MEMS 411: Soccer Robot

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The Ultimate Weapon

Our senior design project is based on the 2018 ASME Student Design Competition, which was to build a robot for soccer to compete in a FIFA World Cup style elimination Tournament. The regulations stated that the robot must fit inside a 0.5 x 0.5 x 0.5-meter cube box, must be powered by batteries, and be controlled with a wireless transmitter or through an electrical "umbilical" cord. There were 5 design teams, and each team played each other. The point distribution was 3 points for winning, 1 point for tying, and 0 for losing. The team with the greatest number of points wins.

The final prototype consists of four omni wheels, a flywheel, a ball feeder, battery pack, wood, and cardboard. We purchased an RC car and reused the motherboard, the motors for the wheels, the controller, and the frames for the wheels. The motherboard was rewired to allow functionality of using a flywheel as the shooting mechanism and the servo motor as a ball feeder whenever the ball was collected from the right side of its body. We wanted our robot to collect tennis from the front and the side of it. The flywheel is based on how baseball pitching machines work, which supply enormous amounts of rotational kinetic energy to the baseball. This method of shooting ensured that enough kinetic energy was supplied to the tennis ball, and to be able to shoot from at least the mid-line of the playing field.

We wanted our robot to be focused on speed, hence why only a portion of it is made of wood, and the rest of it is made of stiff cardboard. The functionality of the omni wheels and the controller allowed us to have excellent maneuverability throughout each game. Ultimately, the car was a complete success, winning the competition and satisfying all of the performance goals and most of the customer needs.

Group A3
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# Contents

List of Figures .......................................................... 1

List of Tables ............................................................. 2

1 Introduction ............................................................ 3

2 Problem Understanding .................................................. 3
   2.1 Existing Devices .................................................... 3
   2.2 Patents .................................................................. 5
   2.3 Codes & Standards ................................................... 8
   2.4 User Needs ............................................................ 8
   2.5 Design Metrics ........................................................ 10
   2.6 Project Management ................................................. 10

3 Concept Generation ....................................................... 12
   3.1 Mockup Prototype ..................................................... 12
   3.2 Functional Decomposition ......................................... 14
   3.3 Morphological Chart ................................................ 16
   3.4 Alternative Design Concepts ....................................... 17

4 Concept Selection ........................................................ 21
   4.1 Selection Criteria ..................................................... 21
   4.2 Concept Evaluation .................................................. 21
   4.3 Evaluation Results .................................................... 22
   4.4 Engineering Models/Relationships ................................ 22

5 Concept Embodiment ...................................................... 23
   5.1 Initial Embodiment .................................................... 23
   5.2 Proofs-of-Concept ..................................................... 30
   5.3 Design Changes ........................................................ 30

6 Design Refinement ........................................................ 30
   6.1 Model-Based Design Decisions .................................... 30
   6.2 Design for Safety ...................................................... 34
   6.3 Design for Manufacturing .......................................... 36
   6.4 Design for Usability ................................................... 39

7 Final Prototype ............................................................ 40
   7.1 Final Prototype Performance Goals ................................ 40
   7.2 Views of The Final Prototype ..................................... 40

## List of Figures

1 Robo-soccer robots ....................................................... 3
List of Tables

<table>
<thead>
<tr>
<th></th>
<th>Interpreted Customer Needs</th>
<th></th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Target Specifications</td>
<td></td>
<td>10</td>
</tr>
</tbody>
</table>
1 Introduction

The 2018 ASME student design competition was to build a robot that would play in a soccer tournament that is FIFA World Cup style. The original game consists of 4 robots playing at once, but our project is to build a soccer robot that will play in 2 players with 4 balls. Our selected project will follow constraints and guidelines provided by ASME with few changes. The customer of this project is assigned, but the game itself will be played by project team members. By using our own ideas and engineering knowledge, the robot will be built so it could be mechanically controlled with a rechargeable remote controller to skillfully handle the balls and survive collisions with an opposing robot. The robot should have a battery that will ideally last the whole tournament by the customer’s need and should be made to be free of being hazard in any situation. The aesthetic feature that customers desire is not particular, but the request was that it should be made to look neat and securely store electrical cords inside the robot.

2 Problem Understanding

2.1 Existing Devices

The following are devices that are similar to the soccer robot that we are designing. The following devices can be used as inspirational starting points in developing our own design and concept for the soccer robot.

2.1.1 Existing Device #1: The ”Terminator”

![Figure 1: Robo-soccer robots](https://hyperleap.com/topic/Soccer_robot)
Description: These robots are not particularly made for the ASME competition, but this robot includes a kicker and a dribbler. It also has a controller board with Atmel controller which is easy to install and one of the fast controllers among eight-bit microcontrollers. This robot can also be programmed using the GNU GCC compiler form the PC. This robot is on official RoboCup Junior competition website and is an omni drive robot that can be used for this competition.

