = -0.13\,m/s^2$$

6. Mechanical Advantage:

$$M_A = \frac{N_{Out}}{N_{In}} = \frac{45T}{15T} = 3$$

a. Stall Torque:
   - Input Torque from Motor = 0.10062 Nm

$$M_A = \frac{T_{Stall}}{T_{Input}} \Rightarrow T_{Stall} = (0.10062\,Nm)(3) = 0.302\,Nm$$

b. Stall Weight:
   - Wheel Radius = 0.0425 m
   - μ (friction coefficient) = 0.7
   - Actual Rover Weight = 10.094 N

$$Stall\,Weight = \frac{Stall\,Torque}{\mu \times (Wheel\,Radius)} = \frac{0.302\,Nm}{0.7(0.0425\,m)} = 10.147\,N$$

   - Actual Weight vs. Stall Weight:
     - 10.094 N < 10.147 N

c. Why the 45T Gear?

- As a team, we chose the 45T gear because one of our main objectives was to maximize our speed. Thus, we chose the gear with the least amount of teeth for a higher speed. However, this would lead to a lower torque, which compromises the stability and strength of our rover to hold weight. Thus, we needed to minimize our weight by using coroplast as our main chassis material, which was the lightest. This allowed our rover's actual weight to remain below the stall weight and function properly.

Test Plans

1. Steering
    - Decide on what material to use in chassis based on samples in class
    - Research steering types (Parallel vs Ackermann) and decide on which to use
    - Select type of wheel to use
    - Choose gear based on torque calculations and objectives for rover
    - Model initial chassis and steering designs in Solidworks
    - Modify designs as needed in order to meet rover requirements
    - Submit Parts Order form by end of Week 4 to ensure all chosen parts (e.g. wheel and gear choices) are received
    - Finalize design by Week 5 in order to begin fabrication
2. Electronics
    - Secure heat sink onto buck converter with double sided tape
    - Cut power (red) and ground (black) wires from servo connecter
    - Solder power and ground from servo to out+ and out- of buck converter respectively
    - Solder power and ground wires from ESC to in+ and in- of buck converter respectively
    - Cut sections of red and black stranded wires to solder onto motor
    - Solder red wire onto side of motor with red dot, and black wire on opposite side
    - Cover up end of wire connected to motor with heat shrink tubing and secure with heat gun
    - Cut off excess wire attached to motor
    - Crimp bullet connectors to each end of motor wire and secure with heat gun

  - Measure voltage running through buck converter and adjust it to only output 5.5V
  - Connect bullet connectors from motor to bullet connectors from ESC
  - Connect battery to ESC and turn on switch
  - If done correctly, there should be a red light on the buck converter
3. Steering (Actual)
  - Submit Solidworks drawings of steering mechanism to be 3D printed
  - Fabricate chassis based on finalized Solidworks design
  - Sand down finished chassis to make it look nicer and less messy
  - Assemble rover using fabricated parts + 3D printed steering
  - Test if steering mechanism works by seeing how steering wheels move when servo is moved
4. Transmission
  - Connect signal (yellow) wire from servo to channel 1 of the receiver
  - Connect three wires (red, black, white) from ESC to channel 3 of the receiver
  - Plug bind key into top of receiver
  - Connect battery to ESC and turn on switch
  - Flashing red light should show up on receiver
  - Turn on transmitter while holding down bind key at back of transmitter
  - Unplug battery and unplug bind key, then plug battery back
  - If paired correctly, red light on receiver should no longer be flashing
  - Adjust settings on transmitter
  - Test transmitter and receiver by seeing if servo and motor move according to signal received from transmitter
5. Entire Rover
  - Secure electronics to rover via double sided tape
  - Zip tie wires to ensure they will not get in way of rover
  - Test driving on flat ground first
  - Check if rover runs in right direction (if moving in wrong direction, swap the red wire from the motor with the black wire
  - Test if rover can navigate final obstacle course properly (able to go up ramp and able to drive on cones)

