Fall 2021

MEMS 411: Soccer Robot Project

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FALL 2021 MEMS 411

Mechanical Engineering Design Project

Soccer Robot

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FL21 MEMS 411 Mechanical Engineering Design Project

Soccer Robot

This project aims at designing a robot that is capable of playing a simplified form of soccer against other robots. The original competition was created by the ASME organization as a student design competition in 2018. This project is an adapted version in which some of the rules and guidelines have been changed to fit the goals of this class better. The design parameters for this project include: having the robot drive around the parameter of the playing field in under 17 seconds, having the vehicle successfully capture the ball within 2 seconds of approaching 8 out of times, and having the vehicle make more than out of shots from the mid-line of the field with having the robot approach from the sideline with the ball placed in the center. The robot utilized two DC motors to power the rear wheels and a modified steering system to achieve the first goal. A shovel like arm was used to capture the tennis ball and load it into the shooter in under 2 seconds, achieving the second design parameter. A spring loaded shooter with an spindle release system was constructed to shoot the tennis ball, achieving the t
For future iterations or standarization of this design,

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1 Introduction

This project aims at designing a robot that is capable of playing a simplified form of soccer against other robots. The original competition was created by the ASME organization as a student design competition back in 2018. This project is an adapted version in which some of the rules and guidelines have been changed to fit the goals of this class better. In this project, the customer needs are generated by our group due to the purpose of the design. The robot is being designed to compete against other groups so the importance of design specifications are determined by our group. Key features for this design include a way for the robot to collect and shoot the ball accurately, move around and defend against opponents shots, and overall durability of the robot whether it is surviving collisions from other robots or not running out of battery during a round. These specifications need to be met while also meeting the guidelines of the competition.

2 Problem Understanding

2.1 Existing Devices

The market for existing devices for this project is fairly limited. Most existing devices were created for the 2018 ASME student design competition or for a design project related to it.

2.1.1 Existing Device #1: UNLV Student Design Team

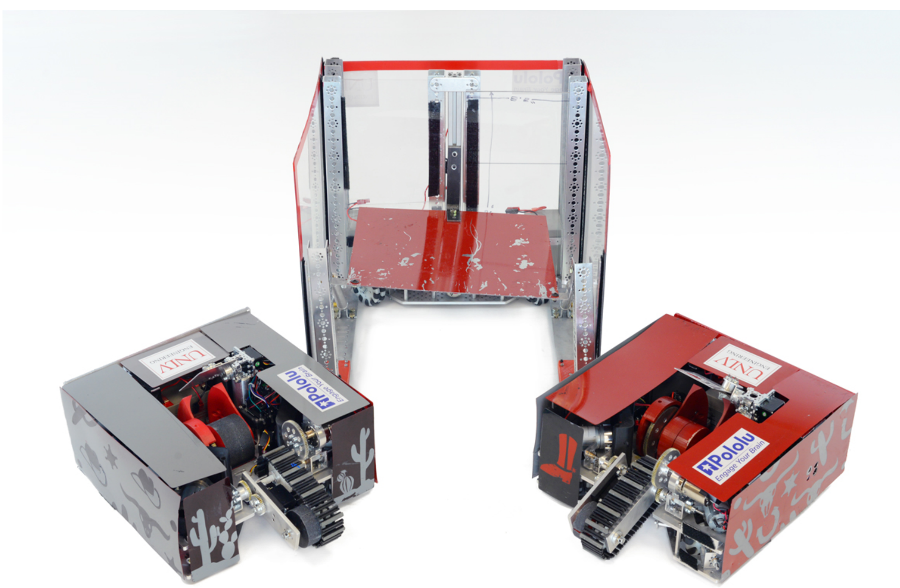


Figure 1: The Rebel Bandits [1].

Link: https://www.pololu.com/blog/760/unlv-wins-1st-place-in-student-design-competition-at-asme-e-fest-west
Description: The UNLV student design team created these robots for the 2018 ASME student design competition. These robots were created for the ASME guidelines which vary slightly from ours. They created three separate robots for this competition. They made one defending robot called

the The Outlaw and made two identical offensive robots called The Renegade and The Desperado. The Outlaw was designed to be big and bulky and mainly just get in the way of other robots while also blocking a good section of the field to make shots harder to hit for the other teams. The Renegade and The Desperado were able to collect and ball and drive with it underneath it without impeding the robots motion. The ball was then able to be shot when the robot stopped moving. This was accomplished by revving up a flywheel to high speeds and and powers a ramp that the ball is placed on and launched at a high speed. All three robots are powered by different DC motors and a micro-controller.

2.1.2 Existing Device #2: 2017 WASHU Senior Design Project

Figure 2: The Reverse Shooter [2]

Link: https://openscholarship.wustl.edu/cgi/viewcontent.cgi?article=1072&context=mems411

Description: This is a previous senior design project that built a soccer robot for the 2018 ASME Student Design Competition. The Reverse Shooter was the design that they deemed best out of their concepts. This design had good shot power and ability in return for having a higher cost and energy consumption. This design used a spring push the ball through rotating wheels similar to a pitching machine. The robot had panels that could open and close to collect and shoot the ball. It moved with on rollers and was use a battery to power its motor.

2.1.3 Existing Device #3: iSoccerBot

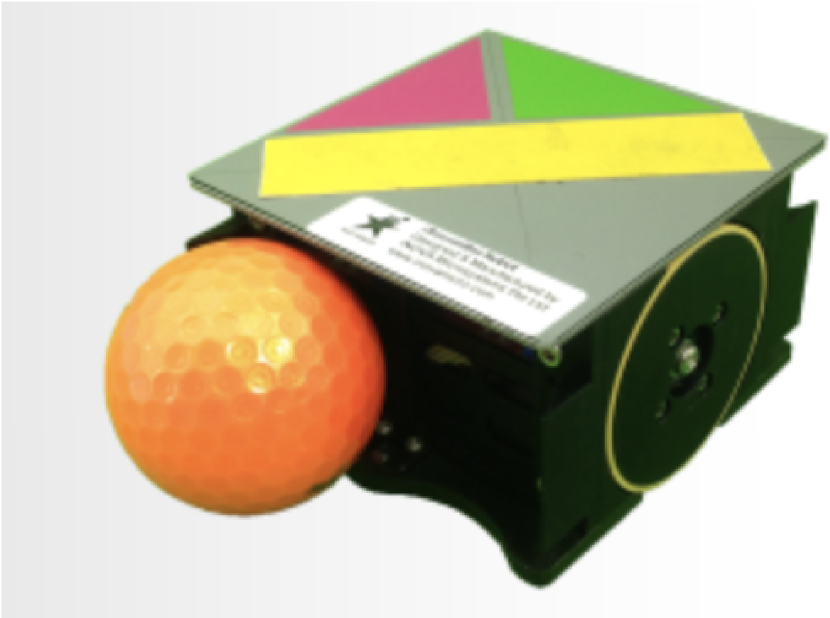


Figure 3: iSoccerBot [3].

Link: http://www.inovamicro.com/isoccerbot.html
Description: The iSoccerBot is a miniature version of our project. The main difference is that a golf ball is used instead of a tennis ball. This allows for much smaller robots, but leaves less room for design mechanism. It relies on computer vision to see and go after the ball. It uses a gyroscope to maintain balance. It has a good battery life and recharge time and is also very fast and agile.

2.2 Patents

2.2.1 Pitching Machine (US20030195061A1)

This patent uses rollers to launch a ball at a certain speed determined by the rotation speed of the rollers. The rollers can spin at different speeds to generated spin and curve in a shot. The rollers are controlled by a control system that allows for different speeds and spins to be inputted prior to launch.

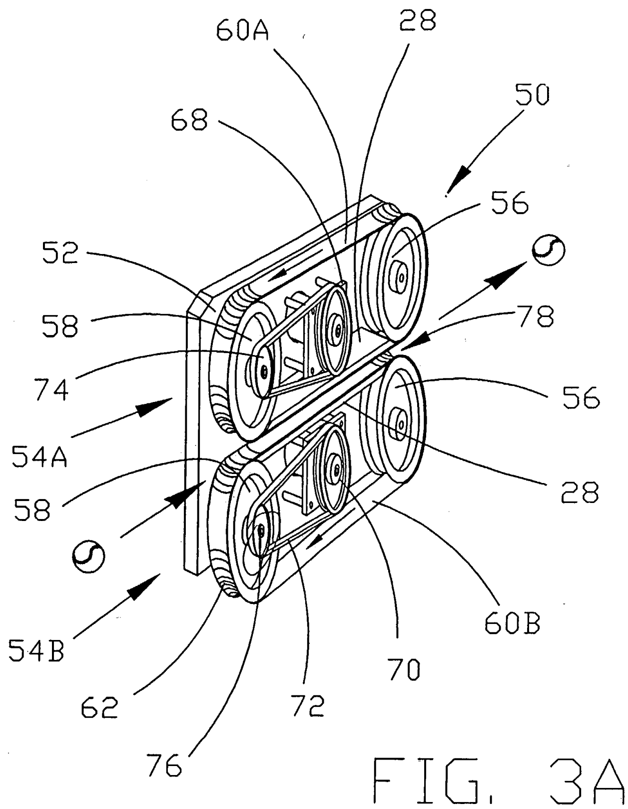


Figure 4: Patent Image for Rollers that launch the ball.

2.2.2 Tennis Ball Retriever (US3593868A)

This patent is an apparatus that is able to move over a surface and pick up balls as it goes. It has a receiving chamber that leads to a ramp that has a brush that pushes the ball up the ramp to collect it. A deflector plate and retriever arms are added to insure that no ball gets stuck under the device.

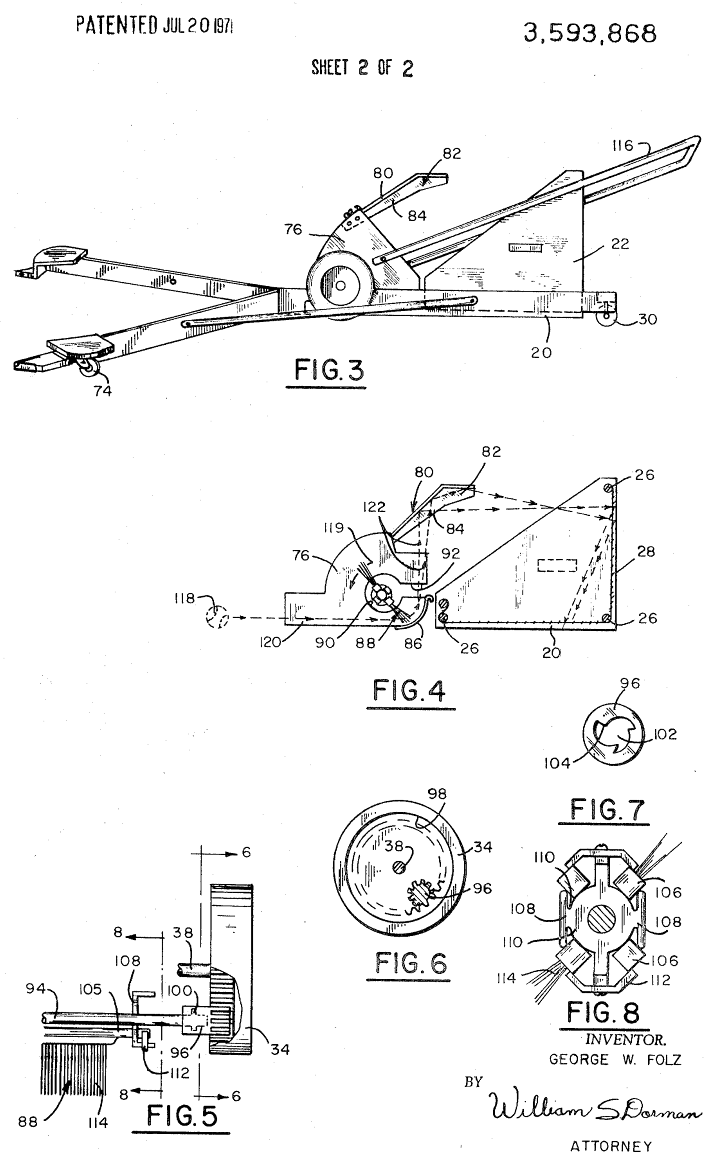


Figure 5: Patent Image showing the collection system under the apparatus.

