



# UCF

## **Solar Tennis Ball Collector**

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# 1.0 Executive Summary

Nowadays, people have a strong passion for participating in sports activities and commit their efforts and hard work in athletic disciplines. People try to get involved in sports to maintain their physical health, to have a healthy lifestyle and enjoy quality time with friends. Engaging in sports can also have a lot of benefits in a person's mental health too. Playing sports helps reduce depression, anxiety, and stress. There are various types of sports that people enjoy playing, such as soccer, volleyball, basketball, baseball, football, tennis, and others.

As we all know, most sports involve the use of a ball as a major equipment in game. Most people think that balls were made hundreds of years ago. However, the first ball had been made in 2500 before the century. The first sport that used ball as their major equipment in game was Mesoamerican ball game. It was first played in China. This sport originated in China. The ball had been made of strings and rags. Field hockey is recognized as Europe's first sports game that involved a ball in it. It happened in 500 before the century. According to fans, soccer is the most popular ball sport right now. Soccer has approximately 3.5 billion fans. Cricket takes second spot with 2.5 billion fans. Field hockey completes the top three spot as a third ranking with 2 billion fans. Tennis is ranked in fourth place. It has 1 billion fans around the world. Asia, America, and Europe are the most fan-based regions for tennis.

Tennis comes from Greece. Playing tennis was ancient Greek culture. First tennis game was held in France and it happened in the 12th century. Back then it was being played with bare hands not with tennis rackets. After that, people decided to wear gloves to play tennis. The ball was from hardwood covered in cottons to make the ball bouncy. The word tennis comes from the French language which means "play". In the 16th century, the first tennis game was held. First tennis court was built in 1530 by an English king. This tennis court is similar to the court that people play tennis on nowadays.

Currently, tennis has several famous tournaments worldwide. For instance, the US Open, Wimbledon, French Open, Australia Open, and others. We can see ball boys or ball girls in every official tennis game. These people play the main role in gathering balls that are being thrown away off the court. They hold onto the balls so that when players ask for it, they can give tennis balls to them as quickly as possible. It is common to see scattered tennis balls around the tennis court. It is challenging to begin and end a tennis match with only one tennis ball. That is why people prefer bringing as many tennis balls as they can so they can have a joyful and satisfying game. It is not fun to collect all the tennis balls that are spread out around the tennis court after a joyful tennis match. It is the last thing that a player wants to do after an intense physical game. This tennis ball collector can be perfect equipment for players who train by themselves on the tennis court. While they will be training by themselves, solar tennis ball collector

will gather tennis balls that are scattered around. With that, players can have time efficient training and a productive outcome of their training.

Solar Tennis Ball Collector is being created for those reasons. This robot device helps to prevent people from worrying about scattered tennis balls all around and it will help to make people's lives easier and more convenient. Solar tennis ball collector is a robot which gets power from direct sunlight and stores it in a small battery to be safe in unfavorable weather conditions. Robots can detect tennis balls, and court fences with the help of sensors that are being provided on it. There can be no doubt that this robot can complete tasks of ball boys or ball girls that were mentioned above. The presence of robots roaming inside of the tennis court will be the least thing that a player wants to see.

Solar tennis ball collector is designed based on specific sensors, computer vision, wheels, motor, solar power, and specific frame. Sensors are going to be one of the primary equipment in this device. There are going to be two different sensor types that are going to be used for court side barriers. The motor will be another key component for the solar tennis ball collector robot. The robot is being designed as lightweight as possible. Based on the weight of the robot, the motor will be able to carry its assigned task. There can be no doubt that if a robot has excessive weight, the motor will not be able to complete its intended function. Solar panels are the main power source of robots. As we all know, the majority of people play tennis outdoors and solar tennis ball collectors are designed for outdoor use only. It can be used indoors too, but it may not exhibit its full performance potential while being on an indoor tennis court.

This robot is capable of meeting nowadays market requirements with its combination of lightweight, performance, and efficiency. Presently, markets are seeking products that offer easy to use, safety, energy efficient, and high performance to meet customer satisfaction. Solar tennis ball collectors meet all requirements that markets are looking for. There are a lot of products on the market that make customers have challenging times to understand the product. Solar tennis ball collector is square shaped equipment. The top part of the robot has a lid. All electrical wiring and PCB are going to be under the lid which means inside of the square. On top of the lid, there is a solar panel. The device contains 2 wheels. Each on the right and the left side. The wire rack is on the front end of the robot. It helps the robot to balance and roll perfectly when the robot is in motion. The wire rack is the only equipment that collects tennis balls. Sensors are mounted on top, and some sensors are mounted on upper arms of the solar tennis ball collector robot. Our brushed motor is also attached inside of the frame. There is not going to be any electrical equipment outside of the frame for safety and visual appeal considering outdoor weather.

## 2.0 Project Description

To start off our report we want to give a detailed description of what our project is going to be about. Behind every project there is a goal. Innovation does not begin without an idea or a burning passion. In this section we want to give a detailed background for what motivated us and how we came up with this idea. We want to clearly define our goals to explain what we want to achieve. We also want to find and discuss current related works that model what we want our project to be like.

### 2.1 Motivation & Background

Tennis is a very challenging, demanding, and rigorous sport. Athletes want to spend as much time as possible training to hone their craft. Over time in the field of tennis with technology we have helped athletes to train and become more efficient. With the introduction of machines that can automatically serve the ball to you, Hawkeye Technology, etc. have helped tennis athletes to be able to practice more often and spend more time on their craft. However, what if there was a way to cut down on even more mundane tasks for tennis athletes.

After a long match or practice session the last thing you want to worry about is cleanup. However, what if there was a way to make that easier. In our project we hope to create a Solar Tennis Ball Collector. This will be a small autonomous vehicle that would essentially roam around the perimeter of the court and sweep up all the extra balls that are laying around. Essentially this would get rid of the tedious task of picking up every single tennis ball. This then allows for the players to spend extra time practicing instead of having to worry about and completing the mundane task.

As a group we also have a strong interest in robotics. So much interest that two of our members Jorge and Juan are minoring in robotics. So, when we first conjured up our group, we knew we wanted to involve robotics in some sort of way in our project. A couple of members in our group also have an interest and love for tennis. So we thought why not combine the love we had for both and try to make something out of it that would benefit everyone who used it.

### 2.2 Goals & Objectives

Our ultimate goal for this project is to build this solar autonomous tennis ball collector. We do have some smaller goals we want to specifically showcase in the project. The three main goals we want to achieve are accurate computer vision, accurate sensors, and functioning brushed electric motors.

We want to have our tennis ball collector roam around the outskirts of the tennis court to pick up the balls. The robot must be aware of its surroundings, this way it will not roam onto the court itself or bump into any walls or obstacles. We want

the tennis ball collector to roam around the court until a tennis ball is spotted then it will target and move towards the tennis ball until it is collected. This process is then to be repeated until the storage compartment is full or no more tennis balls can be found.

## 2.3 Existing Product / Past Project / Related Work

Currently there are a few similar projects. However, the most notable is one created by the company *Tennibot* that has produced a model of something similar to which we are trying to build. The model from *Tennibot* is essentially a Roomba. Using an app on your phone you can tell the Tennibot to sweep around a certain area of the court. As it passes over a ball it gets sucked in by a rotating belt and gets launched into the back storage space. Using the app, you can also manually drive the Tennibot.

There have been similar projects at Cornell University, Auburn University, etc. A lot of these projects have different designs and technology that comes with them. For example, in the project done at Cornell university they did not use a belt to transport the tennis balls into the basket, instead they used wooden turnstiles to scoop up the balls and put them into a storage unit on the back end.

## 2.4 Engineering Specifications Table

No	Requirement	Values	Description
1	PCB	3 printed circuit boards	Printed Circuit boards will be used to show and create all electrical connections
2	Energy Storage	30mAh	Energy storage will be used to store energy that is getting from solar panels that is built in on top of the robot
3	Computer Vision	85% Accuracy	Computer vision requires identifying objects correctly.

4	Sensors	14 sensors	Ultrasonic and Bump Sensors
5	Brushed electric motor	37 Watts	Electric motor will help robot to move around tennis court
6	Solar Panel	30 Watts	Small solar panel will help robot to charge in outdoor tennis court
7	Storage Capacity	Up to 7 balls	Storage capacity is being limited to 7 balls

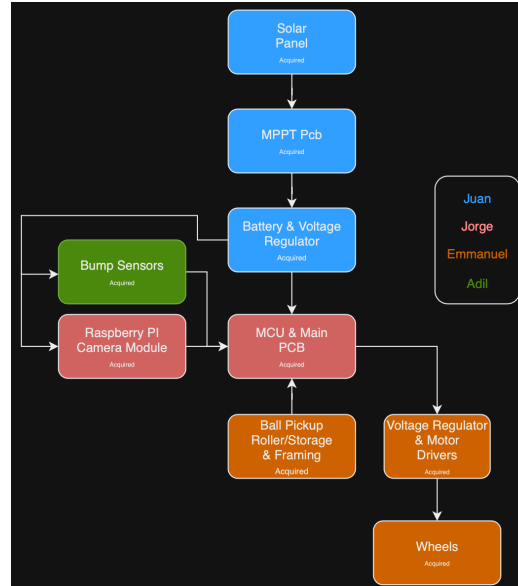
Table 2.4: Engineering Specifications Table

Computer vision, sensors, and electric motor are 3 major requirements of this project. Computer vision is used to detect tennis balls with perfect 120°. It helps the robot to operate better and reach its superior level. Sensors are only to detect collisions between robot and tennis court barriers. Brushed electric motor is the component which helps the robot move with the help of two seven inch wheels.

The Solar Tennis Ball Collector robot cannot move without an electric motor. An electric motor will help to move quickly from each point to another. There are specific restrictions for the robot.

Sensors will help to observe the tennis court's white lines and it is not going to be able to enter into the court for safety reasons. Signal analyzer will come from sensors and computer vision.

## 2.5 Hardware Block Diagram



The system is expected to be powered entirely by a solar panel, which will provide DC power that needs to be converted to AC for many parts of the system. An array of various sensors will be employed to gather necessary information from the operating environment to find tennis balls and other obstacles the robot may encounter. These sensors will be feeding information to the microcontroller unit (MCU) which serves as a central processing and control unit for the whole system. As the MCU takes input from the sensor array, it outputs commands to the drivers for the motors, which in turn send control signals to the motors. Metal arms will extend in front of the collector to help guide the tennis balls into the rolling wire cage, which also serves as storage for collected balls.

## 2.6 Software Summary

The software design for the collector was always based on a loop that repeatedly checks sensor readings and reacts to them accordingly. Originally, this loop was conceptualized to involve wandering to find “objects of interest,” which included tennis balls and other obstacles. When the sensors on the robot detected a specific object of interest, it would react in a way that was specific to that object. For tennis balls, this meant turning and moving towards them, while obstacles were turned away from. This initial idea also involved tracking of court lines to guide movement, which implied a more complex sense-react system than other sensor systems, as this would require frequent correction and near continuous tracking to achieve. This design was created before the hardware capabilities were fully realized and was meant to serve as more of a framework to follow as design progressed. Pictured below is an older rough design for our main software loop.

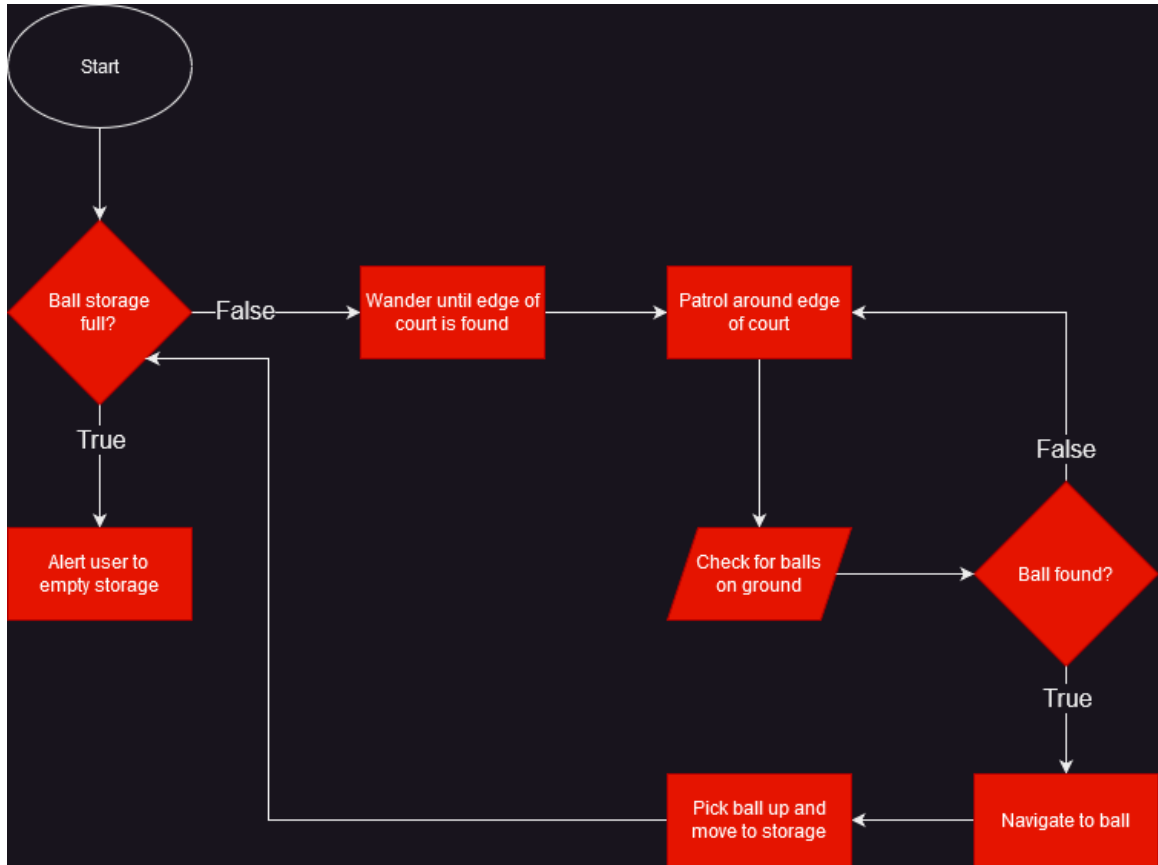


Figure 2.6.1 Original software flowchart

The final design uses a similar concept of reactivity to sensor input, but a notable difference is in the direct response in software. Instead of immediate responses, sensor inputs are taken into consideration as they are checked, affecting the priority of a specific action the robot could take. In this case, the loop checks each sensor once each loop and then ends the loop with a specific action that is considered the most important to execute that loop according to collected information.

This system allows for the independence of the computer vision system for detecting tennis balls, which runs on its own loop and is polled for sensor data via interrupt only when the main controller is ready. This separate loop appears more simple than that of the main controllers, but requires more computational power due to the use of image processing, a typically long and complicated process for low power systems.

Software for the separate charge controller was also written, adapted from a commonly used algorithm for solar charge controllers known as maximum power point tracking, or MPPT. The code on this processor was kept simple and focus was kept on other algorithms involved.

## 2.7 House of Quality

Correlations		Positive	Strong Positive	Negative	Strong Negative
		↑	↑↑	↓	↓↓
Polarity		Positive Polarity	Negative Polarity		
		+	-		

	Dimension	Signal Analyzer	Brushed Electric Motor	Storage Capacity	Energy Storage	Sensors
	-	+	+	-	+	-
Design	↑	↑↑	↑↑	↑↑	↑↑	↑
Cost	↑		↑	↑	↑↑	↓
Battery Life	↑	↓	↓	↓↓	↓↓	↓
Quality	↑	↑↑	↑↑	↑	↑	
Environmentally Friendly	↑↑	↑↑	↑	↑	↓	
Targets of Engineering Requirements	11.5" x 15.5" x 40.5"	Detection of objects	1000 watts	Up to 10 balls	12.8V 30Ah	2 Sensors

Table 2.6: House of Quality

In product design, understanding and creating the house of quality is one of the major keys to success in a product. The house of quality can show clear and understandable information for a product. As we can see in the table above, correlation shows four different parts, which are, positive, strong positive, negative, and strong negative. Correlations were shown based on engineering specification and market requirements. Let's take an example of sensors. If we are going to have 2 types of sensors that we mentioned to use, we are going to meet engineering requirements. Every engineering requirement should have targets which are shown below of the table. So, for sensors, our target was 3 sensors, but we used only 2 types of sensors. For storage capacity, we have up to 10 tennis balls that storage capacity can handle. On left hand side of the table, we can see what the market requirements are

In terms of market requirements, there are major aspects where devices need to meet market demands. Let's take an example of an "environmentally friendly" requirement. Nowadays, some engineering products use elements that might not be environmentally friendly. Markets ask for eco-friendly products. Most people prefer using eco-friendly products instead of non-green or polluting products. We see that correlations of market requirements and engineering specifications are mostly "strong positive". It is one reason for the market to offer this product to people.

Polarity shows the need for requirements. If we take an example of cost in market requirements, we can see that a lower cost will be better for market use. People prefer cheaper and reliable products. Now let's take an example of polarity in engineering specifications. Storage capacity shows “-“ polarity, which means if storage will be less than expected, it will be better for weight saving in the product.

Arrows on top of the table shows how relations between engineering specifications and market requirements are meeting each other. It is called the engineering tradeoff matrix. After creating our own excel file, we started comparing specifications and requirements and we ended up with the table shown above. Spaces means there is no relationship between particular specification and market requirement.

## 2.7 Preliminary Cost Estimates

Item	Quantity	Estimated Cost
PCB	1	\$ 2
Microcontroller	1	\$ 2
Battery	1	\$ 10
Brushless motors	2	\$ 200
Solar Panel	1	\$ 50
Sensors	3	\$ 50
Wheels	4	\$ 100
Structure materials		\$ 50
<b>Total</b>		<b>\$ 464</b>

Table 2.7: Cost Estimates

## 3.0 Research and Part Selection

Research is very important when it comes to any new project. You need to have a significant amount of research done to solve any problem. With good research you will be able to make well-informed decisions. This can help in the part selection. If you do your research well you can save yourself a headache with choosing what parts you need for your project. This can in turn save money and help you find the best parts that are available to you. In this section we plan to go

through and discuss all the research that we compiled. We also plan to decide on the major components that we need to buy for the solar tennis ball collector.

## 3.1 Technology Comparison

Here we will be comparing the design methods we researched before properly designing the collector and choosing specific parts. This is a more general comparison covering methods of functionality and development such as movement and sensing.

### 3.1.1 Movement

#### 3.1.1.1 Axled Wheels

Before deciding on the tennis ball collector, our group was aiming to create a design based on remote control cars, which led us to originally envisioning the collector on four wheels in axles of two wheels like common automobiles. This configuration is often also known as “Ackermann steering” and is common for robot designs that focus more on speed. This allows us to reduce the amount of motors necessary to control the collector robot to a single main motor and a smaller, less demanding servo dedicated to steering.