2.1.2 Existing Device #2: Humanoid Soccer Players

Link: https://spectrum.ieee.org/robot-soccer-players-learning-fancy-human-skills

Description: Humanoid robot soccer players before 2010s were mostly just kicking the ball towards the goal and not too much controlling the ball. They couldn’t take the collision with other players who were programmed to intentionally interfere with humanoid players. But this has been changed. We could see humanoid soccer player passing ball to each other’s and successfully aim the ball into the goal. These robots have built in AI in them so the price could be too high for our set budgets, but we could learn from their movement and try to illustrate that with our designed robot.
2.1.3 Existing Device #3: The 6-Legged Soccer Robot


**Description:** At the front of this robot, it has mechanism that could guide the ball, but it can’t kick it. Since it is not operated by wheels, and it is stable, if the weight support, it could be surviving the collisions from the other players which was one of the customer’s requests.

2.2 Patents

2.2.1 Soccer and Fighting Robot, and Driving and Operating Device of the Robot (US7463001B2)

This patent establishes the problem that conventional robots have in terms of mobility and reproducing the game of soccer. Traditional robots drive in the form of three or four-wheeled vehicles with rotational axes aligned in the same direction which results in the lack of ability to chase the soccer ball in a lateral motion and lacks the speed needed for the fast-paced game of soccer. The patent processes a new robot design that will allow it to have swift motion in any direction with a unique three-wheel drive design. The movement of the robot would be conducted with a joystick that allows to control the robot in six directions.
Figure 4: Patent top view of the three-wheel drive design

Figure 5: Patent conceptional view of soccer robot
2.2.2 Method and System for Remote Control of Mobile Robot
(US6535793)

This patent designs a method of controlling a robot by a remote user using an intuitive user interface. The user interface allows the user to have clear control of the robot with visual aid with the use of a mounted camera on the robot. This concept is suited for when the user does not have a direct visual of the robot and its environment.

Figure 6: Patent conceptional view of robot controlled by remote user
2.3 Codes & Standards

2.3.1 SAE Wheel Standards

(SAE HS-3300/2010)

This standard is used to determine consistent sizing, marking, and fastening for various types of wheels. While this is primarily associated with car and truck wheels, this information will be useful to determine how best to connect wheels to axles on a smaller scale, as well as optimal methods for fastening wheels. Additionally, these standards are useful to guarantee that our selected wheels will be the same size, due to standard sizing conventions.

2.3.2 Wireless Connections

(IEEE 802.15.1)

This controls how wireless devices interact with each other, ensuring that devices can stay connected and move information efficiently via radio waves. While we don’t know the exact mechanism our robot will use to communicate with the controller, this standard covers several types, and will allow us to guarantee that our robot communicates effectively and has little to no latency between our inputs and the corresponding movements in the robot.

2.4 User Needs

An interview was conducted with an intended user to obtain important customer needs. The interview was recorded as well.

2.4.1 Customer Interview

Interviewee: Sam Hudson
Setting: All of the ASME soccer robot groups showed up to interview Sam in a class setting. She sat at the front of the room. Everyone asked Sam various questions about what specifications/requirements are required for the robots. It was then concluded that the majority of the customer needs will derive from the individual groups needs.

Interview Notes:

*Do we need to make more than one robot?*
- Just build one robot.

*Any safety requirements?*
- Not intended safe enough for children to use. Specific safety requirements should be sain the rule document

*What movements are allowed?*
- The robot is allowed to back up and rotate.

*Is there a required time limit to setup our equipment?*
- Yes; your group has one minute to setup.

*Are we allowed to change customization during play?*
- No. Design can change between games possibly, but not during game.

*If something brakes during play, then can we replace it?*
- Yes, but cannot switch it if it isn’t broken.

*Do you prefer remote versus tethered?*
- Remote preferred.

*What is the biggest safety concern?*
- Electrical fire. Misshandling of the robot- pieces are active that weren’t supposed to be.

### 2.4.2 Interpreted User Needs

Based on the interview with Sam, a list of customer needs for the soccer robot was created, and each need was rated on a 1 (least important) to 5 (most important). These needs and rankings are displayed in Table 1.
Table 1: Interpreted Customer Needs

<table>
<thead>
<tr>
<th>Need Number</th>
<th>Need</th>
<th>Importance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>The robot is meant for the intended user</td>
<td>4</td>
</tr>
<tr>
<td>2</td>
<td>Aesthetics of the robot itself; no loose wires, chords, etc</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>Parts replaceable</td>
<td>5</td>
</tr>
<tr>
<td>4</td>
<td>Remote for control</td>
<td>4</td>
</tr>
<tr>
<td>5</td>
<td>Weight</td>
<td>3</td>
</tr>
<tr>
<td>6</td>
<td>Size</td>
<td>5</td>
</tr>
<tr>
<td>7</td>
<td>Safe to use</td>
<td>4</td>
</tr>
<tr>
<td>8</td>
<td>Specific mechanism to control and redirect ball</td>
<td>3</td>
</tr>
<tr>
<td>9</td>
<td>Movement of the robot</td>
<td>5</td>
</tr>
<tr>
<td>10</td>
<td>Feasibility to setup robot</td>
<td>5</td>
</tr>
<tr>
<td>11</td>
<td>Withstand collisions</td>
<td>4</td>
</tr>
<tr>
<td>12</td>
<td>Speed</td>
<td>4</td>
</tr>
<tr>
<td>13</td>
<td>Power</td>
<td>3</td>
</tr>
<tr>
<td>14</td>
<td>Portable</td>
<td>4</td>
</tr>
</tbody>
</table>

2.5 Design Metrics

To address each of the interpreted customer needs in Table 1 above, specific design metrics were established. Ideal and acceptable specifications are shown in Table 2.