2.3 Codes & Standards

2.3.1 Standard Consumer Safety Specification for Toy Safety (ASTM F963.17)

"This specification relates to possible hazards that may not be recognized readily by the public and that may be encountered in the normal use for which a toy is intended or after reasonably foreseeable abuse. It does not purport to cover every conceivable hazard of a particular toy. This specification does not cover product performance or quality, except as related to safety. Except for the labeling requirements pointing out the functional hazards and age range for which the toy is intended, this specification has no requirements for those aspects of a toy that present an inherent and recognized hazard as part of the function of the toy" [4]. This code will be able to influence our design to create a product that is robust and withstand the small impacts from other robots and tennis balls allowing the machine to be operable for the duration of the tournament.

2.3.2 Tests for Flammability of Plastic Materials for Parts in Devices and Appliances (DEF UL 94)

This is a plastics flammability standard that determines the tendency a material has to distinguish a the spread of a flame once the material has been ignited. The standard will influence the design by guiding our choice of materials when constructing the robot. This will ensure a safe environment for the user if there is any type of spark or flame ignition of the batter or any of the electrical components.

2.4 User Needs

An interview was conducted with the customer to determine the specifications, constraints and needs of the customer. The notes from the interview provide information about preferences. The user needs and design metrics tables interpret and quantify this information.

2.4.1 Customer Interview

Interviewee: Samantha Hudson
Location: Wilson 214, Washington University in St. Louis, Danforth Campus
Date: September 10^{th}, 2021
Setting: This interview occurred after we read over the general rules and details laid out in the ASME Competition briefing. Information from the briefing has been added to these notes to complete the user needs.

Interview Notes:
Warmup Sizing Box

- All components (including spares) must fit in a 50x50x50 cm box.
- Multiple robots may be brought for competition but only one may compete at a time.
- Components may be disassembled to fit in the sizing box. However, you must be able to reassemble the components within one minute (the allotted setup time).
- All components need to be easily transported to the field.

Budget

- Hard budget cap.
- Typically $400-500.

Robot Mechanisms

- There are no required mechanisms.

- Goals must result from intentional control and redirection of the ball.
- The robot can rotate and back up.
- The ball cannot be picked up and moved (held while moving).
- Battle bots are not advisable; soccer rules apply.

Safety Requirements

- This does not need to be child-safe.
- Have warnings and procedures in place for potentially dangerous components.
- Generally, use common sense around power and moving components.

Customization

- The robots can be customized between games.
- The robot can be fixed during a game if it stops functioning.

Modified Competition Rules (Not Confirmed)

- Four identical tennis balls as game balls.
- Games will be 1v1.
- Upon one team reaching 7 points, the first team to gain a 2 point advantage wins.
- After 5 minutes, the game ends. Whoever is leading wins.
- Robots start in their penalty boxes. Upon leaving at the game's start, they cannot re-enter.

2.4.2 Interpreted User Needs

The table below provides an interpreted and simplified version of needs specified by the customer and the some rules set by the competition. The importance of each stated need in the design is also shown on the table. The importance is shown on a scale from 1 to 5, where a 5 is the most important.

Table 1: Interpreted Customer Needs

Need Number	Need	Importance
1	Ability to shoot the ball at the goal effectively	5
2	Ability to defend against shots in some manner	3
3	Speed of the robot in a straight line	3
4	Agility of the robot for turning and changing direction	4
5	Ability to take hits from other robots during the competition	4
6	Ability to operate in a cold environment	4
7	Battery life	5
8	Safety of user/observers	4
9	User input difficulty	3
10	Ability to collect the ball to take a shot	3
11	The soccer robot looks aesthetically pleasing.	3
12	The soccer robot can be assembled quickly	4
13	The soccer robot has a console controller like joystick.	2

2.5 Design Metrics

Design metrics were created to quantify any design specifications or constraints determined by the user needs and the competition rules.

Table 2: Target Specifications

Metric Number	Associated Needs	Metric	Units	Acceptable	Ideal
1	2,3,4,7,8	Total weight	kg	<8	<6
2	2,11,12	Total packed volume	cm^3	< 45	< 40
3	7	Battery life	min	> 10	> 15
4	1,2,3	Max speed	m/s	$> .75$	> 1.5
5	5,7,	Lifetime of robot	Matches	> 7	> 11
6	1,4,10	Distance the robot can shoot	m	< 3	< 4
7	5,12	Assembly and customization speed	s	< 60	< 45

2.6 Project Management

The Gantt chart in Figure 6 gives an overview of the project schedule.

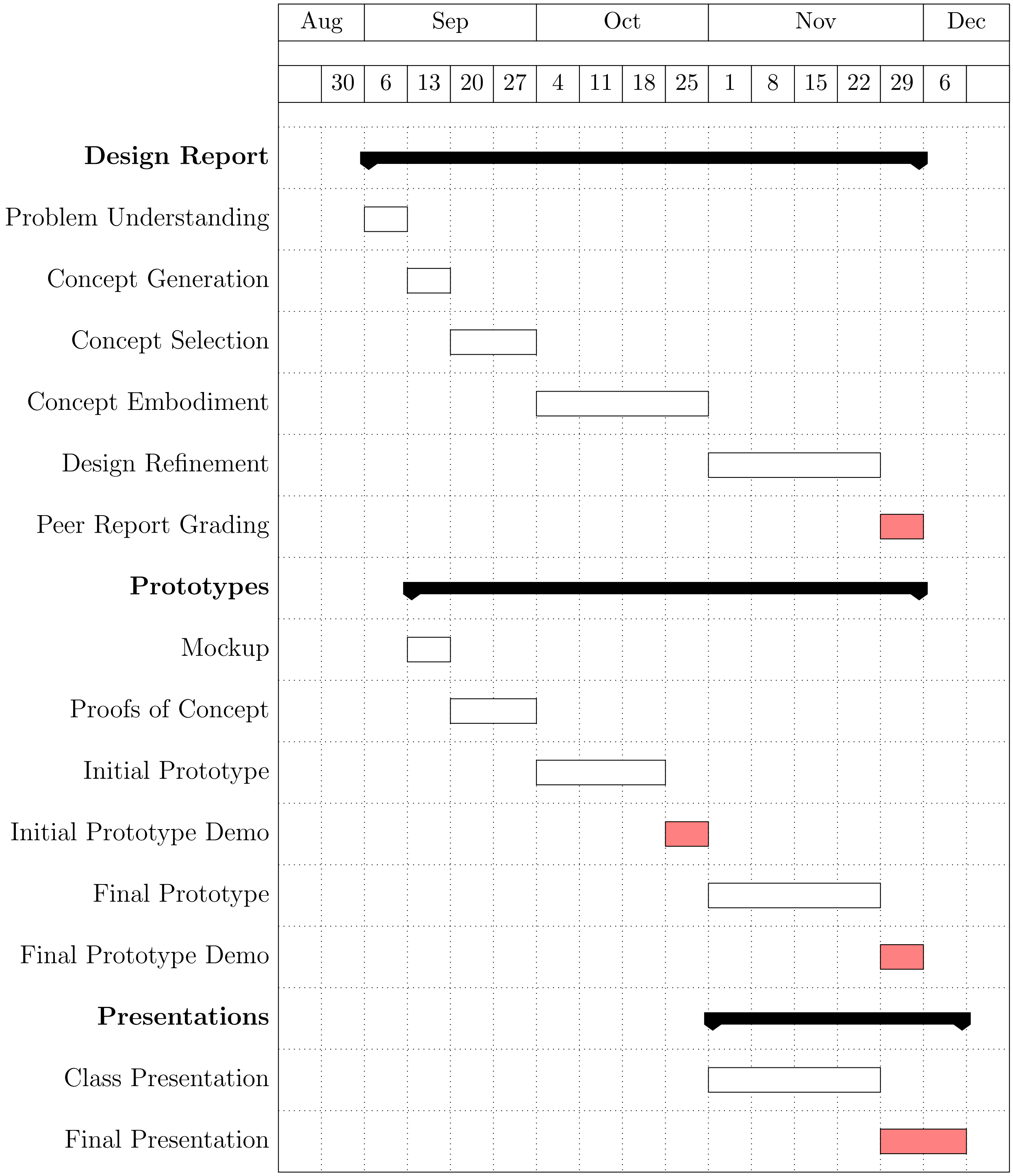
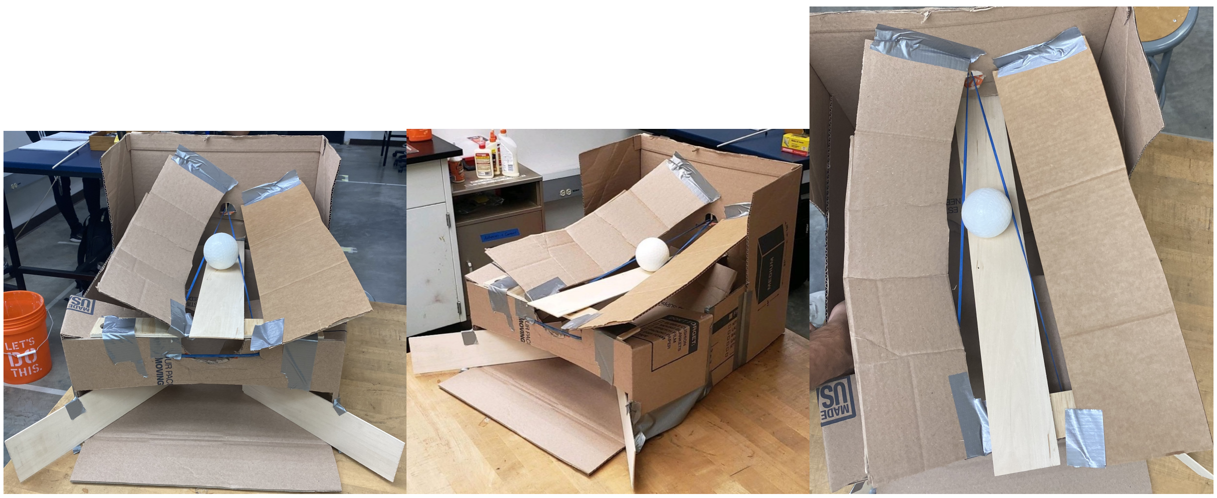


Figure 6: Gantt chart for design project

3 Concept Generation

3.1 Mockup Prototype

The images below belong to the mockup prototype built by the team. The prototype has two ways to collect and shoot the ball. The aerial collector collects balls that fall on the robot and shoot them at a certain height. The ground either receives the ball through an opponent's shot into the robot or by the robot driving towards the ball. The shot mechanism for the mockup is not a viable open but gave an idea for the power we that the ball could be shot with. A rubberband was used to a launch a tennis size ball, but the system would have to be reset after each use causing this method to lack viability. The mockup helped us visualize the different ways the ball could be collected. It also helped us have a general idea of where we would want to shoot the ball from. The mockup helped get a feel for the general size of the robot and how much room there would be for specific design ideas.