Issues start to arise when range of movement is considered, as Ackermann steering provides a limited turning radius. When a car or similarly steered vehicle tries to turn 180 degrees, it is forced to perform a wide U-turn where it won't end in the same place it started or a complicated K-turn, requiring the space to alternate between moving forward and backward. Neither of these turning methods are convenient for the case where a ball that can easily be nudged out of position is detected behind the collector robot. Autonomous driving suffers most from this locomotion method, as software has to take this turning radius into account when pathing to an object of interest, like a tennis ball. Steering like a car also adds some mechanical complexity to the robot, something we aim to avoid as much as possible due to our lack of expertise in the subject.

#### 3.1.1.2 Limbs and Articulation

A common method of locomotion in robotics that allows for greater range of movement is to use limbs and articulation. This method is meant to emulate the way that animals naturally move, which could range from a four-legged dog, an eight-legged spider, or a two-legged human. There have even been designs that emulate the way limbless animals, like snakes, move.

Generally speaking, as the number of limbs and joints increases, so does the possible number of movements the robot can execute. Having an electronic system keep track of this many events and controllable devices becomes complicated quickly, pushing further demand for processing power. Emulating the movements of a living being also requires extensive research on the kinematics

behind those movements, which can be difficult without prior mechanical engineering knowledge. These limb based methods of locomotion allow for very versatile movement, especially over more treacherous terrain. Unfortunately, that wide range of movement is not necessary for this application since we expect to only use the collector on a flat paved environment, so exploring its use would only serve as a detriment to the project due to its complexity.

#### 3.1.1.3 Tank Treads

Treaded, tank-like movement is one example of a simpler means of locomotion, both mechanically and in software. Tanks traditionally move using two treads on either side that rotate independently from each other, which makes controlling speed and turning a matter of only manipulating two separate motor systems. This method of control is often referred to as “skid steering”. Turning radius also greatly improves on that of a car-style layout, as tank movement allows for turning 360 degrees in place. This is achieved by making the motors turn in opposite directions, effectively making one half of the vehicle try to move forward while the other moves backwards, creating a rotational effect. For an autonomous system, this also simplifies the calculation of position and pathing, which will help the robot keep a safe distance from the edge of the court and help it find and pick up loose tennis balls.

#### 3.1.1.4 Differential Drive With Wheels

While the tank treads offer many advantages in control, they are typically designed for larger vehicles and meant to traverse more treacherous terrain, so they would add more weight and take more space than necessary. In their place, we can use simple wheels that can be controlled in the same way, while reducing size and weight. Since there is less surface area making contact with the ground in this steering method, it is referred to as “differential drive” instead of “skid steering”, which also means it has better turning control as it moves forward or backward. This configuration is similar to the wheel layout found on most models of the iRobot Roomba and many educational and project grade “turtle” robots.

Since two wheels would not be enough to keep the robot balanced, other, free moving, non-powered wheels or stabilizers would be utilized to keep it upright and support the weight. This configuration also forces the use of at least two separate motors and accompanying drivers, which will cost more in both price and power consumption than the single motor asked of some other methods.

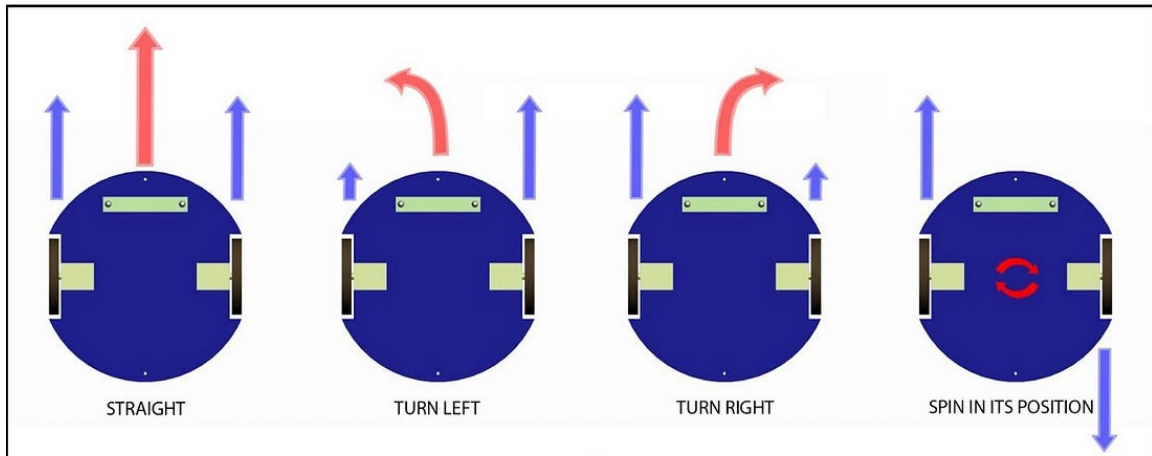


Figure 3.1.1.4.1: Steering Method of Differential Drive Robot. Reference from <https://medium.com/manual-robotics/drives-76c2b2dac97c>

### 3.1.1.5 Omni Directional Wheels

A method of locomotion used almost exclusively in the field of robotics is omni directional drive. This method uses specially designed wheels (called omni-wheels) that allow movement parallel to the direction the wheel faces. These omni wheels often look like wheels with smaller rollers or wheels on their edges and are commonly used in sets of three or four, equally spaced around the edge of the main robot frame. To move in a specific direction with these wheels, only the wheel aimed in the direction of movement is necessary to push the whole vehicle. This allows for completely forgoing the need to steer, as this configuration can move in every direction that the wheels face without needing to rotate the whole body. Rotation is still possible similar to how it is implemented for differential drive, where opposite wheels will turn in opposite directions to rotate the body of the vehicle.

Omni wheels are infamous for making it difficult to track the current position and true speed of the robot, as wheel rotation does not directly translate to distance moved as it would with a traditional rigid body wheel. Omni wheels are also considerably more expensive than traditional wheels, making them less of a realistic consideration. Omni wheels would also promote a redesign of the collection mechanism and storage compartment, as our current configuration has a designated “front” while omni directional movement needs no front side to the robot’s body.

### 3.1.1.6 Final Comparison

The field of robotics is full of options for locomotion, many of which are not listed here or are explained in this section very generally. Sadly, many of these options are not very available to us either due to cost or mechanical complexity. With this in mind, when making the final decision on what locomotion technology to use for our design, we have to prioritize what is the most cost effective and mechanically

simple. Generally, this means we avoid any method that is not solely controlled by very few motor or servo devices, which excludes limbs as an option. We are avoiding anything that has an excessive cost that is not worth investing in for our specific use case, which excludes the tank treads and omni-directional wheels. This leaves us choosing between the car style axled wheels and the differential drive layout. We decided finally on the differential drive due to its mechanical and software simplicity. Below this section, we have made a table summarizing the advantages and disadvantages of using each locomotion method as well as highlighting our final decision.

	<b>Advantages</b>	<b>Disadvantages</b>
<b>Limbs and Articulation</b>	Wide range of movement	High mechanical complexity
<b>Axled Wheels</b>	Requires less motors	Limited turning radius
<b>Tank Treads</b>	Simple control	Too heavy and large for application
<b>Differential Drive</b>	Simple control and lightweight	Needs additional hardware for balance
<b>Omni Directional Wheels</b>	Vast freedom of movement on wheels	Expensive, difficulty tracking robot's own position

Table 3.1.1.6: Movement Method Comparison

### 3.1.2 Ball Collection and Storage

#### 3.1.2.1 Conveyor Belt

One of the first designs we created for the collector robot involved having collector arms guide balls on the ground into a conveyor belt inside the robot. This conveyor belt would raise the balls into a basket positioned behind the main body of the robot. After further research, we realized this method would take up too much space and be difficult to employ considering the many mechanical parts that make up typical conveyor belts.

### 3.1.2.2 Flywheel Launcher

In our research, we found other designs for automated tennis ball collectors. Many of these used fast spinning wheels at the ball collection entrance to launch tennis balls into a basket behind the robot. This launcher would resemble the design of flywheel based sports ball launchers. This design would result in a robot body very similar to the original conveyor belt idea with the advantage of being less complex and less prone to mechanical problems. Being able to launch the balls also allows for a variety of designs for storage. One such example is the design used by the Tennibot, which has a separate hinged basket that can be picked up.

Since the launcher wheels are constantly turning in this design, it would require an additional set of motors and would constantly draw power. The extra vibrations from the launcher could cause problems for other parts of the collector robot and the constant power draw puts a greater burden on the already power limited design. The speed of launched balls would also need to be fine tuned, as launching them too hard and too soft comes with their own sets of issues. Depending on how the storage is set up, balls could miss or jump out of an open top basket and damage a more enclosed basket if launched with too much speed. Designs like this one would benefit from better mechanical engineering knowledge, which a team of all electrical/computer engineers significantly lack.

### 3.1.2.3 Manual Collector

In the end, we realized a non-powered method of ball collection would best fit our constraints. For this, we looked to manual ball collector designs. One design that interested us was one that resembles a lawn mower that uses a large roller that moved as the wheels did. This roller would bring balls up to a basket that sat just above the ground. Another design that further simplified the construction of the autonomous collector was a wire roller, which also handled storage of tennis balls.

The drawback of using a normal manual tennis ball collector is the lack of freedom it allows in designing our own system for storage and collection. We ultimately decided to incorporate an existing manual tennis ball collector into our design as it would bypass much of the need for mechanical research and experimentation, allowing us to focus more on the electronics of the system.

### 3.1.2.4 Final Comparison

Our final decision for the actual collection method is dependent on many of the same priorities and constraints as that for the locomotion method mentioned in a previous section. We aim to keep the design of the collector as mechanically simple as possible to allow for greater focus on the electronics of the system. This leads us to the near obvious choice of foregoing the need to design a collection and storage system of our own in favor of an existing design. While the other options have existing designs we can take inspiration from, we would still

need to build and design according to our needs, which only leads to more complexity in subject areas unfamiliar to us. Below we have a table outlining the comparisons between technology options and highlighting our choice.

	<b>Advantages</b>	<b>Disadvantages</b>
<b>Conveyor Belt</b>	Fully controlled ball transportation	Mechanically complex
<b>Flywheel Launcher</b>	Can launch into open basket	Hard to control launch speed
<b>Manual Collector</b>	Simple, complete design	Forced to design around existing collection device

Table 3.1.2.4: Ball Collection Comparison

### 3.1.3 Sensing

One of the constraints of a mobile robot that patrols around people playing a sport like tennis is the need to see potential obstacles. For an autonomous tennis ball collector, detection of the tennis balls themselves is also essential. These are two separate requirements with opposing purposes that need to be handled by the same system.

#### 3.1.3.1 Computer Vision

One way this can be accomplished is with computer vision, or the use of cameras and software to have the robot see and assess its surroundings similar to how a living being would. Computer vision has a few important requirements to be used in a design like this. The first would be a proper camera to be able to see the varying colors and outlines of important objects in its operating environment. While this does not require full color images for such a specific use case, it does depend on image quality and software complexity to work effectively.

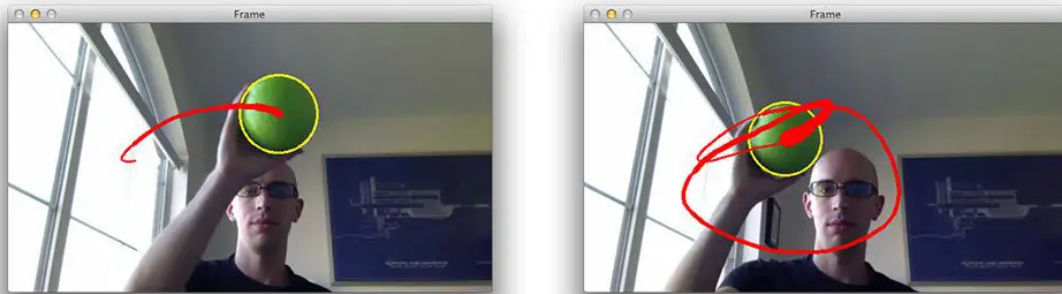


Figure 3.1.3.1.1: Example of ball recognition and tracking using computer vision.  
Reference from  
<https://pyimagesearch.com/2015/09/14/ball-tracking-with-opencv/>

Distance of seen objects can also be determined with computer vision through various means. One way is by comparing known object sizes in a real unit of measurement (like inches or centimeters) with their size in pixels in the camera's image. Another common method, especially for robotics, is to use stereo vision (two cameras aimed in the same direction) to calculate distance. This method is most similar to human depth perception as it emulates having two eyes.

The most important aspect of computer vision to consider when applying it to a system like the tennis ball collector is processing power. Still image processing is already known for being a demanding software workload, so to have an embedded system scan an ongoing video feed can be a challenge for the relatively small processor. This means that the MCUs most qualified to handle computer vision processing in real time along with control of the rest of the system will be much more expensive than we would like to use in a low cost, low power design.

The alternative is to offload image processing to a dedicated premade machine with the ability to communicate with our own design. Raspberry Pi boards are popular for projects involving heavier processing in a small, affordable form factor. In this case we would treat the extra board as just another sensor with a single output, making it effectively similar in function to a simple ultrasonic sensor.

Computer vision algorithms are not perfect and are prone to interference and misinterpretation, especially in cases where it can mistake a simple shape of one object for a similar shape of another. The following is a possible example for our use case: a computer vision algorithm dedicated to finding the white line that marks the edge of the tennis court could see the net, whose border could be similarly straight and white, and wrongly deduce that the net is part of the outer boundary of the court. False positives can be reduced with improved, more

sophisticated software, but even the most intelligent algorithms available today are not perfectly accurate.

### 3.1.3.2 Simple Sensor Array

A more common option for low cost projects is to use simpler sensors with dedicated roles. Simple sensors like ultrasonic sensors send analog signals that can be interpreted in software as individual values from specific pins with dedicated variables as opposed to the large arrays of data that images are often interpreted as. Since the range of these signals is always known and typically stored as a single variable, software that tracks and reacts to changes in these values are often easier and faster to write and run than the image processing algorithms necessary for computer vision.

A specific example of this kind of sensing can be seen in crash avoidance systems commonly found on modern automobiles. Cars are fitted with proximity sensors along each side, which keep track of the distance of any object approaching or near the car, such as other vehicles, people, or stationary objects like sign posts and poles. Other examples of simple sensors include light sensors and thermal sensors, which are usually as simple in construction and interpretation as a resistor. In modern systems, these sensors often supplement other more sophisticated sensors and algorithms, meaning they can be used to enhance those systems even further.

One significant disadvantage of using simple sensors only is the fact that these sensors are typically more prone to error. This can be due to signal interference, misinterpretation of sensing information, or low precision hardware. When designing with a microcontroller, more sensors also translates to requiring more physical pins on the MCU needed to take in each individual sensor input. This issue can be remedied with secondary controllers that are dedicated to interpreting sensor inputs before passing the signals to the main controller in a more manageable form.

### 3.1.3.2 Combination of Simple and Advanced Sensors

One way to make up for the drawbacks of the simple sensor array is to incorporate a more sophisticated and accurate sensor, like LiDAR (Light Detection and Ranging) sensors or infrared cameras. These sensors may not perceive their environment as well as a camera and a computer vision algorithm would, but they can ensure better accuracy and range of sight than most simple proximity and light sensors. A combination of these two classes of sensors could be utilized to create a middle ground between the price and necessary processing power of the advanced sensors and the simple sensors while also covering each type of sensor's weaknesses and sources of error.

For the purposes of this design, most advanced sensors would be too expensive for practical use and not necessary for the specific needs of the operating environment. We are fortunate to be working in a relatively limited environment

with few significant objects to keep track of, so an advanced sensor would perform almost as well as carefully positioned and monitored simple sensors with greater demands in power, software, and overall cost.

### 3.1.3.3 Final Comparison

The decision between sensing methods is one constrained by processing power and cost more than anything. While more sophisticated sensing systems create more accurate world views and reduce overall issues with sensing, we aim to create a lower power cost efficient design, so compromises had to be made. Computer vision was ultimately what was decided, but with the caveat of using a separate processor just capable of processing images and just that. Since simple sensors are very affordable, they will also be used to supplement the computer vision system, helping to cover any of its weaknesses and create a more complete worldview for the robot.

	<b>Advantages</b>	<b>Disadvantages</b>
<b>Computer Vision</b>	Accurate and wide range of vision	High processing demand, expensive
<b>Simple Sensor Array</b>	Simple software, low cost	Low precision, less information to interpret accurately, must have enough input pins on MCU
<b>Combination of Simple and Advanced Sensors</b>	Covers weaknesses of other sensors	Advanced sensors remain too costly for the benefits they can provide

Table 3.1.3.3: Sensing Design Comparison

## 3.1.4 Power

### 3.1.4.1 User-Charged Battery

Power to robots like these is often provided via a battery that is charged when not in use. This means that the capacity of the battery is an important aspect to keep in mind, as a smaller battery results in shorter intervals without charging, but a larger battery comes with the drawback of greater weight that motors controlling movement have to compensate for, which in turn creates higher demand for more power capacity. This creates an inconvenience for the user of the ball collector, so we feel we need to automate powering the robot.

### 3.1.4.2 Charging Dock

Many domestic robot designs, like those produced by iRobot, utilize a charging dock that the robot can navigate to on its own, effectively automating the process of charging the battery. This dock design has an added complexity of requiring the robot to be able to navigate to the dock on its own. This dock design would also be drawing power from another source, most likely a wall outlet. The issue with this method is the fact that the tennis ball collector is intended to work outside, where power outlets are not expected to be accessible.

### 3.1.4.3 Solar Power

The robot being used outside provides us with another possible method of obtaining power, solar power. Solar power ensures a near constant source of power with no need for external hardware, including a charging dock. Solar power is also a renewable source of energy that helps us create an eco-friendly design that avoids wasting non-renewable resources in a time when climate consciousness is considered a very important topic in current events.

One major issue with a solar powered design is the dependance on the sun for operation. In other words, the tennis ball collector would only be operable during the day and work most consistently on days with clear skies. A battery would still be necessary to use with the solar panels since solar power tends to fluctuate with various environmental factors, such as cloud cover, shadows, and sun intensity due to time of day. Using solar panels for power also encourages us to make a frame with greater surface area to absorb more sunlight to use for power. To aim for a design with a smaller battery or smaller frame would force us to be more power efficient to make up for the loss in power gain or storage.

### 3.1.4.4 Final Comparison

The decision for the method to power the system was derived more from the goals and expected use of the design than anything else. As the collector is expected to be both mobile and used outside, solar power seemed to fit our needs for the design best and added something unique and useful to the robot. There have been many examples of tennis ball collectors and similar purpose domestic robots, but many of them prefer the other power options discussed.

While the larger battery is the typical choice, batteries are known to add excessive amounts of weight we can not afford to compensate for.

Charging docks and other automatic charging methods fulfill the autonomy focus for our design but are inconvenient for use outdoors. The use of solar panels alleviates most of the problems we would encounter with other power methods while remaining user independent. For the specific purpose of this project being a way for us as students to show what we know about electronics, using solar power helps with standing out and testing our knowledge. Despite the disadvantages, the solar powered design seemed to be the obvious choice when compared to other options. A table summarizing the comparison and highlighting our decision is shown below this section.