Table 2: Target Specifications

<table>
<thead>
<tr>
<th>Metric Number</th>
<th>Associated Needs</th>
<th>Metric</th>
<th>Units</th>
<th>Acceptable</th>
<th>Ideal</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5,10,14</td>
<td>Total weight</td>
<td>kg</td>
<td>&lt; 10</td>
<td>&lt; 5</td>
</tr>
<tr>
<td>2</td>
<td>6,12,13,14</td>
<td>Total size</td>
<td>$m^3$</td>
<td>&lt; 0.125</td>
<td>&lt; 0.1</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>Budget</td>
<td>$</td>
<td>&lt; $400</td>
<td>&lt; $250</td>
</tr>
<tr>
<td>4</td>
<td>9,12</td>
<td>Top speed</td>
<td>m/s</td>
<td>&gt; 1</td>
<td>&gt; 3</td>
</tr>
<tr>
<td>5</td>
<td>3,13</td>
<td>Battery life</td>
<td>minutes</td>
<td>&gt; 5</td>
<td>&gt; 90</td>
</tr>
<tr>
<td>6</td>
<td>8,13</td>
<td>Ability to score</td>
<td>Score from Centerline Entire field</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>4</td>
<td>Control method</td>
<td>Wired Wireless</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>2,3,7,10,11</td>
<td>All parts secured/safe/replaceable</td>
<td>Yes</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>2</td>
<td>Aesthetically pleasing</td>
<td>Pretty</td>
<td>Very pretty</td>
<td></td>
</tr>
</tbody>
</table>

2.6 Project Management

The Gantt chart in Figure 8 gives an overview of the project schedule.
<table>
<thead>
<tr>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>6</td>
<td>13</td>
<td>20</td>
<td>27</td>
</tr>
<tr>
<td>4</td>
<td>11</td>
<td>18</td>
<td>25</td>
<td>1</td>
</tr>
<tr>
<td>8</td>
<td>15</td>
<td>22</td>
<td>29</td>
<td>6</td>
</tr>
</tbody>
</table>

- **Design Report**
- **Problem Understanding**
- **Concept Generation**
- **Concept Selection**
- **Concept Embodiment**
- **Design Refinement**
- **Peer Report Grading**

**Prototypes**
- **Mockup**
- **Proofs of Concept**
- **Initial Prototype**
- **Initial Prototype Demo**
- **Final Prototype**
- **Final Prototype Demo**

**Presentations**
- **Class Presentation**
- **Final Presentation**

Figure 8: Gantt chart for design project
3 Concept Generation

3.1 Mockup Prototype

Figure 9: Front view of soccer robot

Figure 10: Side view of soccer robot
Figure 11: Back view of soccer robot

Figure 12: Isometric view of soccer robot
The mockup of the soccer robot helped us visualize our design concept and find improvements that need to be made. The mockup allowed us to see the scale of the robot that we are working with. By knowing the potential size of the robot we now know potential issues such as the final weight of the robot. The current mockup is a 40cmx40cmx20cm. As we progress in creating further prototypes we could reduce the size of the robot to reduce the total weight. Key design functions for the mockup include, the wheels, side arms, a funnel in the front of the robot, and a “pool cue” attachment. From the mockup we realized that the wheels would need to adjusted as the current design causes the robot to be raised from the floor; an adjustment would lower the robot by placing the wheels’ axle higher up on the robot then directly underneath it as currently placed. The side arms were placed to aid the robot move the soccer ball when the ball is next to a wall or corner. A funnel system was created to help the robot dribble the ball around the field. The current design holds the ball inside the robot but could be improved or changed. A “pool cue” is attached to the robot that will serve as the method of kicking the soccer ball. The current idea is to design the pool cue mechanism after a pinball launcher. The mockup will allows us to find potential flaws that can be improved after each iteration of the robot as we move forward.

### 3.2 Functional Decomposition

The function tree below describes sub functions that the soccer robot must achieve. These are not all possible functions but rather a selected few that are crucial to the success of the soccer robot. The soccer robot must be able to move around, have the ability to kick the ball, the ability to dribble the ball around the filed, be controlled with a remote control system, have a casing or shell to hold all components, and must be able to store energy to power the robot.
Figure 14: Function tree soccer robot, hand-drawn and scanned
3.3 Morphological Chart

The following morph-chart shows possible design solutions to achieve each function of the soccer robot. These designs are not the final design, but rather initial thoughts design to start the design process. Concept designs will be created using these designs from the morph-chart or from ideas outside the chart as well.