(a) Front View. (b) Isometric View. (c) Top View.

Figure 7: Mockup Prototype pictures.

3.2 Functional Decomposition

Figure 8 shows the function tree of the soccer robot. Different functions the robot is expected to perform are listed.

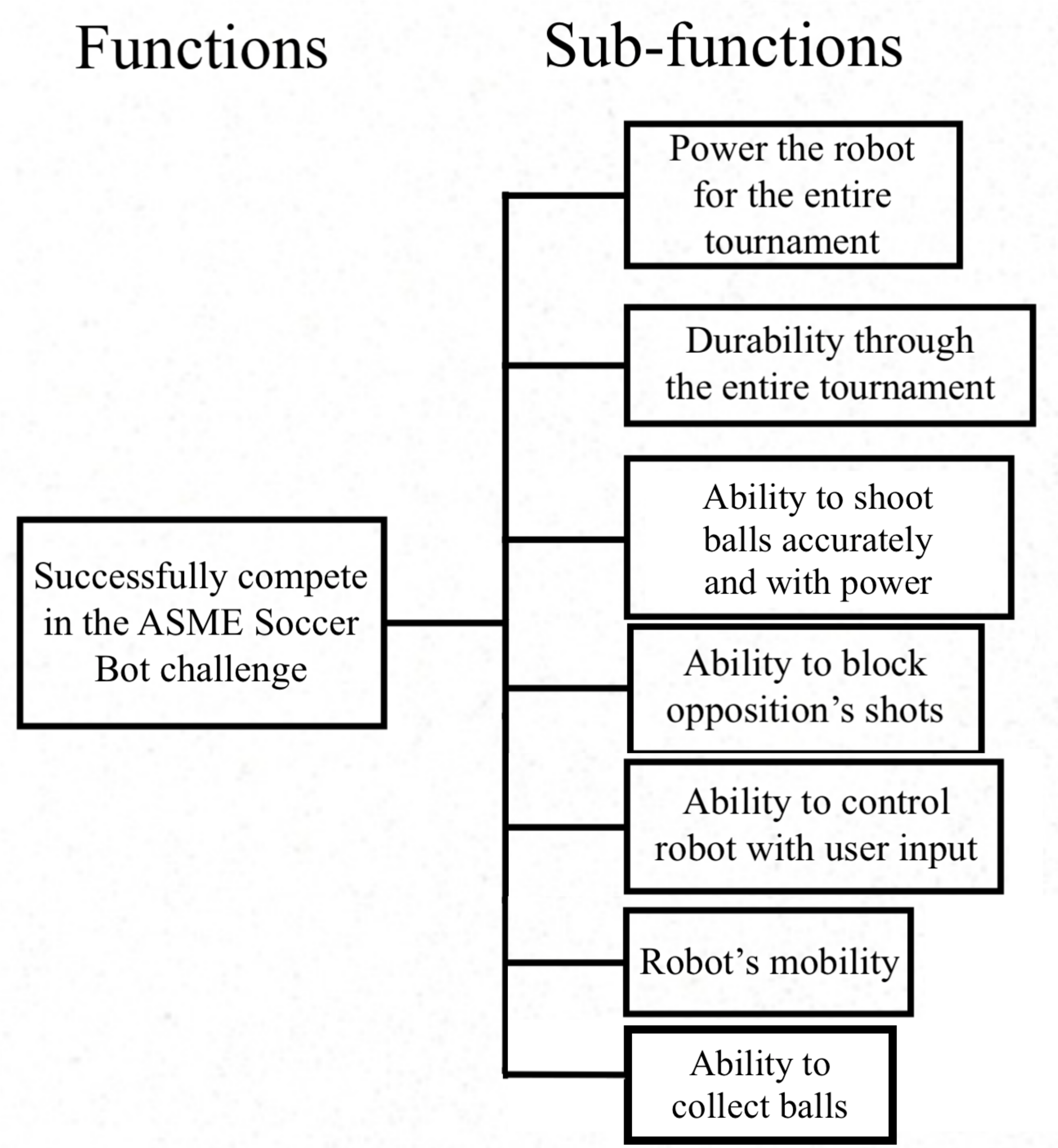


Figure 8: Function tree for ASME Soccer Robot

3.3 Morphological Chart

The morphological chart in Figure 9 exhibits different design options generated by the team for each of the functions listed in Figure 8.

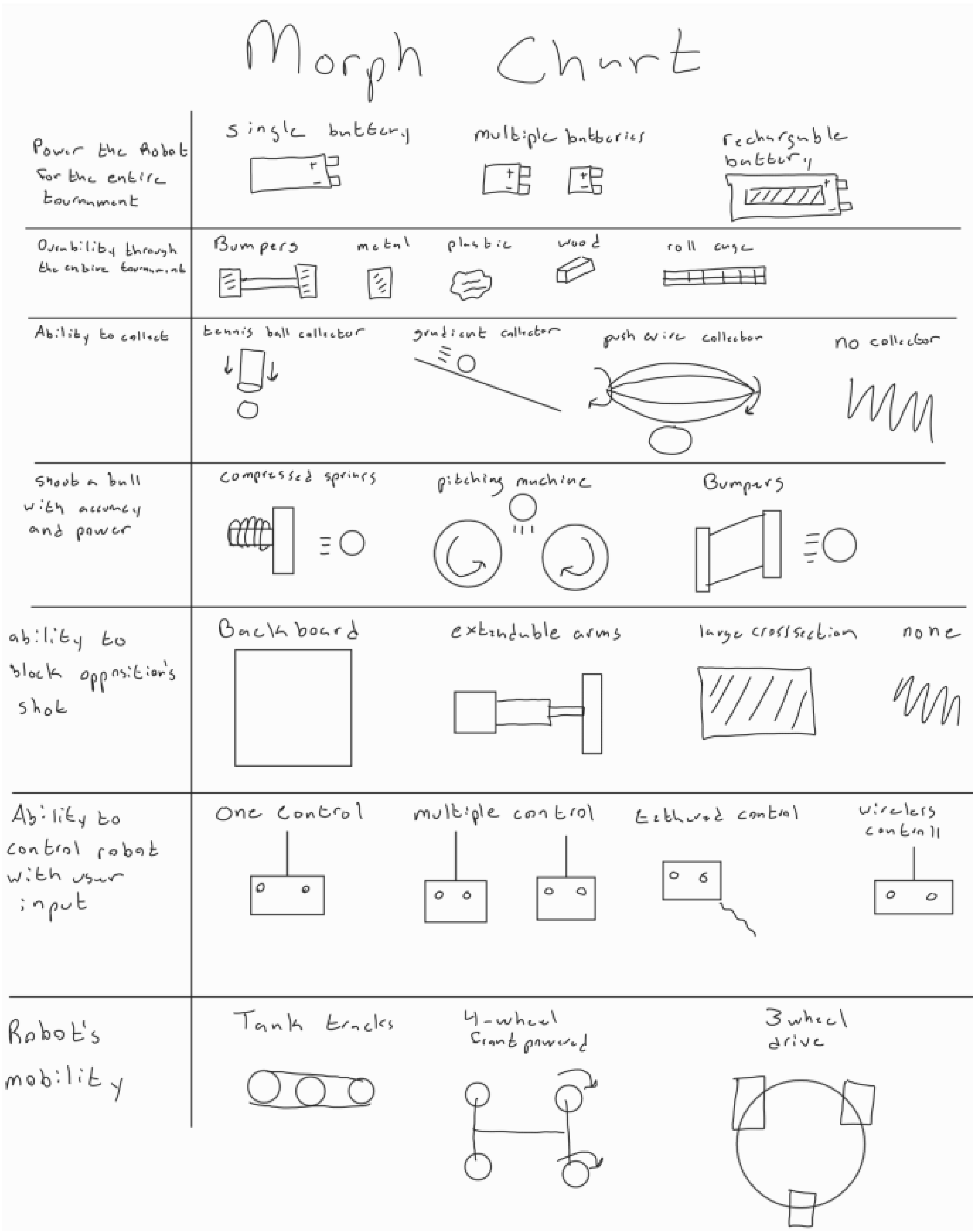


Figure 9: Morphological Chart for a Soccer Robot.