	<b>Advantages</b>	<b>Disadvantages</b>
<b>Large Battery</b>	Long intervals between needing to recharge	Heavy and large, demands more motor power
<b>Charging Dock</b>	Automatic charging	Requires other power source
<b>Solar Power</b>	Smaller battery, constant power	Requires sunlight which fluctuates in intensity

Table 3.1.4.4: Power Design Comparison

### 3.1.5 Programming Language

This section concerns the language used to program the MCU on the board we design and does not involve the language used for the computer vision system. This will be further discussed in the section specifically for software design further in the document.

#### 3.1.5.1 C

C is one of the most popular languages for programming on MCU devices, meaning it has a good reputation for compatibility across a wide range of applicable devices. C is an older, low level language, meaning it runs quickly with little overhead once compiled, which is perfect for smaller devices with limited memory and processing power. C has no automatic memory management, unlike most newer programming languages. This means that C offers more direct

control over hardware memory than higher level languages, which is very useful when programming for smaller chips with limited memory like those used in embedded systems.

The tradeoff with C has to do with debugging and the heavier burden on the programmer to find and manually fix issues. If a program written in C runs into an exception, the error logs provided do not provide useful information for debugging when compared to newer languages. Integrated development environments (IDE) are commonly used to help with this process, but often do not have the ability to fully debug software. When working on a physical controller, testing will likely have to be done on a prototyping board, which adds one more layer of possible error to the debugging process.

Most MCU manufacturers have function libraries made in C for their microcontrollers which are often essential for programming the MCU. Some manufacturers have their own IDEs, like Texas Instruments' Code Composer Studio, which help streamline development of software for their line of microcontrollers by automatically managing libraries for associated devices. Arduino offers a simplified IDE for their project boards (which are often fitted with Atmel microcontrollers) that is compatible with a wide range of microcontrollers thanks to their highly active amateur developer community and open source software.

### 3.1.5.2 C++

C++ is very similar to C, as C++ is effectively an upgrade to C with new functionality. C++ allows for object oriented programming, which differs from the explicitly manual memory management utilized in C, where all data is stored as a primitive variable type or an array of variables typically located adjacent to each other in memory. While working with objects simplifies the development process and opens new possibilities for development, the new object variables tend to take up more space and will become slightly more demanding on hardware, which is something we want to avoid as much as possible when programming for microcontrollers. C++ is still a lower level language like C since it also lacks automatic memory management. C code can also be compiled with a C++ compiler with few compatibility issues, so it is also possible to avoid more intensive features of C++ while still utilizing new libraries for convenience. C++ shares C's issues with debugging but is often compatible with the same IDEs made to help with said issues.

### 3.1.5.3 Python

Python is a higher level language that has become very popular for use in almost all applications due to its simplicity and wide range of support. Python has become especially popular in robotics with a vast range of software made to control a robotic system with minimal code. Debugging in Python has also shown to be much simpler and straightforward than debugging in almost all languages that came before it, including C.

Despite all these advantages, Python is not used often in embedded systems, despite support from systems like MicroPython which are made specifically for developing in Python for microcontrollers. The main reason this is the case is Python's high overhead from being a very recent and high level language. Python's conveniences come with the drawback of running very slowly on less performative systems with limited memory and power. Python is also not often officially supported by MCU manufacturers, meaning we would be reliant on user made libraries with sparse or poor documentation.

Because of this, Python is not recommended for use in real time systems like the one we are designing, though immediate reaction to environmental input is not a strict requirement of a tennis ball collector that runs continuously.

#### 3.1.5.4 Assembly

If C is considered a low level language, assembly language is even lower level. Assembly is considered the lowest level programming language that can be read by humans in a reasonable amount of time, and even so requires a well trained programmer to work efficiently. Most programming languages, including C, are "compiled" into assembly language before being "assembled" into machine code, which is made of entirely numerical commands to be interpreted by the processor. What this means for programming in assembly is that it gives the programmer almost full control over the hardware they are working on. This level of control comes with almost no convenience or safety net, but at the same time as much efficiency as the programmer is able to create themselves. Efficiency and control makes assembly a strong contender for a low power embedded programming language.

The deciding factor for programming in assembly depends on the system it is being developed for. Different processors and controllers can have different assembly languages with different capabilities and commands, as these are defined by the manufacturer and not guaranteed to be standardized across different product lines, so development support for any specific microcontroller's assembly language is likely very limited. This almost guarantees a level of difficulty and room for error far beyond that offered by C, which means it is not a likely choice for this design.

#### 3.1.5.5 Final Comparison

While the ultimate decision for a programming language is more decided by the capabilities of the specific microcontroller that we use, we can still have a preference to help guide our decision for the model of microcontroller. The most convenient language would be a modern high level language like Python, but has the drawback of running slowly and inefficiently on a low power system. While this implies that a lightweight, low level language would be better suited to embedded programming, a language as low level as Assembly would be detrimental to development time as it is hard to debug and is more prone to

human error. The most preferable choice would be somewhere between these two extremes.

Conventionally, programming for embedded systems is done in a modified C or C++ language, which are among the more preferable languages to use. C is a common language for electrical and computer engineers to use for a variety of applications, so as students in this field, we are all most familiar with this language. Personal preference would promote a language with automatic memory management, but this isn't a feature that is common or recommended to use in embedded programming. Finally, the top contender for preferred programming language is C, due to its efficiency, wide availability, and our familiarity with it when compared to other languages. Below is a table summarizing the comparisons between the various options for programming languages.

	<b>Advantages</b>	<b>Disadvantages</b>
<b>C</b>	Fast and efficient, wide range of support	Difficult debugging, longer code
<b>C++</b>	Simplifies C code	Same as C, plus slightly less efficient
<b>Python</b>	Widely supported, easy to read and debug	Runs slow on MCUs, less support for embedded systems specifically
<b>Assembly</b>	As efficient as possible, full control over hardware	Difficult to read and write, sparse support

Table 3.1.5.5: Programming Language Comparison

## 3.2 Part Selection

### 3.2.1 Motors

Motors are a big part of our project. The motors we choose will have to account for all the movement our robot will make. The motor we choose has to be able to meet the power constraints of our robot. It also has to be able to propel the entire weight of the robot. When it comes to motors there are 4 different types which we will have to consider. Each type has its own advantages and disadvantages.

#### 3.2.1.1 Brushed Motors

A Brushed motor is an electric motor that works by using a direct current. The direct current in the motor is caused by the use of electromagnetic induction. A brushed motor consists of 4 main parts: the Rotor, Stator, Commutator, and the Brushes.

1. Rotor: The rotor is the part of the motor that rotates. The rotor has two parts to it. The first part is the central shaft, the second part are the electromagnets which are mounted onto the rotor itself. The magnets on the rotor are affected by the magnetic field from the magnets on the stator. This in turn makes the rotor rotate when the motor is on.
2. Stator: The stator is the part of the motor which stays stationary. The stator consists of a various number of electromagnets. Each magnet is then wound by copper wire. Once an electric current is passed through a magnetic field is produced.
3. Commutator: The commutator is a conductive cylindrical surface that is attached to the rotor shaft. It works in unison with the brushes. Each different piece of the commutator is electrically insulated.
4. Brushes: The Brushes are a big part of this motor. The main job of the brushes is to provide an electrical current to the rotor. This is achieved by the brushes making constant contact with the commutator, this then switches the direction that the current is flowing so that it reaches the windings of the rotors.

Brushed Motors are very common in the market today. They have been found in a variety of different appliances, power tools, etc. However, Brushed motors come with their advantages and disadvantages. The advantages are they are very easy to operate and control, they are available in many different ratings and sizes, and they are very cheap. The disadvantages to brushed motors is they run hotter, they have a shorter life span, and they require more maintenance. [GPTD]

### 3.2.1.2 Brushless Motors

Brushless motors are seen to be the successor of Brushed motors. Brushless motors are very similar to brushed motors except they are missing a few crucial components that are found in Brushed motors. Brushless motors are missing the commutator and the brushes themselves. The stator and the rotor also have different configurations compared to brushed motors.

In Brushless motors the Stator has a bunch of electromagnets. The Rotor is the one that contains a bunch of permanent magnets. Since there is no commutator and brushes to switch the direction of the current to make the rotor spin, the electromagnets in the stator have to rely on the microcontroller to take control of sending the current. The microcontroller determines which way the current is flowing, this then creates a rotating magnetic field. The rotating magnetic field then has an effect on the permanent magnets that are located on the rotor causing them to spin.

Since there are no commutators or brushes in brushless motors. This causes there to be a whole new set of advantages and disadvantages. The main new advantages that brushless motors have are greater reliability and efficiency, they are very precise, they can provide a lot of power for their weight and size dimensions. The disadvantages are brushless motors tend to be more expensive, they require a microcontroller to run, and as a whole are more complex to operate.

Brushless Motors are very common and are found in a lot of newer products. They are very common to find in drones, robotics, electric vehicles, etc. It is safe to say that anything that requires reliability, precision, and efficiency will most likely use a brushless motor at some point in the manufacturing process. [GPTE]

### 3.2.1.3 Servo Motors

Servo motors are very precise motors. They are used when you want great control of velocity, positioning, and acceleration. With this in mind there are two different types of Servo motors. You have your Alternating Current (AC) or the Direct Current (DC) Servo motors. AC servo motors are mostly used when you want to push a very large current as they will withstand it better. Whether the servo motor is AC or DC they are made up of the same major components.

1. Feedback Device: Typically, an encoder or a potentiometer are incorporated into the servo motor to relay back information to the controller. This information sent back ranges from velocity, position, etc.
2. Control Circuitry: A controller is used to take control of the servo motor. This is a closed loop system. The motor controller sends and receives signals from the microcontroller to make sure the motor is where it is supposed to be at.

3. Gear Train: The purpose of the gear train is providing precision in the position of the motor. To achieve this precision the gear train works to drop the velocity of the motor, this then leads to an increase of the amount of torque that is provided by the motor.
4. Motor: The motor is used to push the system. The motor is usually a simple DC motor. The use of permanent magnets helps to create the electromagnetic field for the motor to spin and rotate.

Servo motors have different advantages and disadvantages in their own right. The advantages of servo motors are they are compact in size, precision in positioning, compact size, etc. The disadvantages range from Jitters, and a limited range of motion. Jitters are caused by the feedback system trying to correct any drift. This will make the motor constantly twitch to try to get in the best positions.

Overall servo motors are very common and widely available. They are used a lot in the fields of robotics, RC cars, etc. Wherever you need precise control you can find a servo motor. Since servo motors are very common they come in a lot of power ratings and different sizing. [GPTF]

#### 3.2.1.4 Stepper Motors

Stepper motors are brushless DC motors. They take digital pulses and convert them into mechanical rotations. Stepper motors thrive when the input signal is a digital pulse and not a typical analog voltage. A normal brushless motor continuously rotates; however, a stepper motor moves in small increments like taking steps. The number of steps taken, and their size depends on the design of the motor.

A Rotor and Stator are present in stepper motors. The Stator has multiple coils that when charged with a current create a magnetic field that helps to rotate the Rotor. The rotor consists of a toothed core and a bunch of permanent magnets. The stator is the stationary part of the motor while the Rotor is the only part that rotates. All stepper motors consist of these parts but there are three different subdivisions of stepper motors that can be defined.

1. Variable Reluctance Stepper Motors: This type of stepper motor has both toothed stator poles and a toothed rotor core. Due to the magnetic attraction between the two the stator poles and the rotor core are aligned. This allows them to be for a higher drive, but they will offer less torque.
2. Permanent Magnet Stepper Motors: These stepper motors are the basic ones where the permanent magnets on the Rotor are caused to move by the magnetic field caused by the charged windings on the Stator. These stepper motors will provide a great amount of torque but will provide less drive.

3. Hybrid Stepper Motors: The Hybrid Stepper motors provide the best of both worlds. With a combination of permanent magnets and toothed core on the Rotor, and multiple windings with toothed poles on the stator. These stepper motors are able to deliver a great amount of torque and drive.

Stepper motors are very common in 3D printers, robotics, and automation systems. They are very precise and very easy to use. A big takeaway from stepper motors is that they do not need any external feedback to figure out where they are. This allows them to keep their position and have great control in taking small steps. [GPTG]

### 3.2.1.5 Motor Comparison and Selection

Overall, there are 4 great different motors that we can choose from for our tennis ball collectors. Each motor has their specific advantages and disadvantages that will help us to decide which is best for us. A big thing we need to overcome is the price of the total project. We want to make sure our tennis ball collector is economically tangible. The motors can range from very cheap to very expensive. It mostly depends on how much power we are hoping to get from the motor. The amount of power we will need is dependent on the weight of the tennis ball collector itself. To compensate for this we collected the average price points for the motors on the low and high end.

	Low End	High End
<b>Brushed Motor</b>	\$10	\$239
<b>Brushless Motor</b>	\$16.58	\$413.99
<b>Servo Motor</b>	\$7.29	\$588.23
<b>Stepper Motor</b>	\$6.99	\$971.01

Table 3.2.1.5.1. Pricing of Different types of Motors

As you can see these motors can be either very cheap or very expensive. We have to accommodate the fact that we will most likely have to have two different motors for the tennis ball collector to function and drive. With this being said the motors we choose will probably be a little more expensive than the cheapest ones to make sure that they can deliver the amount of power that we need.

The advantages and disadvantages of each motor will also play a great part in the one that is chosen. Each motor is suited best for a different tasks, so by comparing our needs and wants to the advantages and disadvantages of the motors we will be able to choose the best motor for us

	<b>Advantages</b>	<b>Disadvantages</b>
<b>Brushed Motor</b>	<ul style="list-style-type: none"> <li>• No controller is required</li> <li>• Easy to Control</li> <li>• Good on lower duty cycles</li> <li>• Simple to operate</li> </ul>	<ul style="list-style-type: none"> <li>• Require a lot of Maintenance</li> <li>• Terrible Heat Dissipation</li> <li>• Lower Speed Range</li> <li>• Can be noisy</li> </ul>
<b>Brushless Motor</b>	<ul style="list-style-type: none"> <li>• Very Efficient</li> <li>• Very reliable</li> <li>• Longer life Span</li> <li>• Less Maintenance</li> <li>• High Power Density</li> </ul>	<ul style="list-style-type: none"> <li>• Expensive</li> <li>• Can be Very Complex</li> <li>• Can cause a lot of electromagnetic interference</li> </ul>
<b>Servo Motor</b>	<ul style="list-style-type: none"> <li>• Great variety for different sizes and powers</li> <li>• Can be very cheap</li> <li>• Good torque at high speeds</li> </ul>	<ul style="list-style-type: none"> <li>• Jitters</li> <li>• Can be limited in their range of motion</li> </ul>
<b>Stepper Motor</b>	<ul style="list-style-type: none"> <li>• Easy to Control</li> <li>• Precise Positioning and Speed control</li> <li>• Can provide great torque at low speeds</li> </ul>	<ul style="list-style-type: none"> <li>• Not very efficient</li> <li>• Can skip steps</li> <li>• Can be very noisy</li> <li>• Not a lot of torque at high speeds</li> </ul>

Table 3.2.1.5.2. Advantages and Disadvantages of Different Types of Motors

At first we thought the best option was for brushless motors. Explained later on, in testing, we realized brushed motors ended up working better for us and that is what is on the robot in the end.

We started with the brushless motors. While testing the brushless motors we kept running into various issues and problems. The first issue was the motor would always want to travel at a certain speed. So, if the motor was slowed down with a load it would continue to force itself to reach the set speed. Once we tightened the wheels to the motors, the motors would try to spin but instantly cut out. This would then force the esc into low voltage protection. This is when we realized the brushless motors provided a great amount of speed but not torque. To combat this, we then switched to brushed motors. Since we switched the types of motors, we also had to change the ESCs. When we began testing the brushed motors it was clear that they provided a lot more torque. We tested two different types of brushed motors, before we ultimately decided to stick with them.

### 3.2.2 Gearbox Transmission

Our solar tennis ball collector weighs roughly 30 pounds. So, we need a good amount of torque to be able to make the solar tennis ball collector move. One of the ways to increase torque is to use a gearbox transmission. A gearbox transmission is composed of different sets of pinion gears. The pinion gears vary in ratio. The higher the ratio the more torque will be produced. However, there is a tradeoff with this, and this is that the higher the torque produced by the gears the slower the speed will be. The gearbox transmission works in the form of that there must be a minimum of two gears and the driving gear is the smaller gear connected to the motor. The motor spins the driving gear, this causes the driving gear to spin a larger gear.

Common Gear Ratios	Torque	Speed
1:1	-	-
3:1	↑	↓
9.76:1	↑↑	↓↓
16.6:1	↑↑↑	↓↓↓
40.3:1	↑↑↑↑	↓↓↓↓

Table 3.2.2.1: Common Gear Ratio With Torque and Speed Comparison

Testing these gearboxes has proven to be a tedious task. Normally to get the necessary gear ratio you need you can use the equation  $Torque_{output} = Torque_{input} \times Gear\ Ratio$ . However we cannot use this equation. As we are using hobby style motors the datasheets are very vague and lack some details. So, to find the perfect gearbox for us we ordered two gearboxes for each of the different common gear ratios. One by one we have been attaching them to the solar

tennis ball collector and running the motors to see which one provided the most torque and was able to make the solar tennis ball collector move on the ground.

### 3.2.3 Solar Panels

The Solar tennis ball collector gets power by solar panels that are attached on top of the robot itself. This renewable energy is more efficient and environmentally friendly. Our goal for using solar panels is to exterminate the use of big batteries and any other power sources. Nowadays, people prefer using renewable energy sources such as solar panels. Instead of getting power from batteries and carbon footprints it is far more beneficial to get power from renewable resource such as the sun. The sun gives energy with photons to solar panels. This process is called the photovoltaic effect. More sunlight means more power. Solar panels produce renewable energy with the transformation of sunlight to the small battery and from that to electricity.

#### 3.2.3.1 Types of Solar Panels

There are different types of solar panels. Such as, monocrystalline solar panels, polycrystalline solar panels, amorphous silicon solar panels, copper indium gallium selenide solar panels, passivated emitter and read solar panels, and cadmium telluride solar panels. Each one of them has its own advantages and disadvantages based on equipment that they are being used on. There are thin film solar panels and thicker solar panels. Thicker solar panels are called crystalline silicon solar panels. Efficiency wise, thin layered solar panels are not as strong as crystalline silicon solar.

		Efficiency
<b>Thin Film Solar Panels</b>	Amorphous Silicon	7%
	Copper Indium Gallium Selenide	12% to 14%
	Cadmium Telluride	9% to 15%
	Monocrystalline	15% to 30%

<b>Crystalline Solar Panels</b>	Polycrystalline	14% to 18%
	Bifacial Crystalline	20% to 38%

Table 3.2.3.1: Types of Solar Panels and their efficiency

As we can see in the table above, crystalline silicon solar panels produce higher efficiency than thin film solar panels. However, it is important to acknowledge that a solar-powered tennis ball collector operates on a smaller scale and does not require the same level of power as our regular household or daily activities.

Thin film solar panels are mostly used with bigger batteries. Since we are trying to avoid using bigger batteries, it is far more beneficial to prioritize usage of crystalline solar panels to decrease usage of bigger batteries. One of the well-known usages of thin film solar panels is in remote powered devices. Our project is not going to use any remote powered devices. That is another reason to not use thin film solar panels in this project.