Figure 15: Morphological Chart for soccer robot
3.4 Alternative Design Concepts

3.4.1 Tri-Wheel Bot

Description: This soccer robot design takes three wheels to control the movement of the robot. A pool cue like attachment coming from the front of the robot will be used to kick the soccer ball toward goal. The pool cue could in theory be controlled to give different amounts of force to kick the ball depending on the need of the player. An opening in the front of the robot will be used to house the ball in order to dribble and align before shooting toward goal. The robot will be powered by batteries that can be either replaced or recharged in between games.
3.4.2 Vacuum Soccer Robot

Figure 17: Sketches of Vacuum Soccer Robot Concept
Description: This design is based off of a vacuum cleaner robot. These types of robots have 360-degree rotation and can move around pretty easily if designed right. There are four entry points for a tennis ball to enter, kind of similar to the plunger mechanism of a pinball machine. The idea is for the spring to be compressed with the ball and when released will shoot the ball out to score. The entry point can also act as a housing when "dribbling the ball." For defense, there is a curve ramp that surrounds the circumference of the robot to deflect incoming tennis balls. The robot is intended to be powered by a rechargeable battery or use replaceable batteries. Hopefully, this will be remote controlled with a simple design.

3.4.3 Circular Sling Shot Robot

Description: The half-circle shape of the robot helps the robot to have a good balance without being too tall or big so that we don’t have many contacts with the other robot. If there is a collision, the two layers of the robot’s shell and the spring between them will absorb the shock so that the battery and "engine" don’t get all the shock directly. It has a cupping mechanism to dribble the ball and a sling shot mechanism to kick the ball.
3.4.4 Spring Powered Robot with Retractable Winch

Figure 19: Sketches of Spring Powered Robot with Retractable Winch

Description: This robot is small, prioritizing speed and agility over power. The front has a "v" indentation to allow the ball to be dribbled. The ball will rest on a thin metal sheet that can be angled upward using a winch to increase the angle of the shots taken. The shooting mechanism is powered by a spring to shoot the entire "v" forward, and once used, a motorized winch will pull the whole thing back, reengaging the spring, before getting locked in place to prepare for the next shot.
4 Concept Selection

4.1 Selection Criteria

Our 5 criterion were battery life, ball control, mobility, speed, and power in order of high weight. Ball control has the highest weight percentage since the goal of the game is to control the ball the way we intended to and lead to score. Without the mechanism that can get us a good control of the ball, no matter how fast and powerful the machine might be, winning the game would be hard. Battery life and mobility got second and third highest weight. These result are due to customer wanting a long battery life machine that could last the whole tournament, and having a good mobility will help the control of the machine and ball.

![Analytic Hierarchy Process (AHP) to determine scoring matrix weights](image)

<table>
<thead>
<tr>
<th></th>
<th>Mobility</th>
<th>Power</th>
<th>Ball control</th>
<th>Speed</th>
<th>Battery life</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mobility</td>
<td>1.00</td>
<td>1.00</td>
<td>0.33</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Power</td>
<td>1.00</td>
<td>1.00</td>
<td>0.20</td>
<td>1.00</td>
<td>0.20</td>
</tr>
<tr>
<td>Ball control</td>
<td>3.00</td>
<td>5.00</td>
<td>1.00</td>
<td>1.00</td>
<td>0.50</td>
</tr>
<tr>
<td>Speed</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>0.25</td>
</tr>
<tr>
<td>Battery life</td>
<td>1.00</td>
<td>5.00</td>
<td>2.00</td>
<td>4.00</td>
<td>1.00</td>
</tr>
</tbody>
</table>

Row Total: 4.33 3.40 10.50 4.25 13.00
Weight Value: 0.12 0.10 0.30 0.12 0.37
Weight (%): 12.21 9.58 29.59 11.98 36.64

Column Total: 35.48 1.00 100.00

Figure 20: Analytic Hierarchy Process (AHP) to determine scoring matrix weights

4.2 Concept Evaluation

Based on the Analytic Hierarchy Process, we have weighted our 4 selected concepts on Weighted Scoring Matrix.
4.3 Evaluation Results

The Analytic Hierarchy Process (AHP) and the Weighted Scoring Matrix (WSM) were used to determine the best concept to move forward with for the prototype stages. All suggested concepts assumed that the battery life would be equal in performance as there is no data at the moment to determine which design has the best battery life. The Tri-Wheel Bot concept and UNFO concept both tied for speed due to their similar design that allows for easier movement in multiple directions similar to a robot vacuum cleaner. The Cupping Dome and Ball Sweeper were ranked lower as they are not focused on speed. The mobility of the Tri-Wheel Bot was ranked the highest due to the three wheel design allowing it to pivot more easily than a standard 4 or 2 wheel design the other concepts used. The Tri-Wheel Bot used a spring loaded plunger to shoot the ball which would allow for the most power for a shoot on goal. The final selection criterion was ball control. The best design choice was the Ball Sweeper which implements a channel design to allow for easier capture of the ball and control when shooting. The Tri-Wheel Bot had a similar design idea but the narrow opening would mean it would require more precision for the ball to enter the robot compared to the Ball Sweeper making it harder to dribble the ball. From the WSM the highest ranked design was the Tri-Wheel Bot. The prototype will take inspiration from the Tri-Wheel Bot as the base model with design choices from the Ball Sweeper for ball control.