3.4 Alternative Design Concepts

3.4.1 The Tank ()

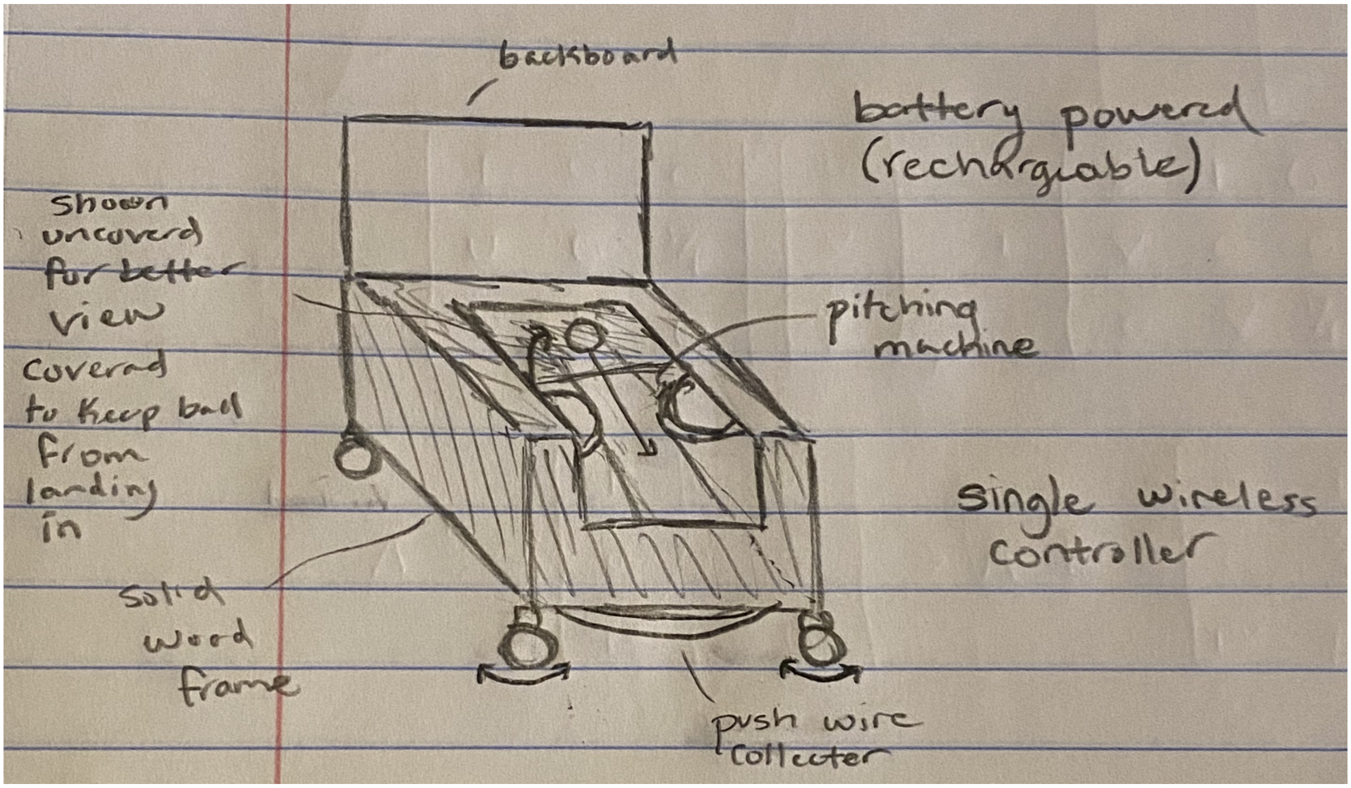


Figure 10: Sketches of The Tank.

Solutions from morph chart:

1. Rechargeable battery.
2. Strong wood frame.
3. Pitching machine.
4. Underneath push wire collection system.
5. Large wall on back.
6. Bluetooth controller.
7. 4 wheels, front wheel drive.

Description: A front wheel drive robot equipped with a pitching machine to shoot the ball. The robot is able to collect the balls by driving over them and using a pushed wire set up to allow the ball to be collected and inputted into the pitching machine to be fired. The outside of the robot is thick wood to be able to take a hit without being damaged. The robot is powered by rechargeable batteries and utilizes a Bluetooth controller for user input. The back part of the robot is taller than the rest to minimize the area that the opponent has to shoot.

3.4.2 Pinball Soccar Robot ()

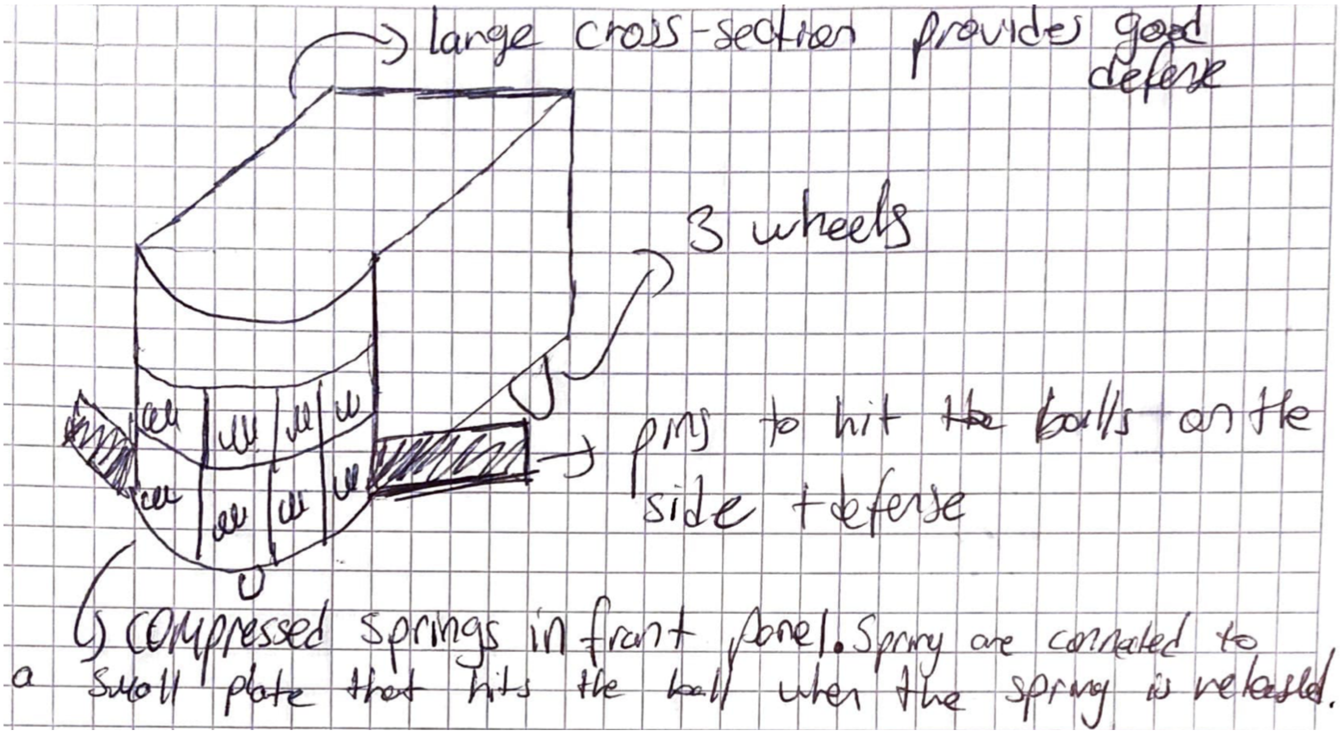


Figure 11: Sketches of Pinball Soccar Robot concept

<u>Solutions from morph chart</u>:

1. Rechargeable battery
2. Metal and wood
3. No collector
4. Compressed springs
5. Bumpers
6. Large cross-section
7. Expandable arms
8. Wireless control
9. 3-wheel drive

<u>Description</u>: The Pinball soccar robot is a large closed box with a half-cylinder attached to it on the side. The box sits on three wheels to allow the box to rotate better. Small rectangular boards are attached to the cylindrical part of the box with compressed springs. The springs are released upon user input when the ball is near the board. The springs are automatically compressed after release. There are two pins located on the front corners of the box. The pins are pushed forward upon user input in order to attack or defend. The robots large size allow it to defend better by simply covering the path between the opponent and the goal.

3.4.3 The Robo-Messi ()

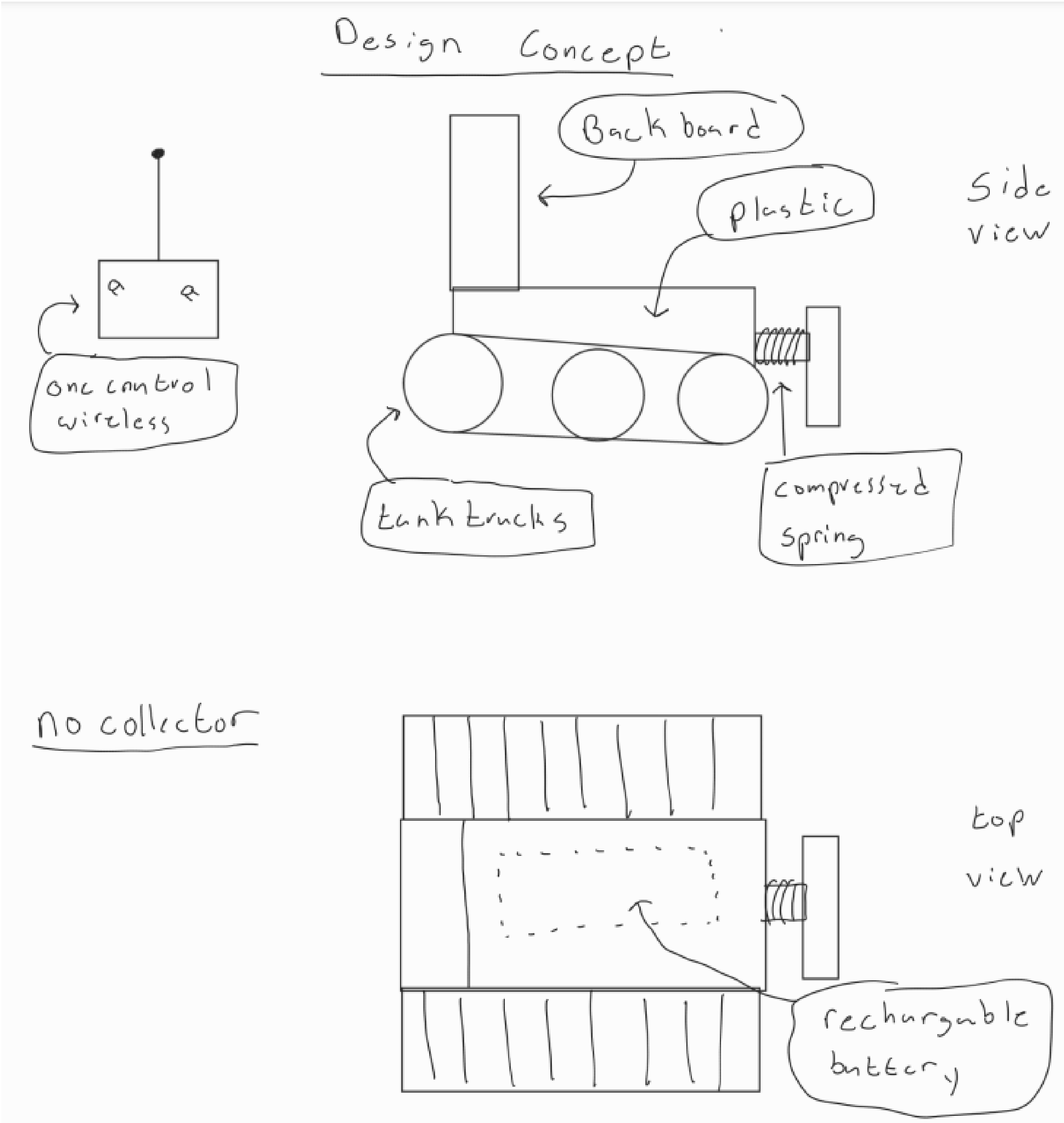


Figure 12: Design Concept of The Robo-Messi

Solutions from morph chart:

1. Rechargeable Battery
2. Plastic

3. Compressed Spring
4. No Collection System
5. Backboard
6. One RC Wireless Controller
7. Tank Drive

Description: The Robo-Messi is controlled by one wireless RC controller. It is mainly composed of plastics making it durable, light and have easy to replace components. Robo-Messi's tank tracks allow for high mobility with a zero turn option as well as increased grip with the floor. The robot is powered by a large rechargeable lithium ion battery. There is a backboard on the rear of the robot meant to block shots made by the opponent. Robo-Messi is able to shoot through the release of a compressed spring that is attached to a large plate. After each shot the spring is automatically drawn back to the firing position.