The advantage of using thin film solar panels is their flexibility. It is easy to attach in curved areas. Users can easily position thin film solar panels depending on their choice. However, we are going to position the solar panel on top of the robot. The top of the robot is not going to be curved or arched. That is why the usage of crystalline solar panels is more beneficial for us. Meaning, we do not need to worry about curved surfaces to locate solar panels. [GPTA]

<b>Types of Solar Panel</b>	<b>Average price per 40"x20"</b>
Monocrystalline	\$95
Polycrystalline	\$74
Bifacial Crystalline	\$97

Table 3.2.3.1.2: Average crystalline solar panel prices.

Monocrystalline solar panels are going to be our choice in the solar panel section. There are different kinds of solar panels that will work and function in our

project. However, a monocrystalline solar panel is most suitable equipment for our robot, because of the efficiency that it gives.

### 3.2.3.2 Solar Panel Analysis

In order to determine the proper type of solar panel, we have to know some factors. Such as panel size, output power requirements, efficiency, and so on. Below is a table showing the calculations for analyzing solar panel characteristics.[GPTB]

Description	Equation
Power consumption of Robot	$P$
Efficiency (type/quality of solar panels)	$e$
Solar irradiance (weather, shade, sun light, time of the day)	$I$
Total power for robot	$P_t$ =Sum of all overall power consumption. (Sensors, motors, weight, etc.)
Power needed from solar panel	$P_n = \frac{P_t}{e}$
Area of solar panel should be same or slightly smaller than dimension	$A = \frac{P_n}{I}$
Approximate efficiency (%)	$E_f$

Solar irradiance ( $\frac{W}{m^2}$ )	$S_i = \frac{\text{Solar power}}{A}$
Panel Size ( $m^2$ )	$P_s = \text{width} * \text{height}$
Output Power (watts)	$O_p = P_s * S_i * E_f$

Table 3.2.3.2: Solar Panel Analysis

If we take monocrystalline solar panel with efficiency of 17%, solar irradiance 1000 watts per square meter ( $\frac{W}{m^2}$ ), and panel size of  $0.173 m^2$  (20" width, 14" height), our output power will be  $\approx 29.41$  watts if we put numbers to the given equations above.

### 3.2.3.3 Monocrystalline Solar Panels

Monocrystalline solar panels are far more beneficial to use in comparison to thin film solar panels. As mentioned in the table above, efficiency is higher on monocrystalline solar panels. Meaning, it guarantees sunlight to be directly converted into more usable power with the parts that we are having in the solar tennis ball collector.

Monocrystalline solar panels are one of the most known for its superior performance and well-known solar panels in the industry. These panels are known for their reliability too. As we know that, monocrystalline solar panels have lots of advantages. Nonetheless, they come with disadvantages that we have to consider. Such as,

- Performance in different weather conditions
- Cost
- Weight
- Non-flexible
- Fragility

Monocrystalline solar panels can be low on performance when weather conditions change. If a solar tennis ball collector is being under shade or experiencing bad weather conditions, then there is going to be a higher chance that the robot will not reach its peak performance. The cost of monocrystalline solar panels is not the same as thin film solar panels.

As we can imagine, thin film solar panels are going to be cheaper in comparison to bigger, bulkier, heavier solar panels. In order to increase size, weight, and efficiency, people use different materials to provide them. The price of manufacturing is going to be expensive in comparison to thin film solar panels.

As mentioned above, the weight of monocrystalline panels is one of the major disadvantages of solar tennis ball collector project. The output power requirements of solar tennis ball collector are typically affected by its weight. Thin film solar panels provide weight reduction, but they have lower efficiency in comparison to monocrystalline panels. Although they may add extra weight to the robot's system, but improved efficiency balances necessary output power. Unlike thin film solar panels, monocrystalline solar panels are not flexible, and they can get resilient cracks and damages from nature. Meaning, monocrystalline solar panels require cautious installation to avoid any exterior stress cracks or other damages.



Figure 3.2.3.3.1: Thin film solar panel & crystalline solar panel. Reference from <https://www.linkedin.com/pulse/incredible-facts-solar-panel-part-ii-amit-thussu/>

### 3.2.4 Sensors

Solar tennis ball collector robot is going to have sensors and computer vision to detect tennis balls and tennis courts. Nowadays, different types of devices use various kinds of sensors to detect specific objects or distances. For instance, smart vacuum cleaners, smart robot suitcase, smartphones, thermostats, safety cameras, and others. All of these devices use different kinds of sensors to detect objects or distances. There are motion sensors, temperature sensors, sound sensors, contact sensors, pressure sensors and other sensors to measure different kinds of measurements.

Solar tennis ball collectors use sensors that are related to detect objects and distance. Sensors are ultrasonic sensors, limit switch bump sensors, and a camera. Each sensor has its own advantages and disadvantages based on the

solar tennis ball collector. All 3 sensors are well known and commonly used sensors in the robot industry field. These sensors have been well-established themselves in many widely recognized devices, helping to interact robots with the real world.

At the beginning we chose Infrared distance sensors to detect tennis court lines. GP2Y0A21YK0F sensor had the ability to detect tennis court lines, but it was not enough for us. However, after testing them we decided not to use them and changed it with Raspberry Pi Camera Module 3. Infrared distance sensors were giving us a hard time to detect lines and we did not want to lose time and we put that time to computer vision.

There were 3 pins, 1 receiver and 1 emitter. Pins are VCC, GND, and OUT. VCC is supply input which is going to be from 3.3V to 5V. GND stands for ground and OUT stands for output.

	<b>Advantages</b>	<b>Disadvantages</b>
<b>Ultrasonic Sensors</b>	Accurate sensing of shape, color, distance, material. High frequency. Not affected from dust, snow, rain	Change in temperature over period of time
<b>Infrared Sensors</b>	Perfect for objects that are in close distance	Frequencies affected by smoke, dust, light
<b>Infrared Distance Sensors</b>	Expanded detection range	Weather conditions
<b>Proximity Sensors</b>	Rapid switching rate	Negative effect of humidity and temperature

<b>Limit Switch</b>	Easy to use with other technological sensors, Costs low	Wear and Tear
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Table 3.2.4: Comparison of Sensors

The table above shows us the advantages and disadvantages of each sensor. We can clearly see that proximity sensors are not beneficial for the solar tennis ball collector. Since robots are going to be used outdoors, it is important to prioritize weather conditions and the surrounding environment. Let's take an example of Florida state. Our demo product will be made in Orlando, and central Florida weather is known for its humid weather conditions. There is a high likelihood that the sensor may fail while testing the product in Florida.

Infrared sensors are well-known sensors worldwide. They are perfect for detecting small objects in close and far distances. Frequency range is almost as good as ultrasonic sensors, and it is also known for its rapid switching rate similar to proximity sensors. However, frequencies are getting affected by particles, such as dust, smoke, light and others. Solar tennis ball collector is being made for outdoor use. As the players will be playing outdoors, it is important to consider the presence of dust and other natural particles that are going to have an impact on the performance or accuracy of the sensor's frequency..

Ultrasonic sensors are an ideal option of sensor that can be utilized and reach its optimal performance. Firstly, we planned to use this sensor to detect a ball while being at an outdoor tennis court. However, we decided to use an ultrasonic sensor as a safety sensor for the solar tennis ball collector. There are not going to be any issues with nature particles or weather conditions. However, one main disadvantage of ultrasonic sensors is weather change. If weather changes instantly, the sensor may not perform at its highest performance. For instance, if the weather changes from sunny weather to rainy weather immediately, then the sensor will not perform as it used to be. At the same time, the majority of people stop their tennis game because of rapid weather change.

It can be challenging to know a robot's response when it will contact an object other than tennis balls. Nowadays, smart vacuum cleaning robots use bump sensors to help robots to know when it hits a wall or any other objects. It helps smart vacuum cleaning robots to adjust its way and to continue doing its job. Most tennis courts are typically enclosed with a fence. It is for safety purposes. Our solar tennis ball collector robot can get stuck in fences if there will not be any bump sensors provided in the robot's system. We chose a limit switch sensor as our bump sensor to prevent collision with the fence.

We decided to use two sensors that are highlighted in table 3.2.3 which are an ultrasonic sensor, and a limit switch as a bump sensor. After researching their

prices and given outcomes, we can easily say that these two sensors are going to be the most beneficial sensors for our project.

### 3.2.4.1 Ultrasonic Sensor

Ultrasonic sensors have 4 pins which are,

- VCC: Also known as voltage common collector, comes the pin which gives sensors electrical power. It usually comes with 5V, and it's connected to the power supply.
- Trig: As we can see from the name Trig, it means Trigger. This pin is used to trigger a sensor to generate ultrasonic waves. That is when ultrasonic pulses are being released. Trig is an input pin.
- Echo: This pin is being used to receive echo when the sensor is being reflected back with ultrasonic pulse when it detects an object. The Echo pin is beneficial for calculating distance while ultrasonic pulse is being reflected back after determining an object.
- GND: It stands for Ground. This pin is connected to the ground.

Ultrasonic sensors are mounted on top of the robot, and it will be centered. Ultrasonic sensors provide high frequency sound waves. The sensor sends ultrasonic waves, and these waves hit an object that the ultrasonic sensor detected. After that, it sends sound waves back. While doing that process, an ultrasonic sensor detects objects, measures distance, analyzes time. The ultrasonic sensor that is being used for the solar tennis ball collector is HC-SR04. [GPTB]

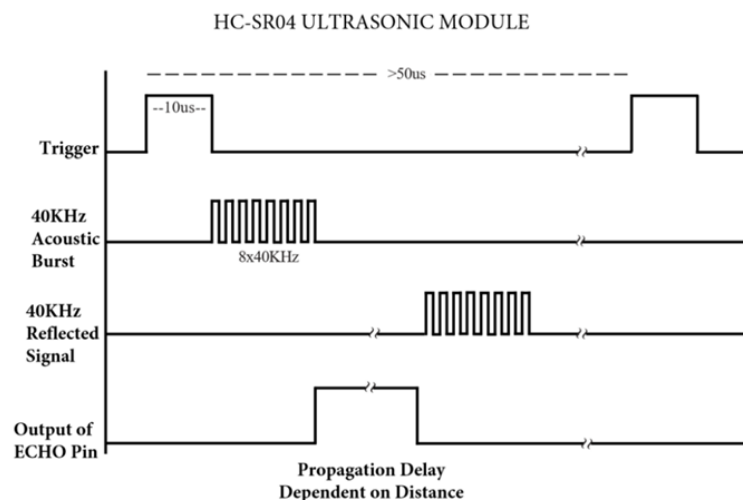


Figure 3.2.4.1.1: Representation of Ultrasonic pins. Reference from <https://www.microcontrollertips.com/principle-applications-limitations-ultrasonic-sensors-faq/>

Ultrasonic sensor starts to produce ultrasonic waves when it hits 40kHz of frequency. Trigger signal is 10  $\mu$ S for ultrasonic sensors. Acoustic bursts and reflected signals are shown as trig and echo pins.

<b>Voltage</b>	5V DC
<b>Current</b>	15 mA
<b>Frequency</b>	40 kHz
<b>Detecting object</b>	2 cm to 400 cm
<b>Measuring angle</b>	15°
<b>Dimension</b>	45x20x15 cm

Table 3.2.4.1. Main specifications of Ultrasonic Sensor (HC-SR04)

### 3.2.4.2 Calculations of Ultrasonic Sensor

To calculate distance, we simply do  $\frac{time * speed\ of\ wave}{2}$ . Time starts measuring when the sensor starts to send waves to detected objects, and it ends when the reflected wave reaches back to the receiver. Speed of sound is being measured with *ms* and it shows how fast the speed was starting from transmitter to the receiver.

<b>Time of flight</b>	$\mu$ S
<b>Speed of sound wave</b>	$\mu$ S/cm
<b>Range</b>	$\frac{time\ of\ flight * speed\ of\ sound\ wave}{2}$

Table 3.2.4.2. Calculations of Ultrasonic sensor

Approximate speed of sound will be  $\approx 29$  uS/cm at room temperature. It will give us  $\approx 45$ cm of range.

In figure 3.2.3.2.1, we can see how an ultrasonic sensor sends and receives waves back. There are transmitters and receivers built in ultrasonic sensors. When the sensor detects a barrier, the transmitter sends sound waves to determine the object instantly. After that, sound waves are sent back rapidly to the receiver. If an object is transparent or colorful it is still not going to stop ultrasonic sensors.

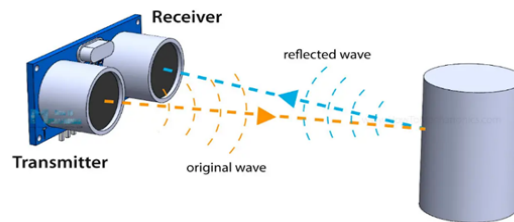


Figure 3.2.4.2.1: Ultrasonic sensor detecting object. Reference from <https://howtomechatronics.com/tutorials/arduino/ultrasonic-sensor-hc-sr04/>

#### 3.2.4.4 Limit Switch

Limit switches are known for detecting the presence or absence of an element. We cannot let robot roam around the tennis court without providing a sensor which will help the robot to detect collisions and turn on the designated degree that will be given to the robot. If a solar tennis ball collector collides with a fence or any other object besides tennis balls, it will find its own path with the help of a limit switch. The limit switch sends a signal to the robot's control system when it gets physical contact with any object. After sending a signal, the robot will receive specific action that needs to be done. It will be turning right, turning left, backing up, or changing direction in specific angles. There might be questions about how the limit switch will know that the tennis ball is not a fence or an object that will not let the robot move forward? If ultrasonic sensors will not be able to detect barriers such as fences and nets, then bump sensors are going to be in charge.

We use MS0850502F030P1A limit switch sensor in this project. This sensor is one of the famous bump sensors that a lot of technology companies use. As we all know, bump sensors can be expensive depending on their performance and manufacturers. MS0850502F030P1A sensor is a budget-friendly product and well-regarded for its performance which lets us use it in our solar tennis ball collector.

### 3.2.5 Tennis Ball Gathering Equipment

Nowadays, people use different kinds of equipment to collect tennis balls after players are done playing or while playing a tennis game. Such as, tennis ball hoppers, ball baskets, ball tubes, and others. During an official tennis match, the task of collecting balls are assigned to tennis ball boys or tennis ball girls. They make sure that tennis balls are being held in designated areas of the court.

As we all know it is hard to imagine having an enjoyable game with only one tennis ball. Players prefer to bring a collection of tennis balls to have an entertaining game. At the same time, players know that they have to collect balls after they run out of tennis balls in their pocket or in the storage that they keep tennis balls. It is common to see tennis balls dispersed around the tennis court area. Equipment that were mentioned above are the stuff that can make players have an easy way to collect balls and save some time. What if players wouldn't even need to worry about collecting tennis balls by themselves? What if players would spend more time playing tennis instead of collecting tennis balls? What if players would see a clear tennis court area while they play their favorite game? Solar tennis ball collector is going to give an easier and better solution for all of that.

As previously stated there are different tennis ball gathering equipment. Some of them are heavy, some of them are expensive, and some of them are not reliable.

Description	Estimate Price	Estimate weight
Tennis Ball Pick Up Tubes	\$26	3 lbs.
Roller Tennis Ball Collector	\$99	16 lbs.
Tennis Ball Hopper	\$55	6 lbs.
Tennis Ball Collector Mower	\$600	38 lbs.
Wire Racked Tennis Ball Collector	\$21	2.5 lbs.

Table 3.2.5. Tennis ball gathering equipment list that are on the market.

The majority of individuals prefer affordable, best quality, and dependable products in the market. They prioritize having equipment that is lightweight and easy to use. All tennis ball pick-up tools that are shown above rely on manual operation of individuals. Let's take an example of tennis ball pickup tubes, tennis ball hopper and tennis ball mower. These two products work differently. Pickup tubes require people to walk around and manually pick-up tennis balls by bending down and using tubes. Tennis ball hoppers require collecting balls by hand and dropping them to the hopper. Lastly, a tennis ball mower requires people to walk around and control the mower manually in the direction that they are walking.

Wire racked tennis ball gathering equipment is the cheapest way for people to collect tennis balls. The average weight of a wire racked tennis ball collector is about 2.5 lbs. It is based on products that are on the market.

We chose a wire racked tennis ball collector as the one and only equipment for collecting tennis balls. It is the cheapest and most reliable tool that we can use in our robot.

### 3.2.5.1 Wire Rack

The wire racked tennis ball collector is the convenient, easiest, and most efficient way to collect balls for the solar tennis ball collector robot. It is oval shaped with carbon steel wires. As it was mentioned, the whole product weighs 2.5 lbs. Products that are in the market come with upper roller, handle, and wire racked pick up roller. Most companies offer 3 types of size in wire racked pick up rollers. Which are small, medium, and large. Only wire racked pick up roller weights are around 1lbs. The remaining weight consists of a handle and upper roller.

We chose to use only the wire rack of the product. Which are going to be beneficial for us. Benefits of using only wire rack are,

<b>Lightweight</b>	Wire Rack weighs only 1 lbs. to 1.2 lbs.
<b>Easy to Customize</b>	Wire racks can be bent into a group formation to access tennis balls to enter easily to the storage.
<b>Material</b>	Carbon Steel
<b>Durable</b>	Rust and water resistant

<b>Function and Performance</b>	Can gather from 3 to 15 balls depending on a size
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Table 3.2.5.1. Specifications of Wire Rack ball gatherer.

The wire rack is made of carbon steel and is flexible and elastic. It helps tennis balls to enter the wire raked cage easily. The product is rust and water resistant which helps the robot to have longer life and the best outcome. The primary reason for choosing a wire rack as our tennis ball gatherer is its being lightweight. Wholesale of wire raked tennis ball collector equipment is around \$21. Oval shaped wire rack will be around \$6-\$7. We are going to use only the oval shaped roller of the wire raked tennis ball collector product. As previously stated, if the tennis ball collector is going to be lightweight, our solar panel system will ensure a well-balanced weight distribution strategy for our project. Wire Rack can gather up to 15 balls if it is going to be the largest selection. However, we are not going to use the largest wire rack. We are going to use a medium wire rack which will hold 3 to 10 balls. The average tennis ball size is 2.6 inches. The weight of a tennis ball is 2 ounces (57 grams). If there are 5 tennis balls inside the cage, it will weigh 285 grams. Figure 3.2.4.1.1 shows what a wire rack looks like.



Figure 3.2.5.1.1 Wire Roller. Reference from <https://www.macshardware.com/2863372/product/garden-weasel-95404>

It may be difficult to visualize how a tennis ball can stay inside of a wire rack without falling out of it. Due to the elastic design of carbon steel wires, they have the ability to get the same shape after tennis balls are going to be placed inside the wire rack.

The starts rolling when the motors start to activate. After the motors are activated, the robot will start moving. Imagine a wire rack as a big wheel in front end of the device. It rolls and balances equipment. It minimizes usage of wheels, and it gives better stability for our robot. It will be attached to the right and left side of the front end of the frame. Sensors are going to be located on top of the

frame. That means, the wire rack will not have any overlapping component that will stop its functioning.