Results & Discussion

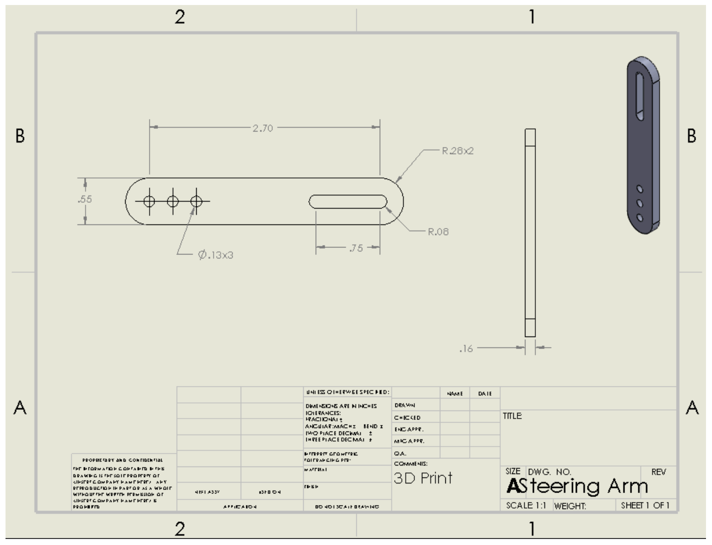
The official rover criteria was that it had to be less than 10 inches wide and 16 inches long with a removable battery. Our rover was 10 inches wide and 8.75 inches long with the battery secured by velcro straps, making it removable. The group decided on additional criteria based on the main goal, which was to build a rover that could win the final competition. The first criterion was making the rover as lightweight and fast as possible. By using coroplast and the 45T gear, the rover was one of the fastest. The second was a low center of mass to increase traction and decrease the possibility of flipping over on the ramp. That criterion was accomplished by putting all the heavy electronics at the bottom.

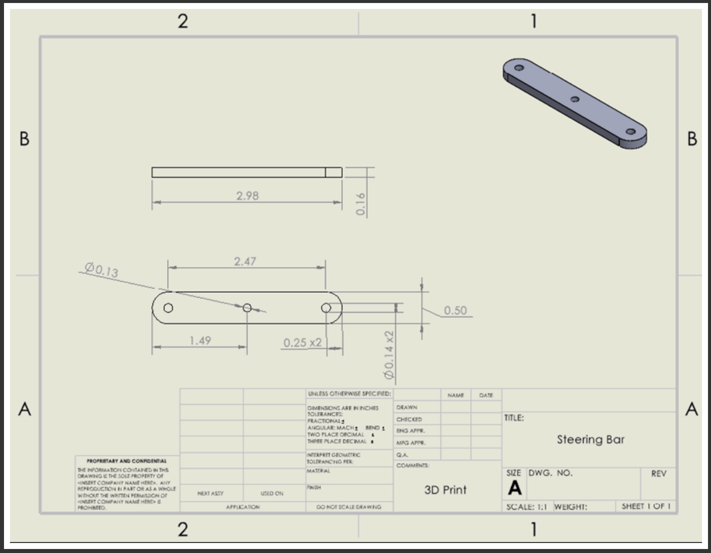
Despite some issues, the rover met all the criteria. In the preliminary competition, it had a time of 22.35 seconds, good for 7th. In the final competition, more issues arose and the rover finished 9th, with a time of 1 minute and 31 seconds. It had one of the fastest straight-line speeds due to the 45t gear and coroplast. The rover also had high agility due to a large turn radius and was very durable, surviving over 50 test runs.

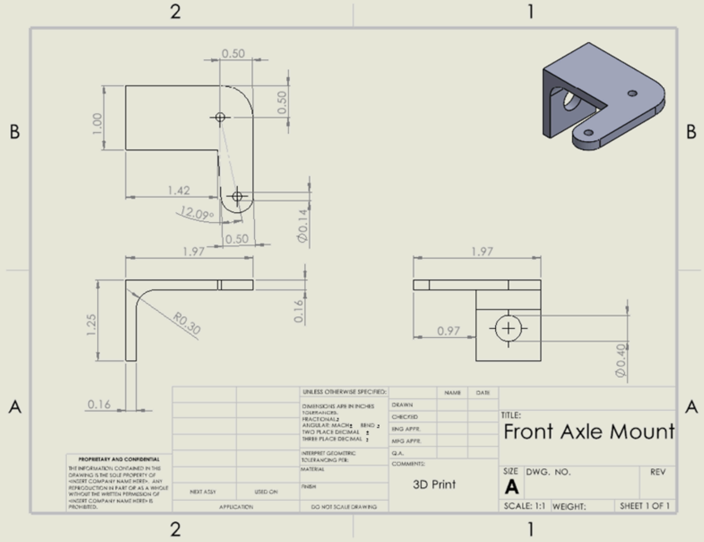
The main issues were the steering arm breaking and the rover's inability to get over the cones. To address the steering arm breaking, a thicker version had to be printed. The cone issue stemmed from the bumpy electronics on the underside of the rover. To combat this, the steering was switched to the back, so the motor, which has the lowest clearance would go over the cones first and apply more torque. This worked reasonably well and it increased the traction when turning. However, moving the steering to the back made the rover hard to control. The turn radius was reduced, which helped a little. Unfortunately, in the final competition, the rover struggled with non-standard turns, leading to a lackluster time.