4.4 Engineering Models/Relationships

Model 1: Motor Power

This model will allow us to determine the power that would be dissipated by each motor to allow the robot to move at a certain speed, and the power of the battery we will need to achieve this speed. This is given by the following equation:

\[ P = F \times v = M(a - \mu_{static}g) \times v \]  \hspace{1cm} (1)

Based on the mass of our robot (M), the velocity of the robot (v), and the acceleration the robot is undergoing based on it’s actual acceleration and the force required to overcome friction \((a - \mu_{static}g)\),
we will be able to calculate the total power required to move the robot. This will help us select a battery and motors that can supply us enough power to reach speeds and accelerations we desire.

Model 2: Conservation of energy
This model will describe the speed of the ball once we launch it using our spring mechanism, as well as the distance the ball will travel once launched. The energy used to pull back the spring will equal the kinetic energy required for the speed of the tennis ball once it leaves the spring. We are assuming that there is no friction between the plunger and the ground. Thus the Work/Energy equation is given as:

\[
\frac{1}{2}kx^2 = \frac{1}{2}mv^2 + \frac{1}{2}I\omega^2
\]  

(2)

We will know the mass of the ball (m), the spring stiffness (k), the maximum deflection (x), as well as the moment of inertia (I), so it should be trivial to determine the linear velocity of the ball (v), and the angular velocity (ω), which is dependent on the linear velocity.

We can also determine the distance the ball should travel based on this initial velocity assuming the floor has friction by the following equation:

\[
v^2 = 2\mu_{\text{static}}g\Delta x
\]  

(3)

Based on the initial velocity (v), the coefficient of static friction with the floor (\(\mu_{\text{static}}\)), and the acceleration of gravity (g), we can determine the distance the ball should travel (\(\Delta x\)). This can then determine the exact amount we need to pull back the spring to achieve this initial velocity, based on our distance from the goal.

Model 3: Center of Mass
This model will help us analyze the weight distribution of our robot to ensure it won’t topple during use. The mass distribution (dm) over the robot divided by the robot’s total mass (M) will give us the coordinates of the robot’s center of mass (\(x_{\text{cm}}\)), given by the equation below:

\[
x_{\text{cm}} = \frac{\int_0^M x \, dm}{M}
\]  

(4)

This will give us the x coordinate of the center of mass. The y coordinate and z coordinate can be found using the same method, but in terms of y and z, respectively. We can use this to make our center of mass as close to the center of our robot as possible, and as low to the ground as possible, to eliminate the possibility of tipping mid-match, as that would be catastrophic.

5 Concept Embodiment

5.1 Initial Embodiment

Our prototype’s performance goals are as follows:

- Drive around the outside edge of the playing field with a captured ball in < 17 seconds.
- Make > 5/10 shots from the field midline, starting from the sideline with a ball placed on the center spot.
- Successfully capture a ball within 2 seconds of approaching it > 8/10 times.
Figure 22: Assembled projected views with overall dimensions.
<table>
<thead>
<tr>
<th>ITEM NO.</th>
<th>PART NUMBER</th>
<th>DESCRIPTION</th>
<th>QTY.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>base</td>
<td>Shown in exploded view</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>chip</td>
<td>Shown in exploded view</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>frame</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>battery</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>omniwheel</td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>6</td>
<td>axel</td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>7</td>
<td>cap</td>
<td></td>
<td>4</td>
</tr>
</tbody>
</table>

Figure 23: Assembled isometric view with bill of materials (BOM)
Figure 24: Exploded view with callout to BOM
Figure 26: Exploded view with callout to BOM
5.2 Proofs-of-Concept

Our Proof-of-Concept helped our design for the initial prototype greatly. We realized that the Proof-of-Concept was extremely off-balance, so we made the base of our prototype much larger to accommodate the potential weight, and transitioned to using 4 wheels from an RC car we purchased. Additionally, we realized that the pinball-style shooting mechanism was much too difficult to implement, so we transitioned to a flywheel to propel the tennis balls. Furthermore, we now have an actual mechanized design, so the wheels are able to move freely with the use of a controller, and the flywheel, while separate from the robot for now, can also be operated with a motor.

5.3 Design Changes

Our selected concept was the Tri-Wheel Bot, with a mechanism from the Ball-Sweeper design to control and shoot the ball. We have almost entirely changed our design. The Tri-Wheel Bot was much too unstable, partially due to uneven weight distribution, but this wasn’t helped by the relatively small area that the center of mass could occupy without tipping due to the 3-wheeled design. We have switched to a traditional 4-wheel design, similar to a car, and widened our base considerably, and the design has yet to topple. Additionally, we no longer have use for the Sweeper Bot’s ball control, as the ball will be controlled within the robot using a track and a servo motor to push the ball forward. Lastly, we will no longer be shooting the ball with a pinball mechanism and a spring. This was much too difficult to implement, so a flywheel will be used, and the servo motor will push the ball from it’s resting position within the moving robot to the flywheel to be shot forward.

6 Design Refinement

We switched shooting designs from a spring-loaded mechanism to a flywheel. It was difficult to automate the load/re-load portion of the spring by relying on our current electronics. Utilizing a flywheel was more feasible since we do not have to worry about any form of compression or tension forces for reloading. Also the motherboard from the original car was designed in such a way to allow for practical use of a flywheel coupled with using a servo motor as the ball feeder.