### 3.2.6 Frame

The frame of our robot is a very crucial part of our project. For the design we decided to go with a very simple design practically like a box. The frame will house all our components from the battery, PCB, motors, etc. Since our robot is going to be operational outside, we have to make sure that the frame can withstand all the elements. We also want to make our frame as lightweight as possible; this will help to lower the required power our motors would have to produce. There are various materials that we need to consider when designing and building our frame.

#### 3.2.6.1 Wood

Wood is a very common and simple material to source. Wood is very durable and can handle dealing with almost all the outside elements. The only one we would have to account for is the rain seeping through the frame. Depending on which type of wood it can be a very lightweight material. The frame would also be very easy to put together, it would just require a couple of 2X4 hinges and screws. Overall wood is a solid option when it comes to building our frame. We would just have to find a solution to make sure the electrical components inside do not get wet when the tennis ball collector is exposed to any rain.

#### 3.2.6.2 Cardboard

Cardboard is another option we have discussed as a group for the frame of our tennis ball collector. Cardboard would be the easiest and cheapest of all the materials to source. It is also the easiest to put together. However, this ease comes as a big issue. Cardboard is biodegradable. Once exposed to the outside elements the cardboard would start to break down. This would make it very hard to keep the electrical components. Our robot is safe and in working conditions.

#### 3.2.6.3 PVC

PVC is a very solid option. The idea here is we would buy flat PVC boards and build a box out of it to store our electrical components. PVC boards can easily be found in any hardware store and are inexpensive in the grand scheme of things. They are also water resistant so they will handle the outside elements well. The only concern when it comes to PVC is it can get pretty heavy depending on the amount you use. In our research we found that a square foot of PVC weighs approximately two and a half pounds. If we were to use about 3 square feet of PVC this would add about 7.5 pounds to our tennis ball collector. This would mean that we would have to pick a higher end motor that we know will be able to push and drive our tennis ball collector.

### 3.2.6.4 Fiberglass

Fiberglass is the fourth material that we considered. Fiberglass is a bunch of glass fibers mixed with resin. This mixture is then reinforced with plastic to give it some type of durability. Since it is mostly glass and plastic fiberglass is a very lightweight and thin material. Fiberglass is used a lot for roofing, so it is easily and readily available at local hardware stores. Although it is reinforced by plastic, fiberglass is not water resistant. This poses a big risk for all the electrical components that will be stored inside of the frame. Another big issue is when cutting and drilling into fiberglass the filaments shatter and spread in the air. This makes it very bad to breathe in and can cause a lot of skin irritation and rashes. A third issue with fiberglass is that hail is known to shatter the fiberglass as they make an impact. So, if hail can cause such a big impact, we are worried that a tennis ball would provide more impact and cause more catastrophic damage to our tennis ball collector.

### 3.2.6.5 3D Printed

A 3D printed frame has also crossed our minds. With 3D printing there are a variety of materials we can choose from. The materials range from plastic, composite material, ceramics, stainless steel, etc. With 3D printing we can make sure the frame is built to the specific dimensions we need. Also since there are a variety of materials, we can choose the best one that will withstand the elements and not add a ton of weight to the final design.

However, there are a couple of downsides with using 3D printing. One the printing itself tends to be very expensive. A second issue that is faced is that to build and design a frame to be printed you have to be proficient in software to get the file. The most common software used to design objects for 3D printing is SolidWorks. All of us in the group have very minimal to no experience in SolidWorks. If we were to go the 3D printed route, we would either have to find a design we already like online or we would have to learn SolidWorks itself to design and print our own.

### 3.2.6.6 Frame Comparison and Selection

To choose the frame we have a variety of great materials and methods that we can choose from. All four candidates we discussed have their advantages and disadvantages to them. These advantages and disadvantages are what will help us to discern which material would be best suited for our tennis ball collector.

Material	Advantages	Disadvantages
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Wood	<ul style="list-style-type: none"> <li>• Inexpensive</li> <li>• Water resistant to some extent</li> <li>• Easy to find</li> <li>• Easy to build with</li> </ul>	<ul style="list-style-type: none"> <li>• Require a lot of Maintenance</li> <li>• Terrible Heat Dissipation</li> <li>• Lower Speed Range</li> <li>• Can be noisy</li> </ul>
Cardboard	<ul style="list-style-type: none"> <li>• Inexpensive</li> <li>• Widely available</li> <li>• No building required</li> </ul>	<ul style="list-style-type: none"> <li>• Biodegradable</li> <li>• Not water resistant</li> </ul>
PVC	<ul style="list-style-type: none"> <li>• Water Resistant</li> <li>• Widely available</li> </ul>	<ul style="list-style-type: none"> <li>• Can be very heavy</li> </ul>
Fiberglass	<ul style="list-style-type: none"> <li>• Widely available</li> <li>• Lightweight</li> <li>• Inexpensive</li> </ul>	<ul style="list-style-type: none"> <li>• Can shatter due to impact</li> <li>• Not water resistant</li> <li>• Can become health hazard when cutting or drilling into</li> </ul>
3D Printed	<ul style="list-style-type: none"> <li>• Many different materials to print from</li> <li>• Let's us build to exact specifications</li> </ul>	<ul style="list-style-type: none"> <li>• Expensive</li> <li>• Requires knowledge of software to be able to design and build</li> </ul>

Table 3.2.7.6.1. Advantages and Disadvantages of different frame materials

The pricing of these materials is also something we want to account for. Our materials can range from very cheap to very expensive. Our goal is to keep cost as low as possible but also get the quality we want and desire.

Material	Price per unit
Wood (2'x 4')	\$2.75
Cardboard (10x6x6)	\$1.10
PVC (6"x12")	\$14.49
Fiberglass (36" x 48")	\$48.65
3D Printed (cubic inch)	\$7.00 + \$40 per hour (lab manager)

Table 3.2.7.6.2. Pricing of different frame materials

Overall, after all things considered, we think our best option is going to be PVC. Cardboard, though it is very easy and inexpensive, would not be able to handle the demands of the environment. 3D printing is too expensive, the prices reported are what we found for the manufacturing lab at UCF. If we took the 3D printed route, we would also have to take time and learn SolidWorks. This valuable time could be used to perfect other necessary items on our tennis ball collector. With wood we are worried about it not being completely waterproof so if we were to use it we would have to do some extensive testing to make sure no water would get through. Fiberglass although it is inexpensive and easy to source, however the durability of the fiberglass makes us question if this would be the best choice. Also having to deal with cutting and drilling multiple holes into the frame would make it very toxic to us even if the effects are minimal. This leaves us with our best option, PVC, which should be easy enough to work with and would be able to withstand all the outside elements. If we are able to make sure the PVC is not too thick or make it small enough where there is no extra material, we can cut down on the extra weight it would produce.

### 3.2.7 Wheels

The wheels we choose will have a great impact on our tennis ball collector. There are two conditions we have to have for our wheels. The first condition we have is that they must be big enough to withstand the weight of all of our components. The second condition is that they have to be big enough to allow the wire rack to rotate against the floor. We plan to achieve this by only having two wheels. The bigger the wheels the further we can go with a single turn of the motor. However,

the bigger the wheels the more weight we will have to account for the motor will have to push.

The wheels come in a variety of different sizes. The size of the wheels we choose will be dependent on the size of the wire rack. We have three different options for the wheels. We have chosen from 5 inch, 7 inch, and 10 inch. The pricing of the different wheels are as shown below

Size	Price per unit
5 inch	\$10.28
7 inch	\$17.96
10 inch	\$32.99

Table 3.2.7. Pricing of different wheel sizes

As you can see the wheels are not too expensive and we have a variety of different options. The current plan is to have only two wheels and the wire rack to add stability to our tennis ball collector. However if we were to need to add extra stability to our robot we have planned to add a third wheel to the back. The third wheel will not be powered at all. It will be like a wheel on an office chair. The third wheel will be free to move in any direction and the main goal for it is to provide stability.

With all this in mind we think our best option will be the 7 inch wheels. With the 7 inch wheels we believe we will be able to get the best bang for our buck. The wheels should allow for the wire rack to roll freely on the floor to pick up the tennis balls. Since the wheels are not too big they should also not add a ton of weight to the final design.

### 3.2.8 Microcontroller Units

The microcontroller is one of the most if not the most important part of our project. It is the whole processing unit for our tennis ball collector. The microcontroller has to be able to send and receive signals from and to every electrical component on our tennis ball collector. The microcontroller needs to be able to receive all the information from the sensors to know where it is and if there are any obstacles in the way.

The microcontroller is also responsible for driving the motors. Telling them when to go and when to stop. Our tennis ball collector will also need to be able to turn left and right. To achieve this we will make it so when we have to turn left the left side motor will slow down while the right side motor keeps at the same pace this will turn the tennis ball collector to the left. To make the robot turn to the right the

opposite will happen, the motor on the right side will slow down while the left side motor keeps running at the same pace. This task is all going to be controlled from the microcontroller itself.

With this in mind there are a lot of great microcontrollers out on the market and each one has their advantages and disadvantages. Depending on what tasks you are trying to achieve you might go with a different microcontroller.

### 3.2.8.1 ATmega series

Arduino is a very common and popular prototyping board for projects. The combinations of ease, simplicity, and great software support are what makes Arduino so popular. Arduino boards can send and receive signals, turn on LEDs, activate motors, sensors, etc. They are commonly used by students, professors, etc. for projects that require a small microcontroller with a decent amount of processing power.

Another benefit to using an Arduino is the software that comes along with it. The software is available on Linux, Mac, and Windows. The software's platform can be used to code. This makes it so not everyone has to learn how to be a master programmer. Thus, in turn only adds to the popularity and ease of use of the Arduino microcontrollers. The software is also an open-source platform. This means that there are already previous projects, source code, FAQs, hardware designs, troubleshooting help, etc. all available to everyone who is using an Arduino microcontroller. The coding language used by Arduinos is a simplified version of C++.

The Arduino boards also come with their downsides as well. One major issue is that these microcontrollers do not have the best precision when it comes to analog to digital conversion. They also lack scalability, so they are not the best for very large projects. Another issue they face is that in real time they can be unresponsive and not as accurate as they should be.

The microcontroller models used by Arduino boards are the ATmega series and other ATmel MCUs. The Arduino boards can be used to test software written in their IDE and eventually translated onto a custom ATmega based board.

### 3.2.8.2 MSP430 Series

The MSP430 is a series of microcontroller units designed and built by Texas Instruments. They provide the same features as the Arduino by being able to send and receive signals, turn on LEDs, activate motors, process information from different types of sensors, etc. The MSP430s are built around a 16 bit CPU. This makes the MSP430s have a lot of processing power, and at the same time they have a low energy consumption. These specific microcontrollers come with different built in low power modes to further lower the energy consumption. As

students at the University of Central Florida, we have prior knowledge of the MSP430 microcontrollers. They were used in our Embedded Systems class.

The peripherals on the MSP430 are excellent as well. The peripherals provided range from. Timers, analog-to-digital converters, digital-to-analog converters, etc. They also can come with various different memory storage sizes and RAM sizes. The launchpad software that comes with the MSP430 microcontrollers is friendly and easy to use. The coding language used for the MSP430s is probably the most basic and simple being the C language. This helps for beginners at coding to be able to pick up one of these microcontrollers and be able to complete simple projects.

The MSP430 also has its disadvantages. One of the biggest disadvantages to the MSP430 is that they are limited in memory. Yes, different versions will have higher memories but even the maximum amount can be very limited. This makes it so you cannot run a very extensive program. Another disadvantage The MSP430 microcontrollers also take a lot longer to learn and understand fully since there are not a lot of different prebuilt libraries. Unlike the Arduino, for most parts of a project you will have to know how to program it yourself as there is a great lack of an open-source platform. As you go higher in the food chain for the MSP430s they tend to get a lot more expensive.

### 3.2.8.3 Adafruit Feather

Adafruit has built and designed a full line of microcontrollers named the Adafruit Feather. These microcontrollers are very unique. The main board is named the Feather and with feathers come Wings. Wings are a customizable option where you can stack more boards on top of each other. These extra boards give you additional features to sensors, connectivity options, drivers for motors, etc. There are 12 different Feather boards each one providing different specifications. The theory is you can add as many wings as you would like so the possibilities are endless.

Adafruit has made their platform very user friendly. They are committed to making the hardware open source. There is also a very active community that has provided projects, examples, source codes, troubleshooting, etc. Adafruit themselves have also built and provided libraries, tutorials, example codes, etc. The Adafruit feather boards are also compatible with the Arduino IDE. This allows the Feather boards to be programmed with the same C++ code that is used in Arduino. That is not the only language that is supported. You can also code in normal C. This gives the user a variety of different options on how they want to make their project unique.

However, all these benefits do come with their downsides. The first one being that they are very expensive. Since they are customizable, buying the feather board itself and the wings will add up. Another downside is that not every wing is compatible with every feather board. The feather boards tend to have very limited

pin outs so being able to put them with the wings and then connecting them to a circuit, sensors, motors, etc. can get a little challenging. Since they are so small the Adafruit feather boards tend to have low processing power and memory.

### 3.2.8.4 Microcontroller Comparison and Selection

There are a ton of different microcontrollers for us to choose from. Whether that is an Arduino, one of the many MSP430, or if we want to go the creative route and customize our own Adafruit Feather with Wings. We are looking for a microcontroller that will be able to handle driving the motors, reading and processing data from all the sensors, etc. It all comes down to what is going to benefit us most from their advantages and does not hinder us too much.

	<b>Advantages</b>	<b>Disadvantages</b>
Arduino/ ATMega	<ul style="list-style-type: none"> <li>• Platform available on multiple operating systems</li> <li>• Able to handle multiple sensors and drive motors at the same time</li> <li>• Large community</li> <li>• Open-source libraries</li> <li>• Simple programming language</li> </ul>	<ul style="list-style-type: none"> <li>• No scalability</li> <li>• Not good for real time responses</li> <li>• Not precise with analog to digital conversion</li> </ul>
MSP430	<ul style="list-style-type: none"> <li>• Variety of different memory sizes</li> <li>• Very Efficient on energy</li> <li>• Very reliable</li> <li>• Excellent peripherals</li> <li>• Prior knowledge and usage</li> <li>• Simple programming language</li> </ul>	<ul style="list-style-type: none"> <li>• Limited in memory</li> <li>• Harder learning curve</li> <li>• Not enough open-source material</li> <li>• Very self-reliant learning about the board and programming</li> </ul>

Adafruit Feather	<ul style="list-style-type: none"> <li>● Customizable so you can pick exactly what you need.</li> <li>● Energy efficient</li> <li>● Open-source platforms</li> <li>● Multiple simple programming languages</li> </ul>	<ul style="list-style-type: none"> <li>● Can get very expensive with customization options.</li> <li>● Low processing and memory</li> <li>● Limited pin outs</li> <li>● Small community</li> </ul>
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Table 3.2.8.4.1. Advantages and Disadvantages of different microcontrollers

All three of these microcontrollers have their good selling points. Each one is unique and brings something different to the table. However, these microcontrollers have several different price points as well. It all depends on what exact board you are getting. For example, there are multiple different MSP430 boards or depending on which customizations you get for the Adafruit Feather. It all depends on what you are really looking for.

	Low End	High End
Arduino/ ATMega	\$5.51	\$27.60
MSP430	\$1.24	\$23.20
Adafruit Feather	\$11.95 + \$\$\$ for each Wing	\$39.95 + \$\$\$ for each Wing

Table 3.2.8.4.2. Pricing of different microcontrollers

As you can see microcontrollers come in a variety of different prices. The Adafruit Feather might be a great microcontroller but due to it having limited pin outs and we have to pay extra to get basic add-ons we believe that this will be the worst option. We believe that Arduino is the best choice we can make. Even though it is not the cheapest, the ease of use that it brings and the open-source library/community we will be able to address and fix any issues that may arise. The Arduino can handle all the sensors that we are going to use, and it can also drive our motors. This makes it the best option for us. We will keep the MSP430 as our backup microcontroller. Our prior knowledge with this microcontroller may come in use if needed. It also is a great microcontroller in its own respects.

### 3.2.9 PCB

PCB or Printed Circuit Board is the most important part of our project. During the building process we have to build and design our own Printed Circuit Board. The PCB is used to give all electrical components all the mechanical support they may need. The PCB has conductive copper tracks and planes. They can also feature tiny resistors, inductors, capacitors, etc. There are multiple types of PCBs ranging from

- Multilayer PCBs
- Single and Double Sided PCBs
- Ceramic PCBs
- Metal Core PCBs

PCBs are designed using some sort of ECAD software. The user designs and builds the PCB to the specifications and requirements that they need. The design is then sent to companies worldwide to be constructed and printed. After you receive your PCB you can then connect it and add it to your project.

In junior design we had an introduction to Printed Circuit Boards. We used the software Eagle to design different types of PCBs. However, we never got the chance to have one printed due to a shortage of parts in the market or inflation on the price of certain parts. With this said we have just a little experience with designing PCBs so as we go into senior design 2 it might bring up a couple of issues as we try to create our own.

## 4.0 Related Standards & Realistic Design Constraints

When starting a project, even before, there are key factors that come into play that limit your design. Standards and Constraints are two of those factors and are present in every step of the project. Considering these factors ensure that the approaches and design of the prototype adhere to industry standards and keep in mind limitations we may have.

- ChatGPT was used to help aid in the search of standards that related to this project and was used for templating the headings of this section.

### 4.1 Related Standards - Electrical & Software

Standards are guidelines that provide engineering methods or requirements for various processes. By following these standards, we can ensure safety, quality, and compliance of our project. There are many organizations already in place

that provide such standards for engineers. We are going to utilize and follow three: IEEE SA (Institute of Electrical and Electronics Engineers: Standards Association), IEC (International Electrotechnical Commission), and ISO (International Organization for Standardization).

The IEEE SA is a global professional organization that plays a crucial role in advancing technologies and supporting professionals in their careers. The Standards Association is a part of IEEE. With a focus on Electrical Engineering, Electronics, and Computer Science it is a perfect guidance to follow and adhere to.

- IEEE is the world's largest technical professional organization
- 1032 Active Standards
- 1,045 Under Development
- +175 Countries

The IEC is an international, not-for-profit membership organization that publishes standards for all fields within electrotechnology. It also provides guidelines to ensure safety.

- 10,000 IEC International Standards
- More than 170 countries involved

The ISO is made up of many national standards organization Representatives. It focuses on publishing standards that provide specifications and guidance. This organization is not only for engineering, it covers many aspects of life.

- Over 23,000 Standards for all industries.

### 4.1.1 Electrical Standards

One aspect of standards we consider to be important is the electrical side of things, for example, power management, safety laws, and efficiency. These standards will guide us to maintain safety.

#### 4.1.1.1 IEEE 1547- 2018

Name: IEEE Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces

The Standard outlines requirements for systems that involve solar-powering with electric power systems. Although this standard is for much larger projects, we are adhering to this design standard because our prototype is essentially the same but on a much smaller scale. It helps ensure integration and safety. Our robot is going to include solar panels and its energy needs to be monitored for proper use, safety, and power quality. Mainly focusing on the aspects that provide

guidelines to Test/Procedures, since this is for Electric Power Systems on a large scale.