3.4.4 EZ-Assembly Mod-Bot ()

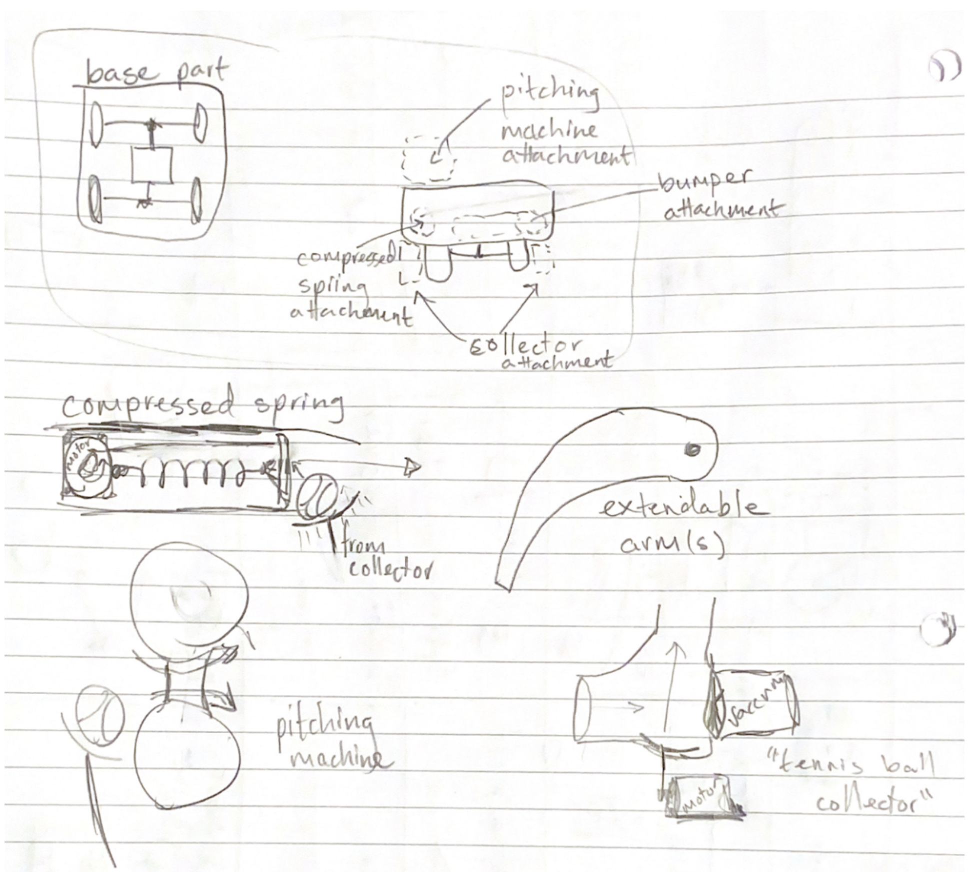


Figure 13: Sketches of Modular Bot Modules

Solutions from morph chart:

1. Single battery

2. Bumpers
3. Tennis-ball collector/gradient collector
4. Compressed spring/pitching machine
5. Extendable arms
6. Wireless control
7. 4-wheel drive, front powered

Description: The EZ-Assembly Modular Bot is designed around the concept of different strategies to beat different opponents. The pitching machine shooter allows for goal scoring against more defensive bots, while the 'compressed spring' is more efficient against offensive bots. The extendable arms operate as a gradient collector to allow for defensive range while the base tennis-ball collector is geared at a more mobile, offensive style. All modules can be quickly replaced between rounds.

4 Concept Selection

4.1 Selection Criteria

The selection criteria we chose are durability, agility/mobility, attacking, defending, and user difficulty. The highest weight went to attacking, with agility/mobility following closely behind. Defending and durability are the next highest weighted while user difficulty was the lowest.

	Durability	Agility/ Mobility	Attacking	Defending	Ease of Use	Row Total	Weight Value	Weight (%)
Durability	**1.00**	0.20	0.20	0.33	3.00	4.73	0.11	10.50
Agility/ Mobility	5.00	**1.00**	0.33	1.00	7.00	14.33	0.32	31.80
Attacking	5.00	3.00	**1.00**	1.00	5.00	15.00	0.33	33.28
Defending	3.00	1.00	1.00	**1.00**	3.00	9.00	0.20	19.97
Ease of Use	0.33	0.14	0.20	0.33	**1.00**	2.01	0.04	4.46

Figure 14: Analytic Hierarchy Process (AHP) to determine scoring matrix weights

4.2 Concept Evaluation

The four design concepts are shown in a Weighted Scoring Matrix below to determine which is the best design to begin construction on.

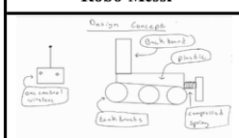
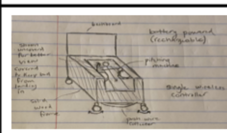
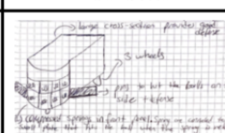
Alternative Design Concepts		**Robo-Messi**		**The Tank**		**Pinball Soccar**		**Mod-bot**	
									
Selection Criterion	**Weight (%)**	**Rating**	**Weighted**	**Rating**	**Weighted**	**Rating**	**Weighted**	**Rating**	**Weighted**
Durability	10.50	5	0.53	5	0.53	4	0.42	1	0.11
Agility/ Mobility	31.80	4	1.27	4	1.27	3	0.95	3	0.95
Attacking	33.28	4	1.33	3	1.00	3	1.00	3	1.00
Defending	19.97	3	0.60	3	0.60	4	0.80	3	0.60
Ease of Use	4.46	5	0.22	4	0.18	3	0.13	2	0.09
	Total score	**3.950**		**3.573**		**3.305**		**2.745**	
	Rank	**1**		**2**		**3**		**4**	

Figure 15: Weighted Scoring Matrix (WSM) for choosing between alternative concepts

4.3 Evaluation Results

Figure 15 shows that the design "Robo-Messi" was selected to be the best degign concept given the selection criteria. Robo-Messi has the highest ranking for each criteria except defending. It exhibits a well rounded design that succeeds in all criteria, while the other design concepts are only effective for some of the criteria. The "Robo-Messi" concept is durable, mobile, easy to use and possibly high scoring. Defensive modifications can be made to the design to increase the concept's defending rating. The team already decided to make small changes to the "Robo-Messi" concept after working on a proof of concept. The wheels will be different as the team will be using the frame of an RC car, meaning that the design options for the wheels will be limited to that frame. Secondly, the team decided to add a ball collector to the concept so that the compressed spring design can be turned into a pinball spring-like design. The ball collector will place the ball at a certain location within the robot and the ball will be shot from there using springs.

4.4 Engineering Models/Relationships

4.4.1 Model 1: Spring Compression

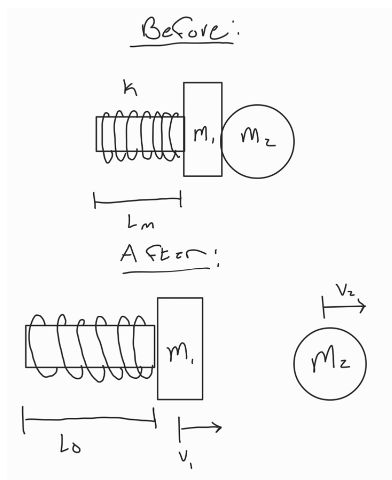


Figure 16: Pinball shooter

A plate with a spring attached to it can be used to shoot the ball. The ball will be collected and placed in front of a compressed spring. The compressed spring can be released upon user input. The final desired velocity, mass and size of the ball are given for this system. The spring constant or required displacement due to compression can each be calculated if the other quantity is known. Equations of impulse and springs can be used to solve this model:

$$I = m \cdot \Delta v = \int_{t1}^{t2} F(t) \cdot dt = \int_{t1}^{t2} k \cdot x(t) \cdot dt \tag{1}$$

4.4.2 Model 2: Pinball Post Radius

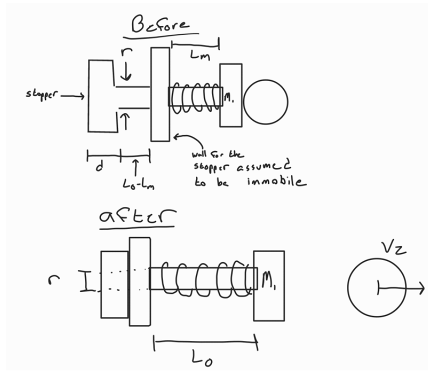


Figure 17: Pinball Post

The radius of the pinball post needs to be determined so that the force resulting force from hitting the tennis ball will not shear off the stopper. First we will let the factor of safety (FS) equal 8, which is standard for bolts, and then solve for $\sigma_{working}$ as seen in Eq.2 .

$$\sigma_{working} \geq \frac{\sigma_{ultimate}}{FS} \tag{2}$$

Since we know the relationship between $\sigma_{working}$ and r, as seen in Eq.3, and the ultimate strength of our material, we can solve for the minimum diameter of r.

$$\sigma_{working} = \frac{F_{working}}{A} = \frac{F_{working}}{\pi r^2} \tag{3}$$

5 Concept Embodiment

5.1 Initial Embodiment

Our three prototype goals are: (1) the vehicle can drive around the outside edge of the playing field with a captured ball in less than 17 seconds; (2) the vehicle can make more than 5 of 10 shots from the field midline, starting from the sideline with a ball placed on the center spot; (3) the vehicle can successfully capture a ball within 2 seconds of approaching it more than 8 of 10 times. Our initial prototype cannot completely meet our goals yet because the shooting and collecting mechanisms are not automated at this stage. However, our initial prototype has safely driven 5 meters in 17 seconds. We have consistently shot balls 1m under manual power and estimate that our shooter will be 2-3x more powerful when automated. Finally, our collector has consistently captured balls while being manually moved.