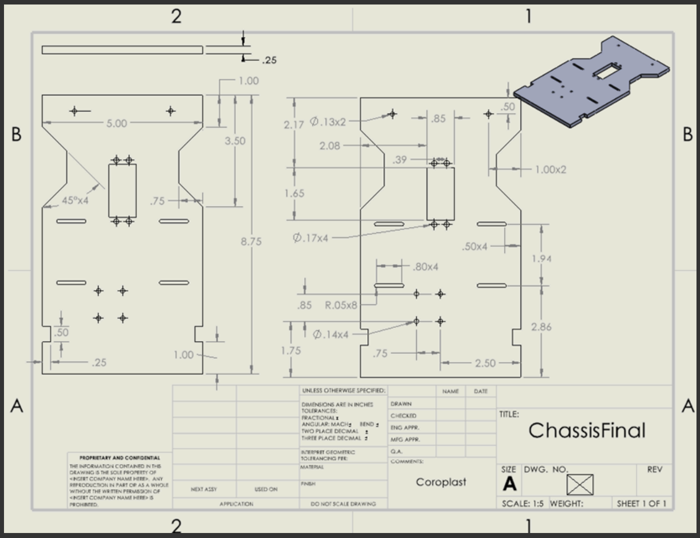
One improvement that could be made with time is to move the electronics to the top, increasing the clearance so the rover could navigate the cones more consistently. None of the rovers seemed close to flipping over on the ramp. Moving the steering back to the front would give the rover better control when making turns. Finally, the rover could have been more aesthetically pleasing. Better concealed wires and the removal of glue stains would have enchanted its looks. The lesson learned when building this rover is to prioritize functionality and controllability over speed. Most of the winning rovers weren't fast, but were very stable. Another is to have backup supplies. When our steering arm broke we had to print another one, which wasted precious testing time. Finally, perform the calculations beforehand to ensure the rover can theoretically make it through all the different challenges.