Scope	Guidelines
Interconnection Requirements	Defines requirements for Distributed Energy Resources
Voltage Regulation and Control	Voltage Control, Power Factor, safety/reliability
Protection Requirements	Specifies Fault Detection, and responses
Testing/Certification Procedures	Guidelines
Safety Considerations	Installation, maintenance, and operations

Table 4.1.1.1: Outline of 1547 Standard. Reference from

#### 4.1.1.2 IEC 61427-1:2013

Name: Secondary cells and batteries for renewable energy storage

This robot will not be connected to the Grid. It will not give back to the grid or utilize power from the grid, it will be self-sufficient. Since it is Off-Grid it will need a battery to store energy for when the Sun isn't cooperating with us, for example, when it's cloudy, dawn/dusk, or night. In order to function it's going to need a Secondary Battery. This Standard deals with this exact function. The standard focuses on guidelines for Photovoltaic Off-Grid applications. We will follow this standard because our project is a perfect fit for it and will help stick with a plan.

The following bullet points are what this standard encompasses:

- Guidelines for design/construction of VRLA batteries, more specifically, the container, the terminals, the ventilation system, and more.
- The electrical design of the batteries themselves, like its nominal voltage, capacity, internal resistance, mass, and size.
- Performance and Testing: procedures and requirements the batteries need to adhere to; capacity, cycle life, temperature, and humidity.
- Safety against short circuiting, venting of gasses, and maintenance.
- Requires that all the battery information is stated.

#### 4.1.1.3 1526-2020

Name: IEEE Recommended Practice for Testing the Performance of Stand-Alone Photovoltaic Systems

This standard states what our project is, a PV system that isn't connected to the electric grid, or to an alternate source. A PV system that consists of solar panels and an energy storage system. This standard deals with poor design/selection of applicable components by the designer.

<https://standards.ieee.org/ieee/1526/7761/>

Testing Methodology	PV system and test requirements
System Inspection	Review, and initial inspection
Data Acquisition and PV system installation	Installing DAS specs & PV
System Performance Tests	Battery & Functional tests
Final Inspection	Maintenance, Visual & Wiring
Pass/Fail Criteria	Load operation, PV Array...

Table 4.1.1.3: Standard Specifications

## 4.1.2 Software Standards

The second set of standards will be about the software side of things. We will follow the guidelines of organizations to ensure quality, design, testing, and practices.

### 4.1.2.1 ISO 13482:2014

Name: Safety Requirements for Personal Care Robots

This specifies requirements and guidelines for the inherently safe design, protective measures, and information for use of personal care robots, in particular the following three types of personal care robots:

- mobile servant robot;
- physical assistant robot;
- person carrier robot.

This standard provides safety requirements, more specifically between human and robot interaction and collision avoidance.

Us following this standard is important due to the fact that the setting is in a Tennis Court, where the Robot and Tennis Players will be sharing the court. We

are still considering what is the best course of action, but for now we are thinking of having a sensor that knows where the tennis base lines are and to avoid those areas where tennis play frequents more.

To go into more detail about the standard, here are a few highlights on what its about:

- Risk assessment
- Safety requirements
  - Mechanical
  - Electrical
  - Software
  - Human-robot interaction
  - Environmental
  - Mobility
- Clear documentation and instructions, maintenance guides, and safety warnings
- Privacy and Data Protection
- Hazards due to: robot shape, emissions, electromagnetic interference, stress, robot motion, durability, energy storage, and more.
- Safety-related:
  - Speed control
  - Environmental sensing
  - Stability control, stoppin
  - Design of user interface
  - Operational modes
  - Manual control and more

#### 4.1.2.2 IEEE 829-2008

Name: Standard for Software and System Test Documentation

This Standard showcases the required documentation for software testing activities. It provides guidelines for Test Plans, Scripts, and Reports. We chose this standard as one to follow because it helps maintain order in all phases of the

programming stage. Following this ensures that the testing of the code is well-documented, controlled, and organized.

The following bullet points lists what this document outlines.

- Integrity levels: It defines integrity onto levels ranging from high to low, to show how important the software is to the user.
- Recommended minimum testing tasking for each integrity level: This portion of the standard defines the minimum testing tasks recommendations for each level.
- Intensity and Rigor applied to testing tasks: Detailing the types of testing done in accordance to each level. Intensity - testing for normal/abnormal operating conditions. Rigor - formal techniques and recording procedures.
- Detailed Criteria for Testing Tasks: This section of the guidelines specifies the criterias for correctness, consistency, completeness, accuracy, readability, and testability.
- Systems Viewpoint: Lists the recommended minimum testing tasks to respond to issues on the system.
- Selection of Test Documentation: Both testing and content need to be selected from the tasks according to the integrity level they are at.

Description	Level
Software must execute correctly or grave consequences (loss of life, loss of system, environmental damage, economic or social loss) will occur. No mitigation is possible.	4
Software must execute correctly or the intended use (mission) of system/software will not be realized causing serious consequences (permanent injury, major system degradation, environmental damage, economic or social impact). Partial-to-complete mitigation is possible.	3
Software must execute correctly, or an intended function will not be realized causing minor consequences. Complete mitigation possible.	2

Software must execute correctly or intended function will not be realized causing negligible consequences. Mitigation not required.	1
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Table 4.1.2.2: Consequence - Based Integrity Level Scheme

#### 4.1.2.3 IEEE 1872-2015

Name: Ontologies for Robotics and Automation

This standard has to do the terminology and classifications. It sets a guideline on how certain aspects should be named. The term robot has many names and its components do as well. We will adhere to this terminology to help spread the correct wordings.

## 4.2 Realistic Design Constraints

Every project that is built has some sort of design constraint. It is what decides what goes in the project or not. When I think of design constraints, I see constraints as limitations that hinder the Design Process. Design Constraints play a key role when coming up with a working system. These are specifications that need to be accounted for in every part of the robot. These limitations ultimately decide everything about the robot. For example, if it's big/small, fast/slow, or bad in general.

These constraints typically could be:

- Economical
- Scheduling
- Environmental/Social/Political
- Ethical/Safety/Health
- Sustainability/Manufacturability

### 4.2.1 Economic and Time Constraints

These two constraints have the heaviest impact by far and play a significant role in shaping our robot. Economic limitations are about managing our budget wisely, cost-effective design, and optimizing resources. Time constraints show how scheduling, meeting deadlines, and tracking our progress. It's what will influence our project throughout the whole design process and implementation.

#### 4.2.1.1 Economic

We are not being sponsored for this project. Resulting in this coming out-of-pocket. Many factors fall in the economic constraint of the design, these include:

- Budget Limitations: We are college Students, we can't really afford to put in large amounts of money for the project.
- Cost-effective Design: Since our budget is more limited, we need to think of ways to make it cheaper while making it just as functional.
- Cost of Components: The cost of things add up quickly.
- Fundraising: One way to counter this constraint would be to hold a fundraiser, but that would cost time and effort. Which we both need for the project itself.

#### 4.2.1.2 Time

We are engineering students nearing the end of our Undergraduate Degree. Time has always been a part of our college lives and on having to deal with it. Time affects quality, if not enough time is put into this it will not be good. Some factors of time are as follows:

- Time Management Skills: This class has its deadlines yes, but there is a big gap of time between those deadlines, so as a group we have to allocate time for this project and everyone must do their part. Some of us have full-time jobs, some of us have to travel a lot. It's difficult to set good amounts of time for this project with our already busy lifestyles at the moment. For this we need to manage our time and not procrastinate as a group. Need to stay on schedule and plan accordingly for extra things that could take longer like shipping, revisions, and set-backs.
- Communication: Constant communication is key in order to not waste time. Crucial conversations must take place in order to make things go smoother.
- Timeline: We have imposed mini deadlines within our group in order to keep managing our times and stay reliable to each other. This constraint helps us tackle the whole project, step-by-step. Making 120 pages not as difficult to complete. Many deadlines to follow.
- Deadlines to follow include:
  - Initial Document Idea
  - 60 page report within group before submitting
  - 120 page final report

- Testing: Need to make ample time for this portion of the design. In order to combat this, we need to start building as soon as we can. This is crucial if we want a working prototype by the final deadline.
- Flexibility: This constraint is mainly a problem because we are a group of four, we all have things going on in our lives. So in order to succeed we need to be flexible with one another, and coordinate accordingly. This constraint we believe is very important to keep in mind. We have to balance our work/study/social lives as best we can.

## 4.2.2 Environmental, Social, and Political Constraints

The development of any project, big or small, includes these types of constraints. Environmental constraints consider having as small a footprint as possible. Social constraints focus on the user-friendly design, and how it will interact and maintain safety all at once. Political constraints involve having regulations, security, and privacy. These types of constraints are matters we adhere to when designing our prototype.

### 4.2.2.1 Environmental

- Impact: The setting where this robot will operate is a Tennis court. A tennis court is made up of concrete and tough surfaces. Our robot will cause zero harm within the court because it will have rubber wheels that will produce no markings on the court. The sensors will account for all aspects of the setting and will be constantly observing the area. There will be a rechargeable battery on board so that it can harness and store solar energy and it wouldn't be a one time use like a primary battery.
- Material Selection: The robot will be made up of mostly recyclable materials, so that our impact on the environment will be very little.
- Energy Efficiency: In theory we want to capture and utilize as much energy as we can from the Sun so that it can be directly used and not be wasted. Another way we are battling this constraint is not using power-heavy cameras and programming code. the code itself will be efficient.
- Footprint: In the process of innovation, a lot of waste occurs. For example, failed designs, drawings, electricity. While trying to come out with solutions, the environment doesn't become a priority and we will aim to keep this in mind.

### 4.2.2.2 Social

- User Safety: This takes place where humans and the robot will have to interact in a shared space.. The robot will be coded to avoid humans when

it's in pickup mode. The robot will be fitted with multiple sensors for its varying tasks, like tracking the tennis balls, keeping outside the lines on the court, and watching out for the net and fence around the court.

- Target Audience: The whole idea around this robot is about saving time and energy to play the sport, rather than spending it on having to pick up tennis balls. The target audience is in mind throughout the process and this constraint helps us keep our core values in mind. A member on our team casually plays Tennis and he will be testing it as a tennis player would.

#### 4.2.2.3 Political

Compliance: This robot will adhere to local and national regulations in place. This constraint allows us to ensure that safety, the motors, and batteries are allowed and accounted for.

#### 4.2.3 Ethical, Health, and Safety Constraints

- Privacy: When we were thinking of ways to visualize the court through the robots eyes, a camera was a solution at hand. If we were to use a camera to visualize its data, we need to ensure that the privacy of the people using it is safe. None of the data will be saved and its main use is for tracking and picking up the tennis balls.
- Safety and Risk: Throughout the project we will be identifying and accessing potential risks for example, it could be running into someone, the robot catching fire, or a battery exploding. All measures will be taken in order to prevent events like these to occur. Another example of something going wrong is soldering. If not done properly, it could all go wrong. The materials need to withstand being in the Sun for long periods of time.

#### 4.2.4 Sustainability & Manufacturability Constraints

We aim to have very little to no impact on the environment with the building of this robot. This constraint ties us down to only looking at recyclable materials to produce the prototype. When the actual building of the robot commences, we want to have as little waste as possible. Reasons include; cost of materials, budget, and making use of the materials are used the best way possible. A manufacturability constraint is ensuring that the design can be reproduced. A solution to this is using materials that are easily available and typically in stock. There is a shortage of chips and this could cause limitations later on for manufacturing.

## 5.0 Comparison of ChatGPT

ChatGPT is a LLM (Large Language Model) which is a type of AI (artificial intelligence) algorithm that has deep learning techniques integrated within. These types of models have massive data sets where it's learning to understand, summarize, generate and predict new content. It's focused on text-based content.

We believe that this tool can be mostly helpful to us as a general knowledge/researching aid to help guide us throughout the process of this project.

While ChatGPT and similar platforms have many advantages that make them useful in a variety of situations, they also have many limitations. In the next section we will talk about the advantages and disadvantages of this type of model.

ChatGPT was used in this section for research about itself and for List of pros and cons.

## 5.1 Pros

### 5.1.1 Accessibility

ChatGPT and other LLM have easy accessibility. These platforms can be used by anyone and can be accessed anywhere in the world with the internet. You don't necessarily need any specific hardware or software since they use API. One of the Only things you need is an internet connection and any devices like a mobile device, computer. Users from different countries for the most part can access and interact on the platform.

### 5.1.2 Availability

Users can communicate with these models whenever they want because they are always open, seven days of the week, so it responds to the user's needs at any time by offering constant access to information, and support. This accessibility may be especially useful for users in different time zones or in situations requiring urgent help. Wait times can be significantly decreased using Chat GPT platforms for simple matters as opposed to more conventional customer support or assistance channels. Users no longer need to wait for a human operator or support representative because they can instantly access the platform and get immediate answers to their questions or requests. The user experience is improved, and user satisfaction is raised by the quick response time.

### 5.1.3 Loads

Platforms for Chat GPT are made to handle a lot of simultaneous interactions. They have the ability to scale their resources to handle many users and requests

at once. This means that the platform can keep giving quick responses even when a lot of people are using it or when there's a sudden increase in demand. It has sometimes slowed responses down, or stopped working, but that was in the early days of the release.. These platforms work well for both one person using it and for implementing its API into your own needs. They can handle a lot of requests.

#### 5.1.4 Languages

The ChatGPT and like models know more than just one language, which allows their users to speak to it in their native language, for the most part. This big selection of languages makes it that users can communicate with the model comfortably, regardless of their native language or the language they prefer to use.

#### 5.1.5 Cost

Using a LLM platform can be less expensive than having human operators or customer support teams. In many instances, it can offer automated assistance at a much lower cost.

#### 5.1.6 Language Understanding

Deep learning techniques are used to train models like GPT-3 so they can comprehend human speech and provide responses that match human speech. They can be helpful in conversations, respond to questions, and offer important information. These models are good at handling complex sentences, determining what's useful to answer from context, and producing responses that make sense. To be accurate, and dependable, the data should cover many aspects of life. This is why the data set is so large...hence the name, LLM.

#### 5.1.7 Reduced Training Time

When comparing Chat GPT platforms to human operators or customer service agents, one advantage could be that there is no need to train on the subject since that should ideally already cover it in the data. It significantly shortens the training period. These systems can be set up quick and made available for customer communication. This makes the process easy to quickly implement support systems, ensuring time cuts and effective customer service. Additionally, ChatGPT - like platforms offer their own API (Application Programming Interface), allowing businesses and third parties to easily add more chatbot instances.

## 5.2 Cons

### 5.2.1 Context:

Sometimes ChatGPT answers the questions wrong because it might have a lack of understanding what it is they are asking for. Chat gpt is generating human-like responses but it doesn't have a big understanding of the world and that could affect incorrect context. The model has relevant data up-to 2021. Therefore it might not understand if the prompt is about recent events. Depends on what the input is.

### 5.2.2 Biases and Incorrect Info

Chat GPT models gain knowledge from the training set of data, which may contain biases and inaccuracies. This might result in biased or inaccurate responses, possibly when dealing with touchy subjects. It's crucial to be aware of these restrictions and to carefully consider the data presented. Chatgpt does give some accurate answers but it can be questionable sometimes due to its training methods or prompt wording. The optimal response depends more on the model's knowledge. If sufficient data is made available to the public audience, ChatGPT can provide accurate responses and information. However, if there isn't enough data, it might produce incorrect information. To make sure that ChatGPT's training methods are accurate, it is essential to validate material and prevent plagiarism.

### 5.2.3 Control

The capacity of users to give guidance and ensure accurate, trustworthy, and relevant responses is constrained by Chat GPT models' limited ability to regulate the generated responses. In certain cases, the model may generate inappropriate or undesirable responses. This lack of control can pose limitations in applications where the accuracy and reliability of responses are critical. Efforts are being made to improve user control through methods such as prompt engineering, specifying output formats, and utilizing external post-processing. These measures aim to enhance the user's ability to shape and refine the generated responses. However, achieving complete control and ensuring precision and dependability in the output remains a challenging task. Applications that rely on accuracy, dependability, and appropriateness face difficulties due to this limited control. The potential for Chat GPT models to generate incorrect or misleading information can pose significant challenges, particularly in contexts such as customer support or sensitive information exchanges. It is crucial for users and developers to be aware of these restrictions and carefully evaluate if Chat GPT models are suitable for a given application. Striking a careful balance between the advantages of text-basing AI and the need for accurate, trustworthy results is of high importance. Both ends should consider the specific requirements of the use of application and the potential consequences of limited

control over the model's output. Maintaining transparency and accountability in the use of all these types of Generative AI models is essential. Developers should continue their efforts to refine the technology and explore ways to enhance user control while ensuring precision and dependability in the generated responses. By understanding the limitations and making informed decisions, users and developers can navigate the challenges and leverage the benefits of Chat Gpt - like models effectively. Reference [GPTC] for this paragraph.

### 5.2.4 Training Data Dependency

Due to this being new technology, the quality of these LLMs significantly depends on the level of their training data. This is where 'Prompt engineering' comes into play. The model is only as good as the questions it is given. To utilize it to the best of its capabilities, you need to tell it the correct questions with information so it can give quality results.

For errors, to be minimized, training data must be of decent enough quality. The model can learn from many points of view, languages, and cultural contexts thanks to a broad dataset, which also helps it better understand and respond to various user questions. Continuous model updates and training on fresh and different types of data are needed to handle newer prompting and also to provide more accurate responses. The effectiveness of the model can also be impacted by bias in the data it has in the system. We have noticed that the Website has been being updated a couple of times since its release to the public.

### 5.2.5 Ethics

The use of Large Language models raises important ethical concerns related to data security, privacy, and the potential danger for misuse. If Companies decide to implement this software, they should do so carefully. Maybe even design safeties, like a firewall of some sort. The data could not be safe to be trusted, or the documents/texts could be sensitive material. Even so, many companies do not allow employees to utilize this API. Measures such as encryption techniques, anonymization, and adherence to data protection laws can help minimize privacy risks.

As Chat GPT technology continues to evolve, it becomes crucial to establish clear guidelines and rules to prevent the dissemination of harmful or false information. More regulations could be set in place to provide clarity and order as this relatively new technology. Developing content moderation tools and ethical standards is essential to stop the spread of misinformation and unethical answers. Users should also be provided with education on models like these. Transparency and accountability are key factors that organizations should prioritize to trust a system like this. Adhering to standards, as we are, and many legitimate businesses need to be placed for ethical concerns and in general.

More discussions should take place for AI, for example, topics we have discussed in this section of the report.

### 5.2.6 Lack of Physical Presence

Chat GPT and similar platforms models do well in language understanding and text-based replies, but they don't have physical interaction with the environment. IT is not the same as going to a tech store and asking about mobile phones. This restriction may reduce their efficiency in tasks that call for hands-on help. Human intervention or on-site help may be required in sectors like healthcare where physical examinations, operations, or treatments are necessary. Text-based AI systems cannot replace physical labor and operations in sectors like construction, manufacturing, and transportation. Understanding the limitations of Chat GPT platforms and the demand for a blend of human experience and Chat GPT models is essential.

### 5.2.7 Reliance

In the long run, I could see the software being a possible problem. IN the aspect that people are probably going to use it for everything they can. People will get used to the fast responses, and will most likely develop a shorter attention span. These types of AI systems could find it difficult to react like humans at first, but over time will continue to improve. In order to get better at human interaction, users must continue to use ChatGPT - like platforms. Another way to optimize results for both people and the system, ongoing feedback and monitoring are essential.