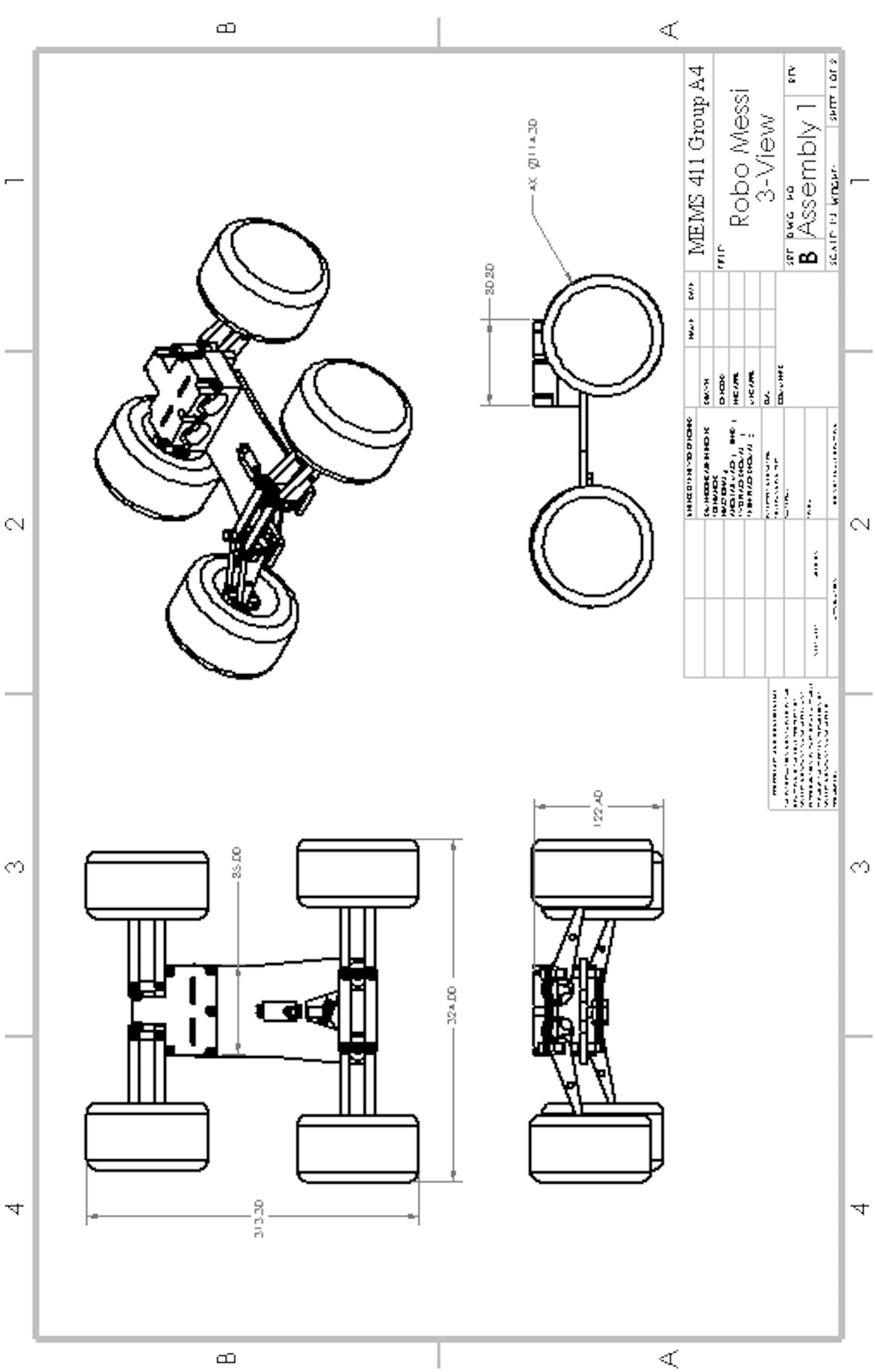


Figure 18: Assembled projected views with overall dimensions

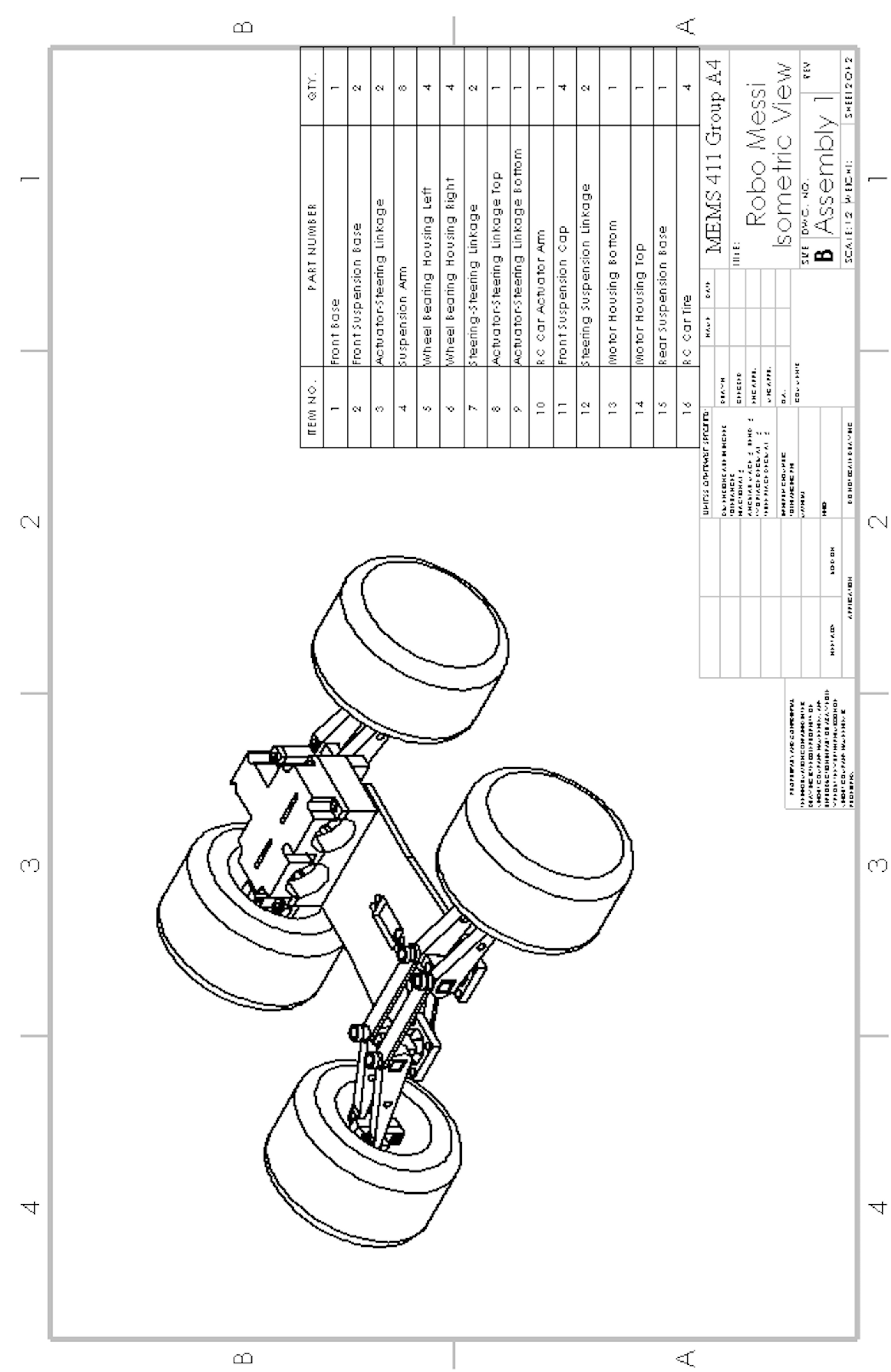


Figure 19: Assembled isometric view with bill of materials (BOM)

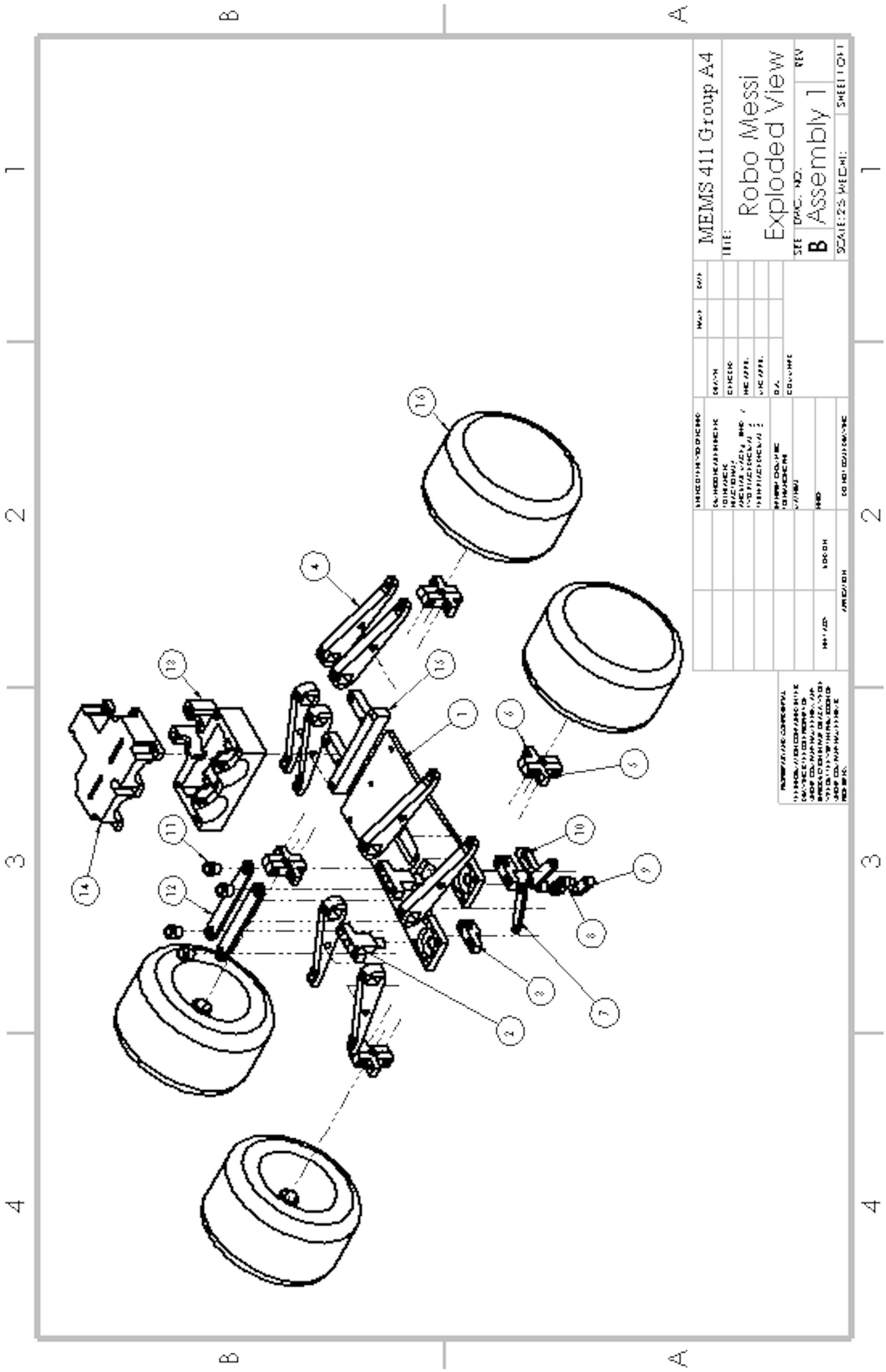


Figure 20: Exploded view with callout to BOM

5.2 Proofs-of-Concept

We developed multiple prototypes for our shooting and collecting mechanisms to determine our best option for each. Our shooting mechanism testing only consisted of testing various configurations of our general design. For the spring-powered shooting mechanism, we tested extension springs and two configurations of compression springs (shooting direction compression and non-shooting direction compression). The non-shooting direction compression spring tested the best because its design was the most simple and did not fail. We also determined that motor placement would be difficult for the other two designs. Our collection mechanism testing was our most varied; we tested a velcro collector, a scooping collector, and a "golf ball picker-upper" collector. The velcro collector failed to collect a ball in testing and was quickly eliminated. The scooping collector was then eliminated due to the relatively simplicity and ease of assembly of the "golf ball picker-upper" collector.