6.1 Model-Based Design Decisions

Model 1: Kinematics

The first model we used was a kinematics model to determine the ball’s final speed and angular speed as it is launched from the flywheel. This model allows to know the speed of the ball and determine how far we can be shoot the ball if we want the ball to reach a certain distance or reach the goal under a certain amount of time. These numbers are helpful when planning game strategies that involve having to play against other robots. Figure 28 below shows a sketch of the flywheel and the tennis ball during and after launch. The ball is assumed to have no slip when in contact with both the ground and the flywheel. The flywheel has a moment of Inertia (I) and radius (R) with an initial speed of (Ω). The tennis ball with a mass of (m) and radius (r) will launch at a linear speed of \( \frac{42.16\text{ ft}}{\text{sec}} \), or 2.40 mph, and an angular speed of \( \frac{32.43\text{ rad}}{\text{sec}} \).
Model 2: Work-Energy

Second model used was create a work-energy equation for the instants before and after ball launch. The model is representing the scenario where the ball is captured at the front of the car at a stationary position; it does not have the kinetic energy supplied by the ball feeder. It is assumed that the ball has zero initial kinetic energy. At the point of contact between the ball and the wheel, the instantaneous work is very minimal, so we neglected the work done by the motor during the tennis ball launch. It is also assumed that energy is conserved since this is for the instant after the two objects make contact. This model also relies on the kinematic equations supplied by Model 1. This model is important in order to determine and compare results with kinematics. This model is also important because it can help give us an idea of how fast the ball will be traveling, and at what optimal distance from the goal is sufficient to have a high scoring probability, which depends on the speed of the flywheel. Figures 29 & 30 below shows sketches of the motion of the flywheel and tennis ball, as well as measured parameters. The flywheel is composed of two inline skate wheels glued together. The only components of the inline wheel are the outer rubber surface, the plastic housing, and two bearings. From personal experience, the weight of the bearings is not sufficient enough to be heavier than the encompassing rubber material of the wheel. Thus, the flywheel is assumed to have a mass moment of inertia of that of a uniform ring. The flywheel has mass moment of inertia \( I \) or \( I_{\text{wheel}} \), weight \( W \), outer radius \( R_2 \), inner radius \( R_1 \), and initial angular velocity \( \Omega_i \). The tennis ball has a moment of inertia \( I_{\text{ball}} \), radius \( r \), weight \( w \), and initial velocity of zero. After launching the tennis ball, the flywheel will have an angular velocity of 536.79 rpm.
Figure 29: Handwritten calculation of work-energy model

Neglect work done by the motor.

Assume energy is conserved.

\[ T_1 + V_1 + U_{\text{stored}} = T_2 + V_2 + U_{\text{stored}} \implies T_1 = T_2 \]

\[
\begin{align*}
\frac{1}{2}mV_f^2 &+ \frac{1}{2}I_{\text{wheel}}\omega_i^2 = \frac{1}{2}mV_f^2 + \frac{1}{2}I_{\text{balance}}\omega_f^2 + \frac{1}{2}I_{\text{wheel}}\omega_f^2 \\
\frac{1}{2}I_{\text{wheel}}\omega_i^2 &+ \frac{1}{2}I_{\text{wheel}}\omega_f^2 = \frac{1}{2}mV_f^2 + \frac{1}{2}(\frac{2}{5}mr^2)\omega_f^2 + \frac{1}{2}I_{\text{wheel}}\omega_f^2 \\
\frac{1}{2}I_{\text{wheel}}\omega_i^2 &+ \frac{1}{2}I_{\text{wheel}}\omega_f^2 = \frac{1}{2}mV_f^2 + \frac{1}{2}mr^2\omega_f^2 + \frac{1}{2}I_{\text{wheel}}\omega_f^2
\end{align*}
\]

From Model 1

\[ V_f = \frac{R_1 + R_2}{2} \]

\[ W_f = \frac{\omega_f R_2}{2} \]
\[ \frac{1}{2} \left[ \frac{1}{2} M(R_2^2 + R_1^2) \right] \Omega_i^2 = \frac{1}{2} m \left[ \frac{-2 R_2}{2} \right]^2 + \frac{1}{2} m f^2 \left[ \frac{a f R_2}{2 r} \right]^2 + \frac{1}{2} \left[ \frac{1}{2} M(R_2^2 + R_1^2) \right] \Omega f^2 \]

\[ \frac{1}{4} M(R_2^2 + R_1^2) \Omega_i^2 = \frac{1}{8} m R_2^2 R_2^2 + \frac{1}{20} m R_2^2 R_2^2 + \frac{1}{4} M(R_2^2 + R_1^2) \Omega f^2 \]

\[ \frac{1}{4} M(R_2^2 + R_1^2) \Omega_i^2 = \frac{2}{40} m R_2^2 R_2^2 + \frac{1}{4} M(R_2^2 + R_1^2) \Omega f^2 \]

\[ \Omega f^2 = \frac{\frac{1}{4} M(R_2^2 + R_1^2) \Omega_i^2}{\frac{2}{40} m R_2^2 R_2^2 + \frac{1}{4} M(R_2^2 + R_1^2)} \]