## 5.3 Examples

### 5.3.1 Good Example of how we are utilizing the LLM.

- <https://chat.openai.com/share/6819b9e9-b9b7-49c4-a584-12ffc873e8e2>
  - Although we didn't end up using it like this exactly, it did help grasp the idea more of what we need to complete and have general knowledge. This would be a good example of how the LLM responds and communicates with the user. As you can see it even asked a question to help understand the prompt further and to see how it could assist.

### 5.3.2 Example on Recent Events (Directly Copied from ChatGPT).

Prompt: "Can you help me find out what the president said at his latest speech?"

Response: "I'm sorry, but as an AI language model, I don't have real-time access to current events or the ability to browse the internet. My training only goes up until September 2021, so I cannot provide information about the latest speeches or events that may have occurred since then."

To find out what the president said in their latest speech, I recommend checking reliable news sources, government websites, or official social media accounts associated with the president. These sources often provide up-to-date information on the speeches and statements made by public figures."

- Here even though it didn't provide an answer I wanted, it helped provide guidance on where to find that answer.
- The prompt itself was quite general and vague as well, so the LLM had to grasp what it could, and decided on guidance.

### 5.3.3 Example at Paraphrasing.

<https://chat.openai.com/share/afddddf9-c70e-42ae-ac5f-f706d150e85c>

- Here, a simple prompt followed by a page whole of text, asking to summarize it.
- You could see that it does well at short, simple requests and cut down the long content by about half.

## 5.4 Conclusion

Chat GPT is a strong tool when used correctly. The Large Learning Machine can be used to research, proofread, compare, train, etc. However, even though it might be very simple to use and make life a breeze there are still some limitations we have to be weary of. For example not all the solutions provided by Chat GPT will always be correct. You have to be prepared to re verify the information and make sure it is correct. We also have to make sure that we do not become overly dependent on the software as of right now. Over time the hope is that the AI will begin to learn and become smarter, eventually being perfectly correct at all times.

## 6.0 Project Hardware and Software Design

### 6.1 Hardware Design

The design of the tennis ball collector is separated into five main sub-systems so that we can provide order and for the testing of parts. Each subsystem plays a different role in the robot and are supposed to integrate with each other flawlessly.

The first system is about power. This subsystem is how we are going to be testing and explaining how it will function and the circuits to do so. The second subsystem is about the collection of the tennis balls themselves. This subsystem is how we will be collecting them and storing them all at once. The third subsystem will be about the sensors and how they will interact with the environment. Another main sub system is about the Frame, and the fifth is about the MCU.

### 6.1.1 Initial Design Architectures and Related Diagrams

When thinking of a way to create this robot we each had our ideas. Through talking it out we came to a conclusion. A design we could all agree on. It will most likely change a little once we start building, since this is all theoretical. The members of our group didn't know each other at the start of this course. We all knew we each wanted something to do with RC Cars/Robots. In the first couple meetings when discussing our plan, a picture started to draw itself. A robot similar to a 'Roomba' but it was to be solar powered and pick up tennis balls on the court.

In these weeking meetings we would pitch ideas, putting what we did in the group exercise to use. All ideas were talked about, expensive, cheap, efficiency, and goals. The group has a discord server where we had channels for specific topics like General messaging, Important Docs, Meetings, Deadlines, and more. This helped with our design process as every portion was clear to follow and organized. In the group calls we discussed which components would be better or worse in context to prices and accuracies. That's when the project really picked up and felt real.

In figure 6.1.1 we have an updated hardware block diagram. Since the 60 page deadline, we added a camera instead of the IR Sensors since, through testing that didn't work out. When doing research it was conducted that we needed a battery to hold the energy from the solar panel, but that was gonna be too much for some parts so we needed a voltage regulator to step down from 12 V battery to a 5 V which was needed for some components of the design.

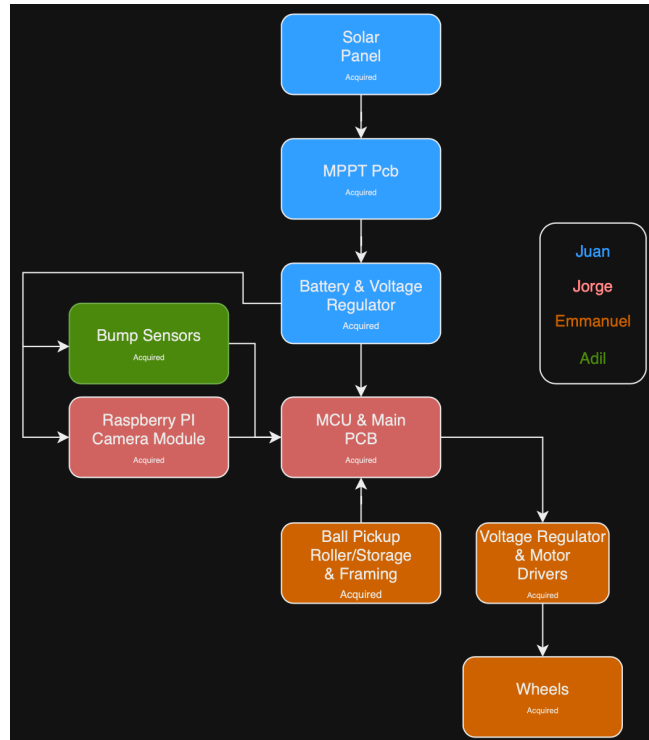
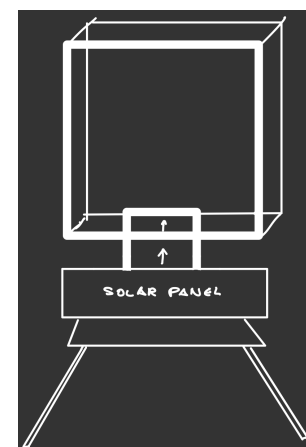
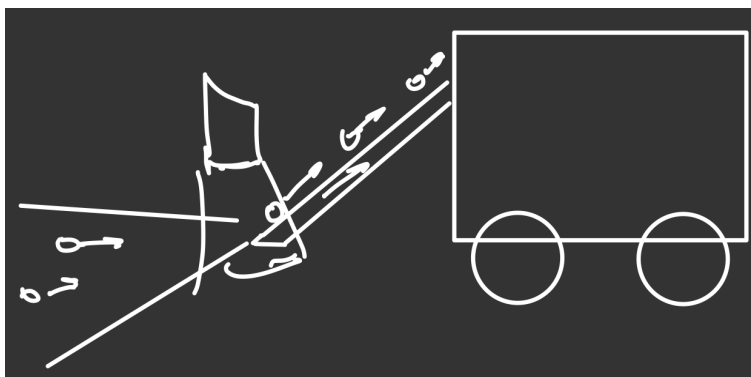


Figure 6.1.1 Updated Hardware Block Diagram

## 6.1.2 Design Overview

The journey from start to finish has many steps to it. It involves a lot of research, time, and communication. In the following you can see the progression of the overall project design. Each iteration addresses problems the prior had. Assuming everything goes as planned, maybe one or two improved versions will come out of our current design.



Figures 6.1.1.1 and 6.1.1.2 - First Project Idea

These images were one of the first ideas we had talked about when we were pitching solutions on this report as you can see in the picture we had first started

off with a conveyor belt method that would have collector arms in front to help guide the balls into the conveyor belt, which would then transport it up into a box followed behind it that would act as storage. This was the first iteration of our robot. As time went on, we soon realized that this would provide more problems for us in the future, and it would have more chance for failure with more moving parts so the conveyor belt was soon put out of question, and was no longer going to be a part of the design.

Another thing we were thinking about when speaking of the design was how the robot would actually move. At first we thought we were going to have a Two Wheel Rear Drive system where the front two wheels would move left and right, and in the back two more wheels which would be driving the robot. An example of this would be a rear-wheel driven car. We then realized that the front would be too heavy, because it would also turn the wire rack, and that would have way more moving parts and could complicate things down the road so we decided to ditch that idea as well. Having less moving parts streamlines and lessens the mechanical components, such that we wouldn't have to focus on them as much.

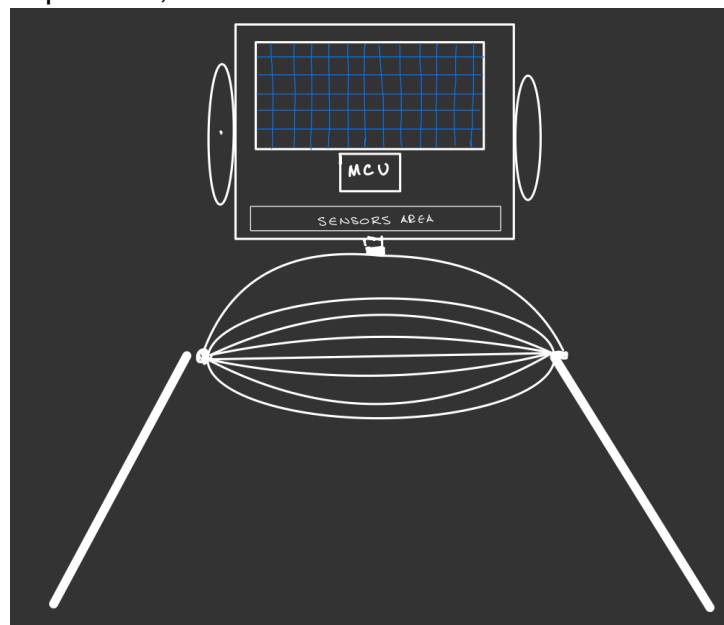


Figure 6.1.1.2 Second Project Idea

In this updated second version of our project, you can see what we have changed. Mainly the wheels from four to now two, that will be independently rotating. This solves the issue of going forward, backwards, and turning instead of having two separate systems, one for turning and one for moving. Another big change in this implementation is the wire rack. This is replacing the storage box and the conveyor belt in the first idea. The collector will pick up and store the tennis balls. This simplifies and involves less mechanical parts so now we don't need to worry about storage, how to get them into storage, and how to pick up the tennis balls. It's a three in one solution to our problems.

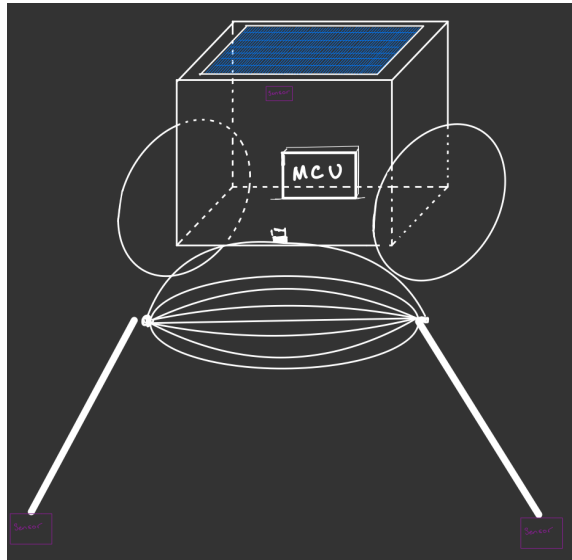


Figure 6.1.1.3 Third Design of Collector

A problem with the second idea is we weren't sure how to place the sensors or the solar panel or the MCU and the PCB boards and quickly realized we would also need to protect these from the environment from getting hurt to just wear and tear so we realized we need a third version that provide housing and durability. Which brings us to our final and current build, Figure 6.1.1.4. We have added the sensors needed and the housing is what we wanted from the third version. We'll talk more about housing/framing in Section 6.5 later on. As you can tell, after each design, the mechanical components got simpler, and each part was a solution to multiple sections.

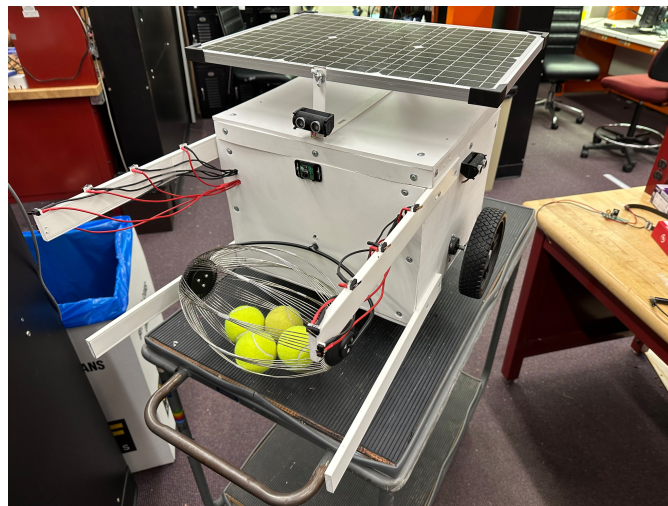


Figure 6.1.1.4 Final Design

### 6.1.3 First Subsystem: Power

This first subsystem deals with solar energy, the brushed motors, the voltage regulator, and the battery. These are all related to the robot's power. This system will also include an on and off switch. This switch is placed with ease of access on the inside of the frame.

#### 6.1.3.1 Solar Energy

Solar energy is an essential part of people's life right now. It is gaining popularity rapidly. Using solar energy in our project shows the importance of renewable energy and its positive impact in our environment.

As said before in section 3.2.2. We will be utilizing monocrystalline solar panels to power our robot. This is considerably the most important aspect of our project as it is an electrical and computer engineering design class. We have chosen this type of panel due to its high efficiency and its sizing. We plan to place the panel on top of the robot parallel to the ground so it can get the sun from any angle.

The selection of monocrystalline solar panels was so that it could maximize energy harvesting. Therefore, we wouldn't need as big a battery as other types of robots of this size making it lighter weight so it is not as intensive on the motors while moving. A 12V battery will be a small battery which will give back up support for the solar panel in adverse situations.

Monocrystalline solar panels efficiency leads to better and higher output power. With that, it will produce better performance. One of the main goals was to make the final product as light as possible. Monocrystalline solar panel's weight is going to be approximately 6 pounds. Which makes it one of the heaviest electrical components in our project. For the best outcome monocrystalline solar panel beats its competitors, such as polycrystalline and thin film solar panels. Based on calculations on solar power, we are ending up with around 30 watts of power produced by a ~15"x20" monocrystalline solar panel. Monocrystalline solar panel cost us fifty US dollars. This panel gives us 30% of efficiency with 17V and 1.8A. It weighs 6 pounds and it is waterproof. This product came with a special charge controller too. However, we made an MPPT controller. Based on our mathematical calculations, area is  $51.556\text{m}^2$ . City of Orlando's solar irradiance is  $5.59\text{kWh}/\text{m}^2$  in a day. After calculations for a 30W monocrystalline solar panel, we got 167.7 Wh/day of output power for our solar panel. It is connected to a 12V 30Ah LiFePo battery which is stored inside of the frame.

#### 6.1.3.2 Battery

When we were conducting research for the solar panels selection, we realized, even though the monocrystalline is our best option due to efficiency and weight, it does not hold a large amount of charge. We needed to run the robot for a

consistent amount of time therefore, we decided on implementing a 12 V battery to hold the charge. The 12V battery serves as backup for when the sky is a bit gloomy, and for any other external interferences.

The battery acts like a buffer for power as fluctuations from both power draw and production are to be expected. Motors are expected to be our highest power consumers and their power draw is dependent on the amount of torque they are producing to move the robot. Higher torque generally translates to higher power draw. This is subject to change as the robot changes speed, direction, and weight. The central processor and peripheral devices are also expected to turn on and off at variable intervals, drawing power at different rates and time intervals.

### 6.1.3.3 Motor

The motor plays a big part in our solar tennis ball collector. It is what is going to constantly drive our robot. For this task we need a reliable motor. A motor that is very efficient and can provide a great deal of power. For our solar tennis ball collector, we have decided to go with Brushed motors.

Brushed motors are a very common type of DC motor found in many power tools, computer peripherals, aircrafts, automobiles, etc. Brushed motors come in a variety of different sizes and power ratings. They are known to be very reliable motors. These types of motors are often chosen for robots due to their simplistic nature, lower costs, and controllability. Another reason is that they typically are more durable and can handle a variety of operating conditions, even though conditions would be a typically sunny day in Florida weather for our prototype.

DC electric motors of all kinds are not directly controlled by microcontrollers and utilize dedicated driver devices. These drivers interpret the control signal and amplify it with the power signal from a source like a battery to “drive” the motor. In a brushed motor system, the motor driver circuit would include MOSFETs (Metal-Oxide\_Semiconductor Field-Effect Transistors). These control the direction and speed of the motor by adjusting the flow of electrical current through the windings within the motors.

Brushed Motors consist of several components. You have a rotor, a stator, windings, brushes, and a commutator. The Rotor is what rotates, and the stator is the stationary portion. These are typically made up of magnetic parts. The Windings, either copper or aluminum, are added to the stator to create electromagnetic coils. The Commutator is a switch attached to the rotor to ensure the winding keeps spinning. The brushes are what come in contact with the commutator, they deliver the electrical current to the rotor windings.

Since this driver takes 6 different control signals, sometimes another device known as an electronics speed controller (ESC) is used to simplify control of the

driver. The ESC takes only one control signal and integrates the driver into one concise device. The ESC is also helpful for timing and sensing the rotation of the motor to prevent it from being damaged.

For our solar tennis ball collector, we have two brushed motors, one for each of the wheels. The motors would be secured inside of the frame and then hooked up to the PCB and the wheels. We could get away with running our solar tennis ball collector with only one motor, but we chose to run two brushed motors for a variety of reasons.

The first reason we chose to run two motors is for turning. We chose a differential drive system to be able to better turn our solar tennis ball collector. With differential drive the wheels will spin at different speeds to turn while moving forward. For example, if you wanted to turn left, the right wheel would spin at a constant rate and the left wheel would slow down. Now if you wanted to turn to the right, the left wheel would stay at a constant speed and the right wheel would slow down. With two separately controlled motors it is a lot easier to program when to keep a wheel at a constant rate and slow down the other. Differential drive also allows for turning in place for better navigation around obstacles.

The second reason we chose to have two different motors is for balance. Brushed motors can get heavier the bigger you go, and our solar tennis ball collector only has two wheels. So, to help balance we chose to have two motors to help with the weight distribution, so it does not tip over.

At the end of the day we are three electrical engineers and one computer engineer. We do not have an in-depth knowledge of the mechanical engineering field. That is why we want to choose a motor that is reliable, low maintenance, efficient, and will deliver the power we need. This is why we chose to build our solar tennis ball collector using brushed motors. With brushed motors we are confident that all of our needs will be met and that hopefully there will be a sense of ease as we implement the motor into our project.

There will also be a gearbox transmission for each wheel. This is to gain much more torque such that it allows the robot to move easier since of the heavy load it has of about 30 pounds.

#### 6.1.3.4 Voltage Regulator

We will need a DC-DC voltage regulator for certain parts of this project. This Regulator is to provide a stable 5V output. The voltage regulator will be for a good portion or components motor drivers, and for some sensors. The voltage of the sensors would be regulated to an output of 5 Volts. For example, one will have an input of 12V, but the voltage regulator will drop it down to five; these different voltage outputs will be used to power the different components.