5.3 Design Changes

Our original concept was the Robo-Messi soccer robot. In our initial prototype, we have replicated certain parts of the Robo-Messi, while drastically changing others. We kept our original strategic ideas behind the Robo-Messi that make it a fast, flexible robot that can both attack and defend. In following these ideas, our prototype uses a back board and is run with a remote controller and rechargeable battery. The Robo-Messi's shooter design worked well upon testing, but we moved it off of the ground to increase our scoring flexibility and avoid violating the robot size requirements. With the shooter now off the ground, we needed to add a collector to feed the shooter balls. After testing multiple ideas, we added a "golf-ball picker-upper" collector to our prototype because it offered the best combination of easy collection and simple implementation.

6 Design Refinement

6.1 Model-Based Design Decisions

6.1.1 Model 1: Spring Compression

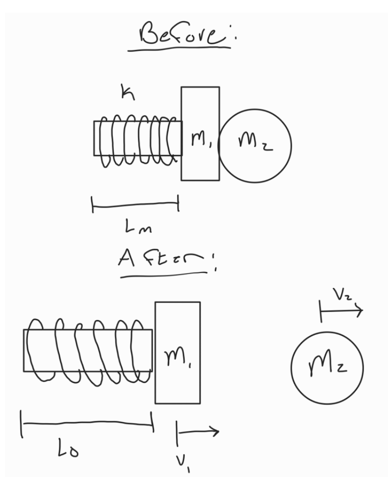


Figure 21: Pinball shooter

A plate with a spring attached to it can be used to shoot the ball. The ball will be collected and placed in front of a compressed spring. The compressed spring can be released upon user input. The final desired velocity, mass and size of the ball are given for this system. The spring constant or required displacement due to compression can each be calculated if the other quantity is known. Equations of impulse and springs can be used to solve this model:

$$I = m \cdot \Delta v = \int_{t1}^{t2} F(t) \cdot dt = \int_{t1}^{t2} k \cdot x(t) \cdot dt \tag{4}$$

6.1.2 Model 2: Gearing for Shooting Mechanism

The shooting mechanism requires gearing from the servo to the strings generating power. The general formula for calculating how two connected gears change RPM is:

$$RPM_o = \frac{T_i}{T_o} RPM_i$$

where T_i is the number of teeth on the driving gear and T_o is the number of teeth on the driven gear. We need an RPM decrease of approximately 90% for the servo to be able to compress the shooting mechanism's springs. We have easy access to 14 and 42-tooth gears, so will use these for our mechanism. Thus,

$$r_{RPM} = 0.1 \approx (\frac{14}{42})^n = (\frac{1}{3})^n$$

We need to solve for n to determine how many sets of gears we need. For $n = 2$, we reduce RPM to $0.\overline{11}$. This is within an acceptable range, so we ended up using two sets of 14 tooth driving gears and 42 tooth driven gears, with the second 14 tooth gear on the same axle as the first 42 tooth gear.

6.1.3 Model 3: Deciding the type of string to pull back the shooting mechanism.

The object that is pulling back the plate that launches the ball from the shooter is a string. We need to find the maximum amount of load that will be loaded on the string in order to find the correct type to use. In our shooter we have two springs in parallel with spring constants of 2.17lb/in. The shooter will compress both of the springs 3 inches before being released. We can find K_{eq} to determine the final tension of the string. We know that with Eq. 5 we can find our spring constant to be 4.34 lb/in.

$$K_{eq} = K_1 + K_2 = 2.17 + 2.17 = 4.34lb/in \tag{5}$$

Then since we are are compressing the springs by 3 inches we know that the applied force on the string will be 13.02lb. We will have a factor of safety of 3 to insure that our string will not break. Therefore, we need to find a string that can withstand 39.06 lb of tension.

6.2 Design for Safety

The safety needs of this robot are confined to that of competition. The soccer robot could be used outside of the event as an RC car, but our design is meant to be used for the competition only so our risks will be targeted to competition use only.

6.2.1 Risk #1: Shooting Mechanism Failure

Description: Two springs are used in the shooting mechanism. The compression of the springs exerts a force on the mechanism holding them and could cause the springs to fly off if they mechanism fails.

Severity: Marginal

Probability: Seldom

Mitigating Steps: Securely connect the metal rods that hold the springs to the 3D printed material to avoid parts detaching under compression.

6.2.2 Risk #2: Battery Failure

Description: The robot uses a rechargeable lithium battery. There is a risk of the battery catching on fire if charging is not safely done.

Severity: Critical

Probability: Unlikely

Mitigating Steps: The battery should not be left unattended during charging and correct procedures of charging should be followed. The correct terminals of the battery should be connected to the charger. A fire extinguisher should be nearby during trials and competition.

6.2.3 Risk #3: Launched Ball Hitting Onlookers

Description: Our soccer robot uses inclined rails to shoot the ball off the ground. The ball might hit members of the audience or objects around the field.

Severity: Negligible

Probability: Occasional

Mitigating Steps: Limit the motor strength that is being used to power the shooting mechanism to prevent the ball from launching at a high velocity. The incline of the shooter should also be kept low enough to prevent the ball from exiting the field while still achieving its design purpose of shooting over the other robots.

6.2.4 Risk #4: Collisions

Description: Our soccer robot might collide with walls and other robots during the competition. These collisions might cause structural damage in the robot and parts of the robot to detach.

Severity: Marginal

Probability: Likely

Mitigating Steps: All the 3D printed parts were printed with large infills and are connected together securely with threaded fasteners to ensure structural integrity is maintained through collisions.

6.2.5 Risk #5: Steering Failure

Description: The steering mechanism has a weak point that will break if the robot is dropped due to the lack of a suspension system to help absorb the the shock.

Severity: Critical

Probability: Seldom

Mitigating Steps: Since we are aware of this issue and we will be handling the robot we can make sure to take proper care to ensure that the robot is not dropped.

		Probability that something will go wrong				
	Category	**Frequent** Likely to occur immediately or in a short period of time; expected to occur frequently	**Likely** Quite likely to occur in time	**Occasional** May occur in time	**Seldom** Not likely to occur but possible	**Unlikely** Unlikely to occur
Severity of risk	**Catastrophic**					
	Critical				Risk 5	Risk 2
	Marginal		Risk 4		Risk 1	
	Negligible hazard presents a minimal threat to safety, health, and well-being of participants; trivial			Risk 3		

Figure 22: Heat map of identified risks.

6.2.6 Risk Prioritization

The highest priority risk is collisions with other robots. Due to the nature of the competition, some collisions are to be expected and collisions with other robots could cause damage to both robots. The robots were worked on for an entire semester and each group put in a lot of work to their designs, so collisions should be avoided to prevent damage to the robots. The risk of onlookers being hit by a ball is fairly low since the ball is launched at a fairly low speed. This risk should be prioritized next since it is easily avoidable through the user input of the robot and onlookers paying attention during the competition. The risk of dropping the robot and damaging the steering mechanism is the next priority, but as long as we are paying attention there should be no problem with this risk. The risk due to the lithium battery could pose a serious threat, but the risk is very unlikely to occur as long as proper care is taken while using and charging it. The risk introduced by the shooting mechanism is very minor due to proper care being taken when assembling it. We made sure that the mechanism was structurally sound and able to withstand the force exerted on it from each launch.

6.3 Design for Manufacturing

Our design is formed of 60 total parts. The design also uses 75 M3 screws and threaded inserts.

Theoretically Necessary Components:

- 4x Wheels
- RC Car Brain
- RC Car Controller
- Arduino
- 2x 360° Servos
- Ball Scooper
- Spring-loaded Shooter
- Powertrain
  - Axle
  - Motor-Wheel Gearing
  - 2x DC Motors
- Steering System
  - Servo
  - Servo-Wheel Connector

The motor-wheel gearing is theoretically necessary because of budget constraints and the motors we already have from the RC car purchased. Our motors need assistance from gearing to produce the correct balance of torque and RPM. The ball scooper is necessary because we do not have enough space at floor level to attach our shooter to the chassis, so we need a method of collecting balls and placing them in the raised shooter. Similarly, there is not enough space to control both the shooter and scooper movement with the same rotating device, so we need two 360° servos. (Even with more space, any theoretical contraption used to connect both the shooter and scooper to one servo would be extremely complex and therefore, poor design.) Finally he RC Car brain is necessary because the motors we use are unique four-wire motors; even if soldered to another mircocontroller, it would be impossible to properly program the motors to run.

Significant changes we could viably make to our design are making our chassis out of only a top and bottom part and directly attaching our steering servo to a hypothetical front axle. Simplifying the number of chassis parts would be easy; our design only has multiple parts because we built up our chassis as we added more parts (motors, steering servo, collector, shooter, etc.) to it. We would not have to make any accommodations for this change. Directly attaching the steering servo to an axle would be more difficult. We would have to modify our chassis to secure the servo in a different location and design an axle (non-rotating) to directly take rotation input from the servo. Finally, we could design a simple suspension system to connect the servo to the axle so that the servo is not damaged. This would allow us to eliminate all of the complexities of the front end of our design. Figure 23 highlights in red all of the parts that would be eliminated.

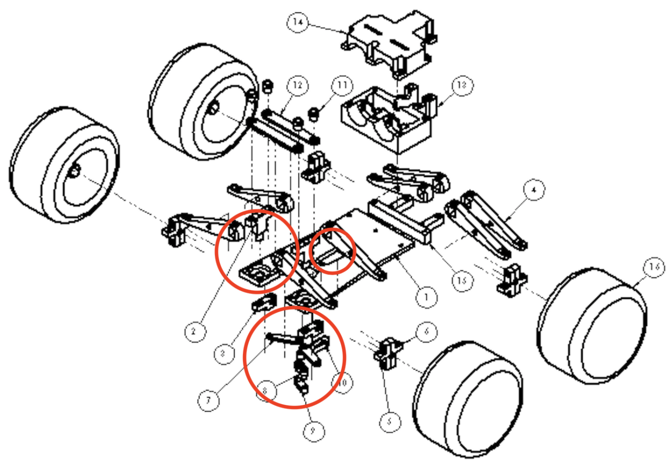


Figure 23: Obsolete Parts With Redesigned Steering

6.4 Design for Usability

Vision Impairment (such as red-green color blindness or presbyopia)

Our soccer robot will need to have status LEDs to make sure that all components of the soccer robot are operational before the games start. The color of the LEDs can create confusion since red-green color blindness can cause the user to falsely identify the functional state of the robot.

Hearing Impairment (such as presbycutia)

The soccer robot sometimes makes loud noises when it accelerates too quickly or when too much force is applied on the servo that controls steering. In the case of an issue, the user needs to be able to hear the sound so that the controls can be adjusted. A hearing impairment might prevent the user from hearing these sounds and noticing problems that may be occurring with the robot.

Physical Impairment (such as arthritis, muscle weakness, or limb immobilization)

The soccer robot will be controlled by a remote controller. Different components of the remote controller need to be designed so that people with physical impairments can use it. People with cumulative trauma disorders, arthritis, muscle weaknesses or limb immobilization might have difficulty turning the steering knob or using the gas/brake trigger. The different knobs, dials, joysticks etc. need to be large and sensitive enough for people with decreased strength.