Using MATLAB,

\[ \Omega f \approx 8.95 \text{ rev/sec} \quad \left( 60 \text{ sec/min} \right) \]

\[ \Omega f \approx 536.79 \text{ rpm} \]

\[ V_{f, 	ext{ball}} = \frac{\Omega f R_2}{2} = 3.51 \text{ ft/sec}, \quad V_{f, 	ext{ball}} = 3.51 \text{ ft/sec} \]

\[ \omega_f = \frac{\Omega f R_2}{2 r} = 32.43 \text{ rad/sec} \quad \omega_f = 309.68 \text{ rpm} \]
Model 3: Battery Life
The last model we will be using will be a power-voltage model to determine the length of time it will take for the battery to die from full charge. This will inform us on how and when to charge the battery between matches. The figure below shows the general layout of the circuit, as well as the calculations used. There is assumed to be no power lost in any of the parts. Additionally, all of the motors are assumed to be in parallel, as we cannot know for sure based on the motherboard. Additionally, our model assumes that all of the motors will be running at maximum angular velocity constantly, which is unrealistic, so this will be a low estimate of the battery life. Knowing the torque \( T \) and angular velocity \( \omega \) of each of the 7 motors, the power \( P \) of each motor can be determined. From this, and the voltage \( V \) and charging capacity \( c \) of the battery, we determined the battery life to be 19.7 minutes. This makes sense, as the RC was initially rated to run for 30 minutes, and we added additional motors, so the actual time should be slightly below that.

6.2 Design for Safety

6.2.1 Risk #1: Battery Charge Malfunction

**Description:** Battery malfunctions while charging up  
**Severity:** Critical  
**Probability:** Seldom  
**Mitigating Steps:** Ensure battery is properly charge
6.2.2 Risk #2: Electrical component hazards

**Description:** Circuit not built/soldered correctly can damage electronics and possibly cause a fire

**Severity:** Critical

**Probability:** Seldom

**Mitigating Steps:** Make sure the circuit is built correctly, no loose wires

6.2.3 Risk #3: Ball fly off and hits someone

**Description:** Ball dislodges and spanks someone on their body

**Severity:** Negligible

**Probability:** Unlikely

**Mitigating Steps:** This was mitigated with the focused channel for ball control.

6.2.4 Risk #4: Refurbished broken tooth gear

**Description:** Car was dropped by accident and the tooth of one of the gears snapped off. It is being held together by super glue now, but may damage the motors to the wheels.

**Severity:** Critical

**Probability:** Seldom

**Mitigating Steps:** Super glue is reliable and works well with plastic materials, which is the material of the gear. Avoid drastic movements of the car whenever possible, especially since the wheels are omni wheels.

6.2.5 Risk #5: Potential fire due to friction between the fly wheel and the wood

**Description:** The flywheel can potentially slide during robot movement, and make contact with the wood. Once turned on, the friction between the two surfaces can potentially cause a fire.

**Severity:** Critical

**Probability:** Unlikely

**Mitigating Steps:** This has been tested. First few tests indicated some fumes from the heat friction. With those tests, there is enough clearance between the outer surface of the fly wheel and the wood.
Based on the heat map, risks 2 and 4 pose the highest priorities. Risk 2 is a high priority since a fair amount of the wiring was re-soldered. If there is one misstep made during the re-soldering process, there is a chance a spark can leak out and possibly ignite the wood. This has a low chance of happening though since the joint of the solder is held together by electrical tape. Risk 4 is also a high priority since during one of the wheels was dropped, which broke off the tooth of one of the gears for the wheel. It is currently being held together by superglue. If the tooth were to somehow fall off, the wheels can possibly be sheared down a little since now there would not be any motion supplied from the motor to the wheels. Risks 1 and 5 are the second highest priorities. Risk 1 has a very low probability of occurring since the battery was store bought. However, if there is some misconfiguration imposed onto the battery during the competition, and it was subjected to charge, the battery may potentially explode. The explosion would not be drastic, but it would still be critically dangerous. Risk 5 I also have a low probability of occurring since now there is enough clearance between the wheel and the flywheel insertion. It becomes Risk 3 is the lowest priority since the channel, the doggy door, and the fly wheel itself help keep the ball fixed in a relative location.

6.3 Design for Manufacturing

6.3.1 Total Parts: 20

- Chassis (Made of wood and cardboard)
- 4 wheels
- 4 gearboxes (w/ motors)
- Flywheel
• - Flywheel axle
• - 2 Flywheel motors
• - Servo motor
• - Servo motor attachment
• - Battery
• - Battery housing
• - Motherboard
• - One-way gate
• - Decorative spider

6.3.2 Total fasteners: 20

6.3.3 Theoretically Necessary Components
• - Wheels + gearboxes
• - Flywheel
• - Flywheel axle
• - Flywheel motors
• - Servo motor + attachment
• - Battery
• - Motherboard
• - Decorative spider

6.3.4 Wheels
Each wheel is necessary because it rotates on its own and without them, the robot would be unable to move around. Their gearboxes are what allow the wheel to rotate, which is why they’re necessary as well.