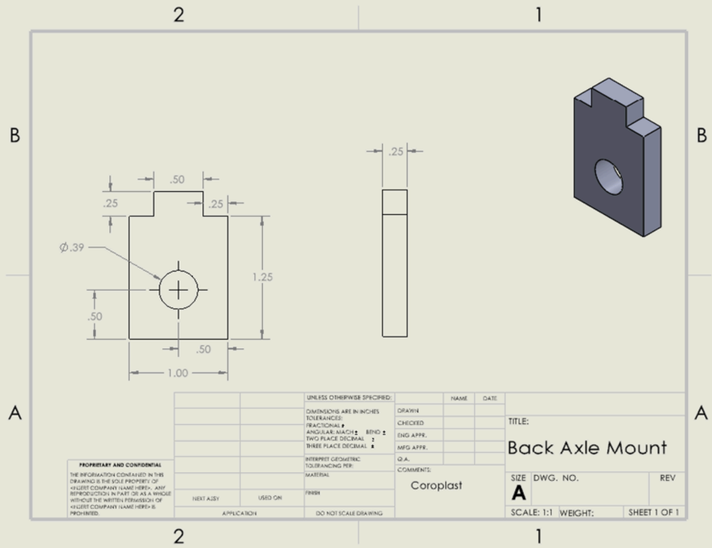
Appendix A: SOLIDWORKS Drawings

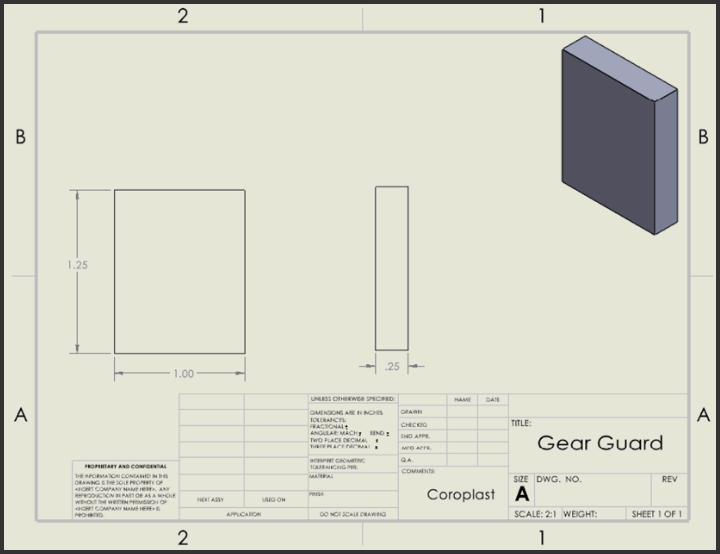


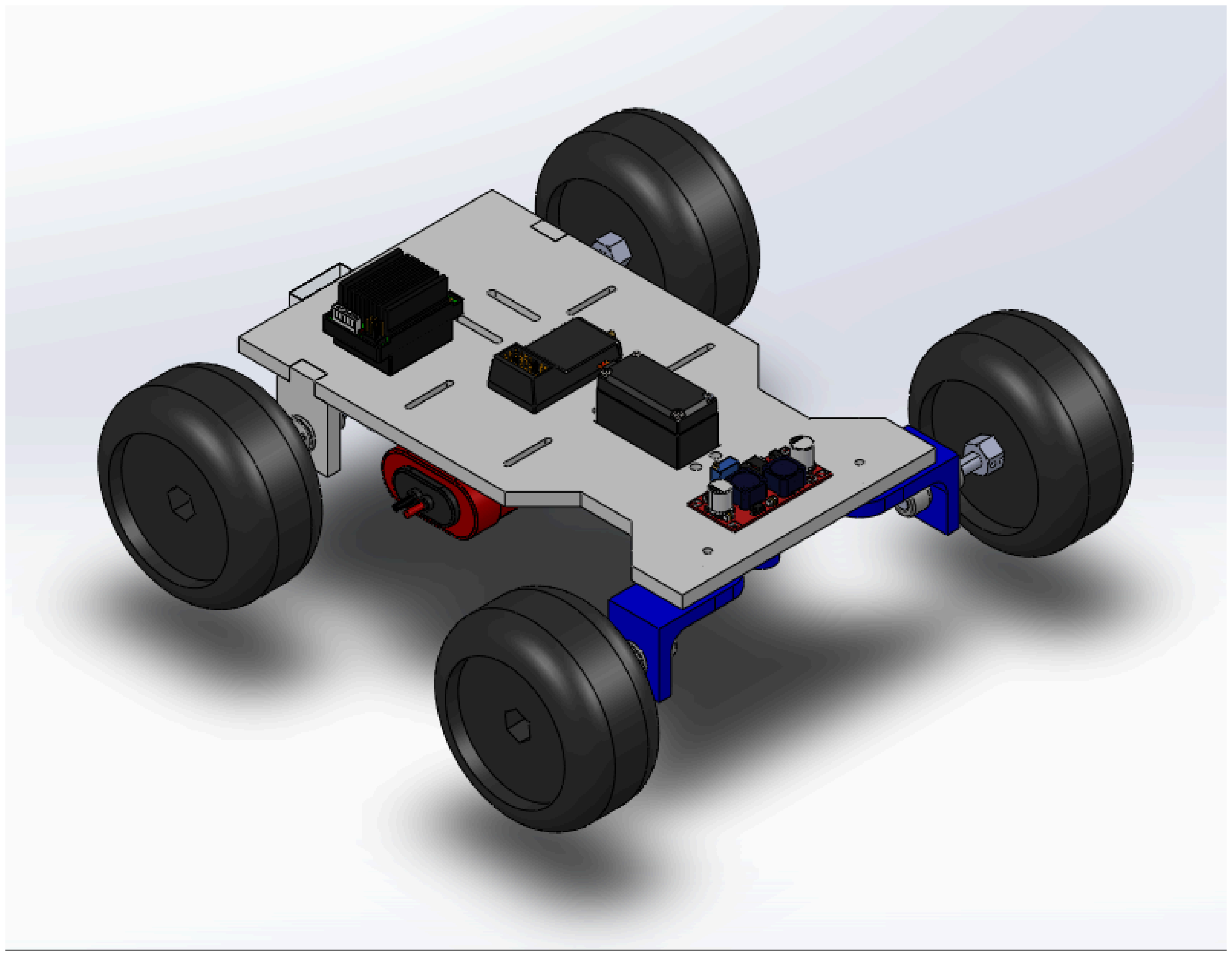












Appendix B: Bill of Materials

Electronic Components:

Item	**Vendor**	**Quantity**	**Price**
4.4:1 Gearmotor	Polulu	1	$28.95
Servo	Amazon	1	$4.50
Brushed ESC	Amazon	1	$11.90
Buck Converter	Amazon	1	$3.50
Transmitter + Receiver	Amazon	1	$75.99
Battery	Amazon	1	$17.50

Hardware:

Item	**Vendor**	**Quantity**	**Price**
45-tooth Gear	Servocity	1	$2.99
Motor Bracket	Polulu	1	$3.98
Servo Horn (25T)	Amazon	1	$1.00
D-Shaft (6mm bore, 50mm length)	Gobilda	2	$4.98
D-Shaft (6mm bore, 200mm length)	Gobilda	1	$5.49
Sleeve Bearing (6mm bore)	McMaster-Carr	4	$8.08
Shaft Collar (6mm bore)	McMaster-Carr	8	$16.64
Wheel Adapter (6mm bore)	Polulu	4	$9.90
Gear Hub (6mm bore)	Servocity	1	$7.99
Pinion Gear (4mm bore, 15T)	Servocity	1	$9.99

Structure Materials:

Item	**Vendor**	**Quantity**	**Price**
85mm Wheels	Amazon	4	$16.99
3D Printing	UCI	3 hrs	$12
1/4” white Coroplast 12”x12”	UCI	1	$1.94