Control Impairment (such as those caused by distraction, excessive fatigue, intoxication, or medication side effects)

The soccer robot will be used by students. This means that the device may be used by a user that is distracted or tired since the games will be held towards end of the semester. This means that the controls of the robot needs to be easy and simple and robot's design needs to account for this so that a distracted user cannot cause any hazards by using the robot.

7 Final Prototype

7.1 Overview

Figure 24 shows the completed final prototype of our design with the shooting and collecting mechanisms attached, as well as their Arduino-IR sensor controller. Figures 26 and 25, respectively, show the completed shooting and collecting mechanisms, while Fig. 27 shows the IR sensor that controls the two mechanisms.

Figure 24: Completed version of the soccer robot

Figure 25: Collection system of the soccer robot.

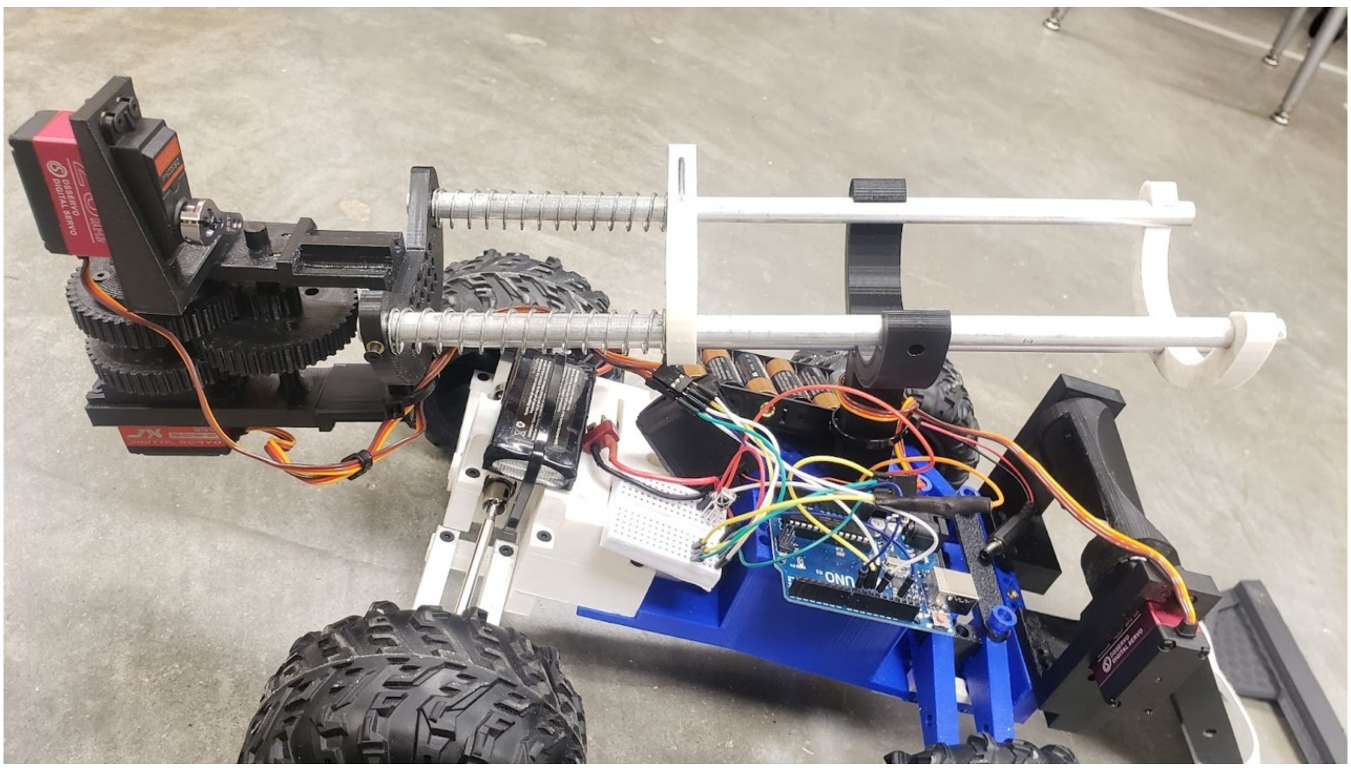


Figure 26: Shooting system of the soccer robot.

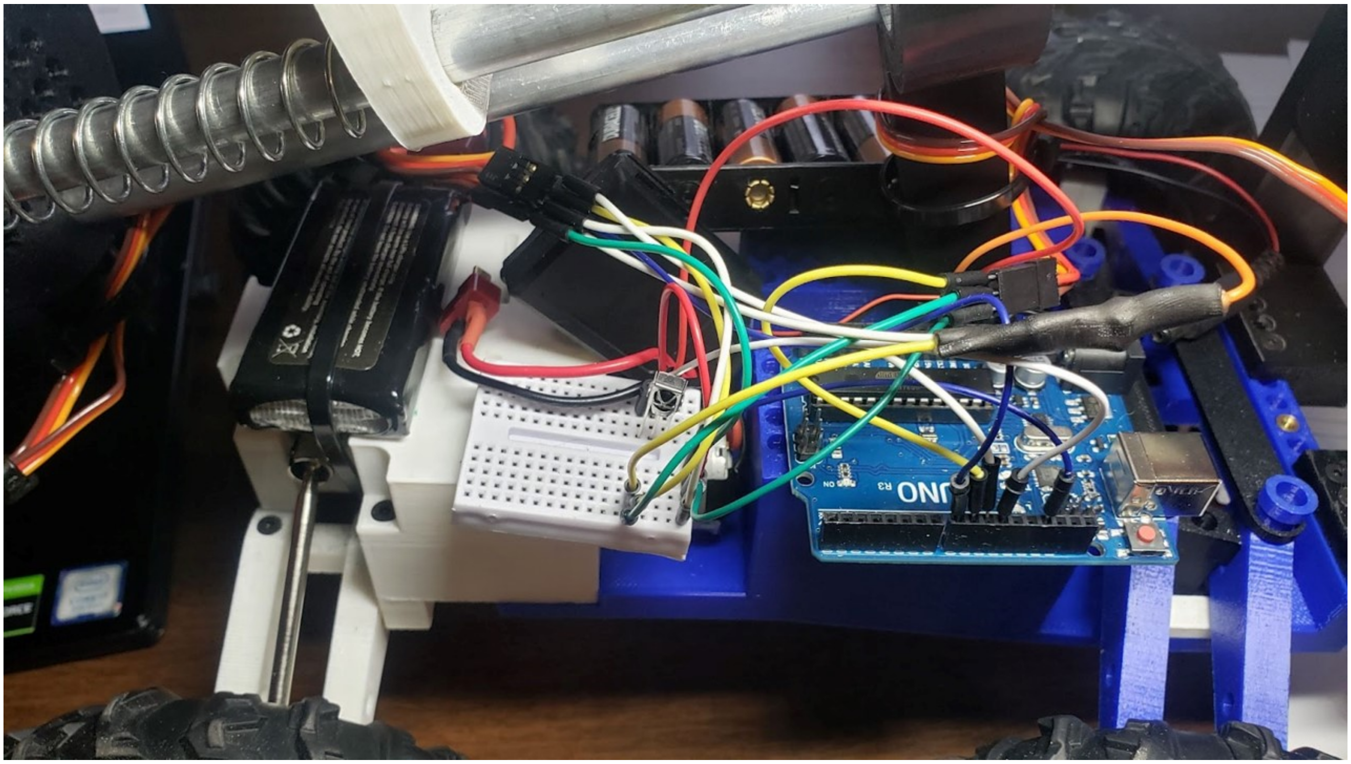


Figure 27: The soccer robot is controlled by an Arduino Uno that receives inputs from an IR sensor.

7.2 Prototype Objective Success

Unfortunately though, the steering actuator, its backup, and a wire controlling the collector, all broke, leaving the prototype unable to compete. That being said, the final prototype successfully completed all three prototype objectives when tested prior to the competition. It easily managed to travel the entire length of the field within the allotted 17 seconds, even without reaching its top speed. It also successfully picked up more than 90% of balls within two seconds. Finally, it successfully shot every ball into the goal from a distance of $2.5m$.

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```
#include <Servo.h>
#include <IRremote.h>
Servo myservo;// define servo variable name
int RECV_PIN = 11;
long on1  = 0x00FF6897;
long off1 = 0x00FF9867;
long on2 = 0x00FFB04F;
long off2 = 0x00FF30CF;
long on3 = 0x00FF18E7;
long off3 = 0x00FF7A85;
IRrecv irrecv(RECV_PIN);
decode_results results;
void dump(decode_results *results) {
  int count = results->rawlen;
  if (results->decode_type == UNKNOWN)
    {
     Serial.println("Could not decode message");
    }
  else
   {
    if (results->decode_type == NEC)
      {
       Serial.print("Decoded NEC: ");
      }
    else if (results->decode_type == SONY)
      {
       Serial.print("Decoded SONY: ");
      }
    else if (results->decode_type == RC5)
      {
       Serial.print("Decoded RC5: ");
      }
    else if (results->decode_type == RC6)
      {
       Serial.print("Decoded RC6: ");
      }
     Serial.print(results->value, HEX);
     Serial.print(" (");
     Serial.print(results->bits, DEC);
     Serial.println(" bits)");
   }
     Serial.print("Raw (");
     Serial.print(count, DEC);
     Serial.print("): ");
 for (int i = 0; i < count; i++)
     {
      if ((i % 2) == 1) {
      Serial.print(results->rawbuf[i]*USECPERTICK, DEC);
     }
    else
     {
      Serial.print(-(int)results->rawbuf[i]*USECPERTICK, DEC);
     }
    Serial.print(" ");
     }
      Serial.println("");
     }
```

A Software Code - Arduino

```
      Serial.print(results->rawbuf[i]*USECPERTICK, DEC);
     }
    else
     {
      Serial.print(-(int)results->rawbuf[i]*USECPERTICK, DEC);
     }
    Serial.print(" ");
     }
      Serial.println("");
     }
Servo servo_1;
Servo servo_2;
Servo servo_3;
void setup()
{
  pinMode(RECV_PIN, INPUT);
  Serial.begin(9600);
   irrecv.enableIRIn();
   servo_1.attach(9);
   servo_2.attach(10);
   servo_3.attach(8);
}
int on = 0;
unsigned long last = millis();
void loop()
{
  if (irrecv.decode(&results))
   {
    // If it's been at least 1/4 second since the last
    // IR received, toggle the relay
    if (millis() - last > 250)
      {
       on = !on;
//       digitalWrite(8, on ? HIGH : LOW);
       digitalWrite(13, on ? HIGH : LOW);
       dump(&results);
      }
    if (results.value == on1 )
       servo_1.write(0);

    if (results.value == off1 )
       servo_1.write(150);

    if (results.value == on2 )
      servo_2.write(90);
    if (results.value == off2 )
       servo_2.write(50);
    if (results.value == on3 )
      servo_2.write(150);
    if (results.value == off3 )
       servo_3.write(180);
      delay(2000);
      servo_3.write(60);
    last = millis();
irrecv.resume(); // Receive the next value
  }
}
```