6.3.5 Flywheel
The flywheel is what shoots our ball forward. It rotates on its own, is a separate material from the rest of the robot, and was constructed specifically for our purposes. Without it, we would be unable to score any goals.
6.3.6 Servo Motor

The servo motor feeds the ball from the inlet to the flywheel. It rotates on its own and was 3D printed using PLA. It can also be removed if adjustments need to be made. Without it, we would simply move the ball toward the goal inside the robot.

6.3.7 Battery

The battery is what powers our robot and allows it to move and shoot. It must be removed to charge the robot, so must be a separate part. Without it, our robot would be a paperweight.

6.3.8 Decorative Spider

The decorative spider is for intimidation and to protect the motherboard and wires. The eyes of the spider also light up to let us know that the robot is receiving power. It could be considered part of the chassis, but the fear it instills into our opponents makes it its own part.

6.3.9 Minimizing/Maximizing Parts

We already have very few parts, but we could consider. Considering most things are glued to the chassis, the chassis comprises a large amount of the robot. In theory, we could decouple some of those parts by instead using threaded fasteners to connect them. The gearboxes would be one example of this. They are technically separate parts, with several gears and axles inside, but we have glued them to the chassis, disallowing access to them. If we connected them to the chassis via fasteners instead, that would not only allow us to change the parts out if needed, but also to manufacture the robot much easier.

![Figure 33: Gearbox Decoupling](image)

Another part that could be decoupled is the flywheel axle and its collars. Ideally, we would be using actual collars, but we couldn’t find any to fit our axle, so we glued washers to the axle as a makeshift solution to prevent it from moving laterally. This, however, prevents the adjustment of the flywheel at all, and should it need repairs, would present a large issue.
6.4 Design for Usability

6.4.1 Vision

Our robot is controlled by a battery running controller with two joysticks and four buttons. There are no color-coded buttons on the remote controller for our robot, therefore a vision impairment will not affect the usability of our machine. When the customer wants to re-connect the wires for any reason, vision impairment might affect since the wires are coordinated with different colors, but the robot will be completely assembled for the customer so it is applicable.

6.4.2 Hearing

During the competition, the environment can get loud, but since our robot will not have any sound effect or alarm that requires a good hearing, hearing impairment will not affect the usability of our machine. However, when there is a mechanical problem that can be distinguished by checking the sound of the machine running, such as gearbox inside the wheel malfunctioning or motor rotating too fast, a person with hearing impairment might not notice it. To prevent any inconvenience from this, a future performance goal can be set to make a warning device that a person with a hearing impairment can notice.

6.4.3 Physical

Our controller operates with a designated frequency and doesn’t use any wires. A person with physical impairment should be able to drive and move the robot without moving or performing physical activity other than finger movements. The controller is light as well, therefore a physical impairment will not affect the usability of our machine. Although, a person with impairment on hands and finger mobility might experience difficulty using the controller. A future performance goal can be set to make a device that doesn’t need concise finger movement such as a wrist band controller.
6.4.4 Control

Control impairment might affect our robot since it requires a player to move the robot with two joysticks and simultaneously press a few buttons to capture and launch the ball. To ease the situation, our robot is made so that the flywheel acting as a shooting mechanism will be rotating the whole time the machine is on so that no additional button has to be pressed. Even though there will be an on/off sign on the robot to turn it on and off, since the English word on/off is simple and universal enough, language impairment shouldn’t affect our machine too much.

7 Final Prototype

7.1 Final Prototype Performance Goals

- The vehicle can drive around the outside edge of the playing field with a captured ball in \( \leq 17 \) seconds.

- The vehicle can make \( \geq 5/10 \) shots from the field midline, starting from the sideline with a ball placed on the center spot.

- The vehicle can successfully capture a ball within 2 seconds of approaching it \( \geq 8/10 \) times.

The final prototype achieved all three performance goals. It can drive around the outside edge of the playing field with a captured ball in 13 seconds. The material use of the cardboard made it lightweight enough to achieve this goal, as well as the amount of power supplied to the motors for the wheels was sufficient. It can shoot from the midline of the playing field and make all of the shots. The use of the omni wheels allowed for feasible maneuverability at different locations of the playing field, including the mid line. It can successfully capture a single tennis ball within 2 seconds of approaching it eight out of ten times. Although the wood, battery, and flywheel mechanism added some weight to the final prototype, the robot was able to approach and capture the ball successfully within a small time frame. The functionality of the omni wheels also made it simple to capture the ball. The controller was critical in the rotation and linear translational motion of the robot. The robot can rotate 360 degrees, which allows the robot to make quick stationary turns when tracking and capturing the ball. The omni wheels permit ball capture from the side of the vehicle. Once the ball enters the channel, a door is pushed into the channel and recoils back once the ball passes fully through the side channel and is not making direct contact with the ball. A button is pushed on the controller and forces the ball into the already spinning flywheel and shoots the ball.

7.2 Views of The Final Prototype

Below are different views of the final prototype.
Figure 37: Front View
Figure 38: Side View
Figure 39: Bottom View