For finding out how to build this voltage regulator we used various sites like [webench.ti.com](http://webench.ti.com) and [snapeda.com](http://snapeda.com) to help us in the design and make sure the

cost was low, but balanced. And we are still working on the voltage regulator. This is one that we found that works for us but currently we are struggling with implementing this component as the 'LMR' chip is proving difficult to work with so we most likely will need to update the voltage regulator.

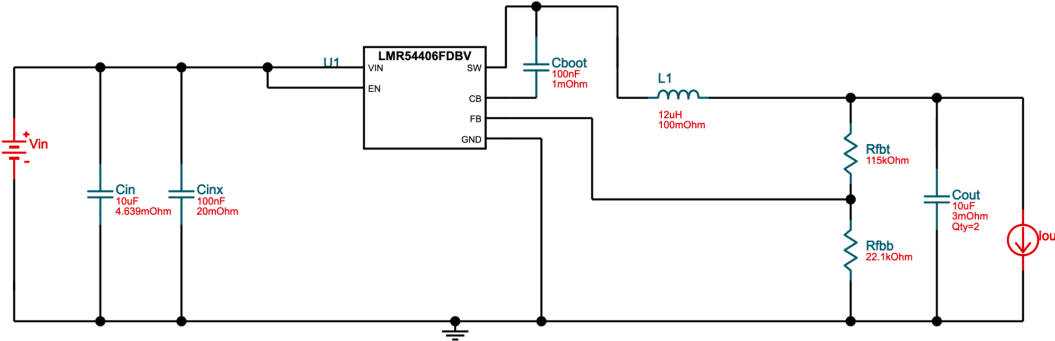


Figure 6.2.4: Example of Voltage Regulator Circuitry

Although we have already designed a voltage regulator, we in the lab, through tests, found out it couldn't work within our system. And on the spot we had to design a new Voltage Regulator for each of the motors. Figure 6.2.5 is the design we went with. Had to update the R2 and R1 values for it to work within our system. R2=10k Ohms, R1 = 2k Ohms. This is what worked for us in the robot.

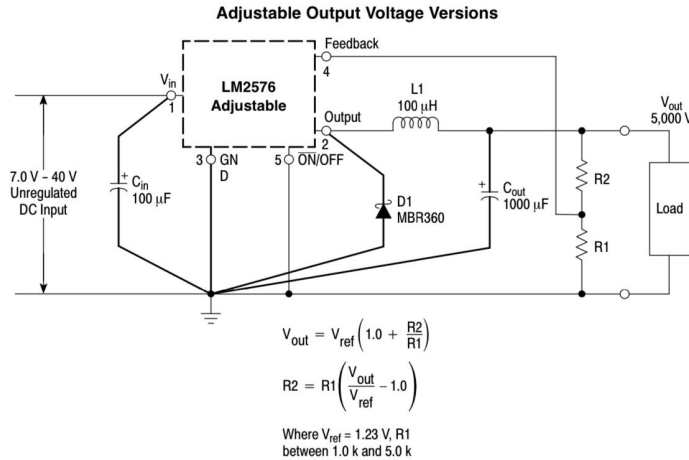


Figure 6.2.5: Voltage Regulator Used

With this LM2576 regulator we are able to drop down the voltage of the battery from 12.8 volts to the 7.4 volts needed by the motors. We had to make two of these circuits because each one is only capable of outputting 3 amps of current. When we calculated the stall current of the motors at a low speed, we received approximately 1.1 amps, and at a high speed it was 2.6 amps. Due to this we had to make a separate regulator for each circuit to be able to supply the much-needed current.

### 6.1.4 Second Subsystem: Collection

Another important part of the design is how the robot will collect and store the tennis balls as mentioned before the solution to this was a wire rack roller. This part would collect the balls and would store them within itself. This works with no motor or battery implementation. It uses an external push, such that the robot will be guiding the wire rack, and with the use of the collector arms, it will streamline the process of collection.

We do need to modify the collector, because as of now it needs a lot of force to pick up the tennis balls. We will be modifying it such that it will have bigger openings, which means it will have less resistance so that the tennis balls can be scooped up but also not fall out at the same time that is currently currently one of our problems at hand we have already ordered this part, so it should not be a problem when putting all of the subsystems together.

Another part of the collection portion of the project is the Collector Arms. These two arms are going to serve as channels, guiding the balls into the wire rack. The arms will be protruding out the front in opposite angles, reference figure 6.1.1.3, fixed to the frame.

When looking at the dimensions of this robot, it's looking at the longer side for travel. It's got the box and then it's got the wire rack and it's got the collector arms sticking out in front, therefore to make it easier for transport, the collector arms will be collapsible. This folding mechanism will provide ease when needing to move to/from the tennis court.



Figure 6.1.4: Wire Rack

This is the Wire Rack that we bought in senior design 1 class, as shown in this image. The Wire Rack works fine when a person is using it the way intended. In the video submission, you will clearly see that some force is applied downwards and in a swift motion and movement, the robot would not replicate since there will

be no downward force so the worry is that it'll just push the tennis ball along instead of collecting it. We will not be using it as it was built.

The roller has a pole attached to it, which allows you to put some downwards force onto the ball it picks up, which will be a problem for us in the future since the robot most likely won't be exerting that same downward force as designed. Therefore a solution to this is modifying the wire racks to have a wider gap in between each wire so the ball can pass through with less force.

As mentioned before the wire rack also serves a purpose of storing the balls once picked up as mentioned in section 6.1.5.1. Even though this is relatively a simple part of the design, it all comes down to this. If it doesn't pick up the tennis balls, easily and efficiently, the whole project could suffer.

### 6.1.5 Third Subsystem: Sensors

These sensors are going to be Robot's vision and touch. There are 3 types of sensors as mentioned before, the Raspberry Pi Camera, Bump, and Ultrasonic. The Camera is for visualizing the tennis balls, and the bump sensor is for when it runs into the net, fence, or obstacle if the Ultrasonic sensors don't work properly. The ultrasonic sensor is for detecting the obstacles at a distance and avoiding them. Specifically these three types of sensors are to work in unison and give information to the MCU so the robot can act accordingly. The Bump and Ultrasonic are for Obstacle Avoidance, and the Camera is for detecting and finding the Tennis Balls. On the software implementation of the sensors and camera, and how they are being used will be discussed into greater detail in Section 6.2.

#### 6.1.5.1 Ultrasonic

Ultrasonic sensors rely on sound waves. It emits high frequency pulses and measures the time taken for the waves to bounce back after detecting an object. We positioned these sensors on the top end of the frame. Each side has 1 ultrasonic sensor with custom 3D built cases that are holding them tight and we can give them any angle we want. These sensors need to be positioned such that it can detect the barriers accurately and react accordingly.

The image below would be an example of how the Ultrasonic sensor is connected to the MCU board. Typically, these sensors have connections for a 5V hot wire and ground. The other two connections are digital communication pins.

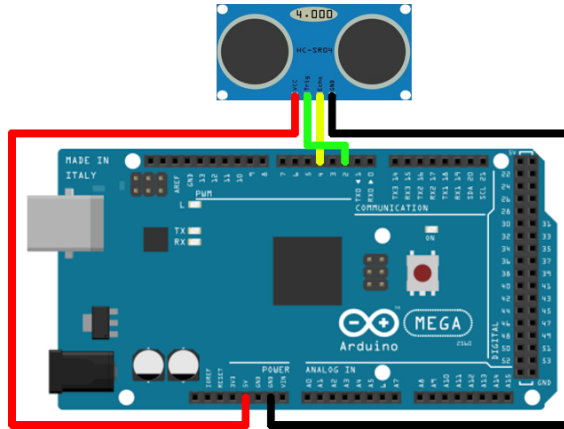


Figure 6.4.1 Wired Example between Ultrasonic & MCU.

Reference from: [https://ozeki.hu/p\\_3069-how-to-setup-a-ultrasonic-sensor-on-arduino-mega.html](https://ozeki.hu/p_3069-how-to-setup-a-ultrasonic-sensor-on-arduino-mega.html)

We have four sensors. Sensors will be for detecting obstacles such as fences, nets, and people. Ultrasonic sensor will act differently depending on the distance between robot and obstacle. If the obstacle is around 50 cm then the sensor will give a signal to motors to slow down immediately. If it is around 200 cm left or right the motor will decrease speed in one of them. Which means if left will slow down then the right will be at the same speed. It will help robot to change direction.

### 6.1.5.2 Raspberry Pi Camera Module

This in the end is the type of technology we used for detecting the Balls. At first we had IR Distance Sensors, but it was pointed out that the IR sensors were not going to work as we had imagined. After the PCB was designed we scrapped the IR Sensors so they aren't in the system at all. The camera was the better alternative and solution to our problem. With computer vision the robot would detect the balls better and not get second as much. The problem we had with the IR sensors was that they only worked at really close range. The camera's range of vision is much, much larger and detailed.

### 6.1.5.3 Bump

The bump sensors act as a secondary safety precaution, and help when if the other sensors are overloaded it is a safety feature that detects collisions with objects on the tennis court. The design of these bum sensors need to have an appropriate sensitivity and response time. The positioning of these sensors are crucial in order for safe operation. Upon detecting an object, the sensor should trigger a safety protocol, such as going backwards, or turning away from the object. A bump sensor will be placed at a higher level than the ground. The reason behind that is to let the robot not confuse itself between tennis balls and barriers.

The most suitable bump sensor for our project is the limit switch. Limit switch is a budget-friendly product that is well known in the electrical engineering field. Limit switch comes with three pins and a lever with the roller tip. Lever with the roller tip detects the collision. A lever is getting pushed by the barrier or object and it sends information to pins. With that, the limit switch is getting activated. After being activated, the robot turns at a designated angle to avoid collision with the same barrier.

Schematic of the limit switch is shown in figure 6.1.5.3.1. NO and NC pins are being triggered when the limit switch's roller tip detects collision. NO pin will let current flow through the pin when it is going to be triggered by collision.

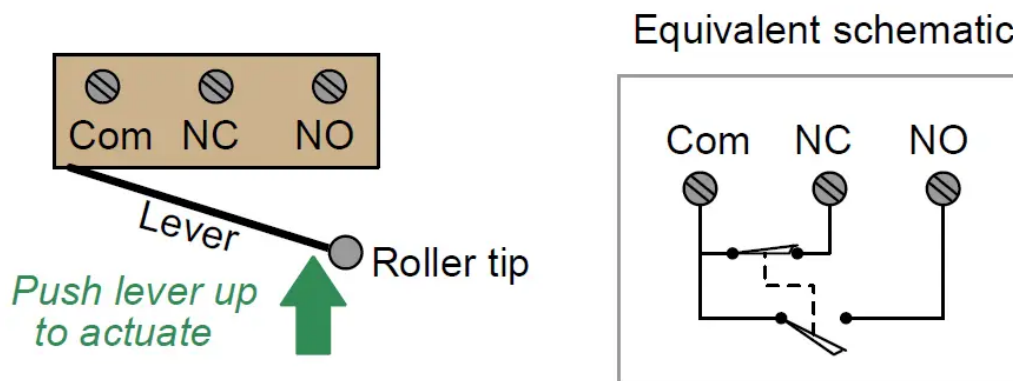


Figure 6.1.5.3.1: Limit Switch Bump sensor.

Reference from: <https://instrumentationtools.com/basics-limit-switches/>

### 6.1.6 Fourth Subsystem: Frame

The Frame is one of the most important subsystems in our solar tennis ball collector. Even though the frame itself does not include any electrical components that we electrical and computer engineers are used to, we cannot skip out on the quality or put minimal thought and effort into it. We need to do extensive research and testing to be able to find the best frame. We need to compare different materials, sizes, weights, etc. All of these are coming to be very crucial for us to decide what frame will be the best for us to use in our project.

The frame is so important because we have very sensitive components that we need to protect and keep safe. Our solar tennis ball collector is meant to be outside for most of its lifetime. So, we need to make sure that the frame can withstand the elements. We have to make sure that the frame is water resistant so that no electrical components get damaged when it rains. We also have to make sure that the frame can withstand any accidental collisions. We are designing our solar tennis ball collector to stay along the edges of the tennis court. However, there are some collisions we cannot completely predict and

account for. For example, it needs to be able to withstand a hit from a tennis ball. The average tennis serve is about 120 mph. We need to make sure that our tennis ball collector can withstand such a collision. This is just one of the different types of collisions that we cannot account for.

For our frame we have gone with the dimensions of 15.5 inches x 15.5 inches x 10.5 inches. This is what we have decided to start with. We believe that this frame would be big enough and provide ample room for all the components we need to fit inside perfectly. We also want to design the frame relatively small like this to cut down on weight. We are predicting the frame to be the heaviest subsystem/part of our tennis ball collector. If we can make our frame as lightweight as possible this would help us out with our motors. The lower the total weight of our solar tennis ball collector we can buy less powerful motors saving us a lot of money. With all the hardware installed our frame weighs approximately 10 pounds.

Now that we have some preliminary measurements we have come up with some simple drawings and schematics for what we envision our frame to be. We want to keep our frame a simple design. A simple cube or prism would serve us best. We discussed going for more of a pentagon or octagon shape, but we concluded that creating a complex shape might make us spend more money on materials. It would also take a lot more time to actually realize an octagon than it would for a cube. A complex shape may also cause issues in the long run with us having to work extra with wiring, spacing, balance, etc. This is why we have stuck with a simple shape for the frame.

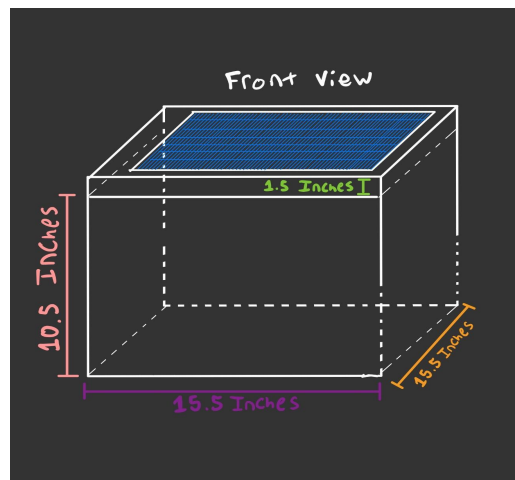


Figure 6.1.6.1: Frame Schematics Front View

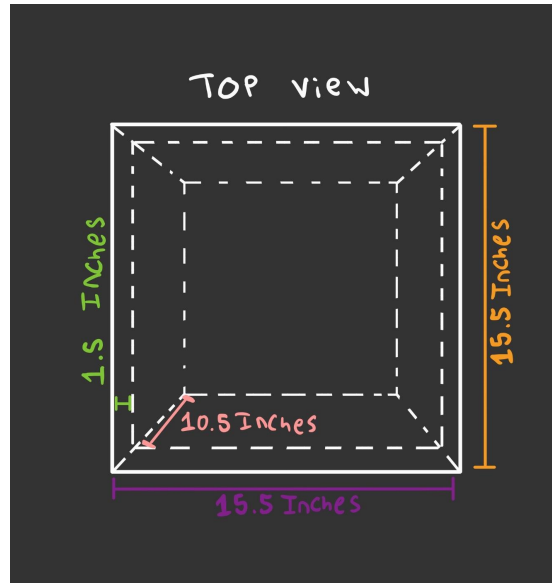


Figure 6.1.6.2: Frame Schematics Top View

### 6.1.6.1 Wheels

Our design has two wheels and each will be connected to a motor. The roller will act as a third big wheel to stabilize the robot since it would be on two wheels. For the robot to go forward, both of the back wheels, which are each connected to the motor, will roll forward in unison, likewise for going backwards, but when turning, each will turn in the opposite direction so that the robot will rotate in place. This will have the robot react quicker than the other option, which was having one stay still and the other term this would also have a smaller turning radius.

We have specified the size of the wheels. The wheels will have a diameter of 7 inches. These specific wheels may have been over engineered for our project, but they can withstand 100 pound loads and still function. We went with these wheels because they were heavy duty and reliable. These wheels provide us with enough height and clearance so that the wire rack will be rolling on the ground and the rest of the frame will not be scraping the ground.

### 6.1.7 Fifth Subsystem: MCU

For the MCU, we will be utilizing one typically found on an Arduino mega board; ATmega2560. This will be the only component we integrate from the Arduino circuit board, which we will also be using for prototyping and breadboard testing. This is part of the brains of the tennis ball collector. Below in the schematic you can see that it has many pins. We went with this version of the MCU because of the amount of input/output pins that it has. The fact that these are digital allows us to customize it even further. When working with such a large number of

peripheral devices like sensors, it is important to have sufficient dedicated pins for reading and controlling each peripheral.

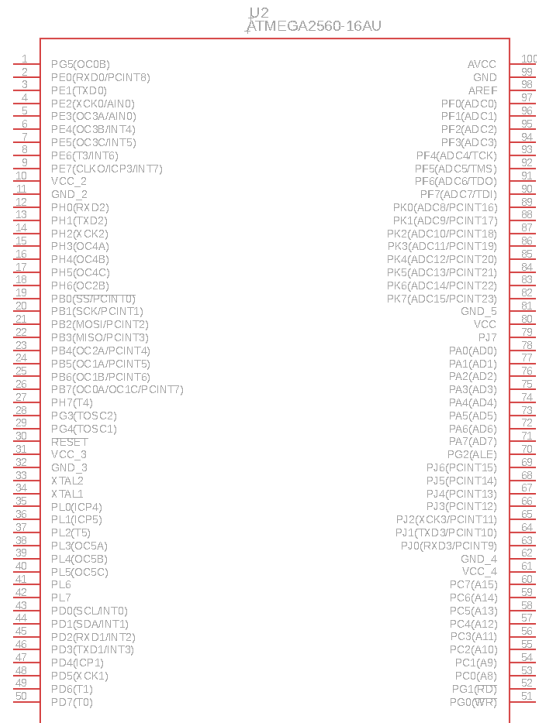


Figure 6.6: Schematic of ATMEGA2560

The ATMEGA2560 was also picked due to its convenience for programming. Being the MCU used on a well known and common project board means that compatibility and documentation are guaranteed to be abundant. Arduino's own software also adds its own layer of convenience, offering an integrated development environment (IDE) for programming embedded microcontrollers.

### 6.1.8 User Interaction

The goal with our solar tennis ball collector is to make life for the user as easy and as simple as possible. It is supposed to make the mundane tasks of going around and picking up tennis balls a lot simpler and faster for the user. For us this means that the user will not have to do very much when it comes to our tennis ball collector.

There are three main tasks that the user will have to do by themselves. The first task is to simply just turn on the tennis ball collector. We plan to add an on off switch somewhere on the frame so that the tennis ball collector is not always running. The second main task the user would have to do is empty the storage when either all the balls have been picked up or the storage is full. The last task would be for error correction. This would only rarely happen. If the solar tennis

ball collector brings up an error code the user is going to have to tend to the issue.

Overall, we are trying to make our solar tennis ball collector very simple and stress free to use. The project might be a complicated one to design and build as a whole due to the big combination of computer engineering, electrical engineering, and mechanical engineering. However, we want to make it as uncomplicated and effortless as possible.

## 6.2 Software

### 6.2.1 General Design

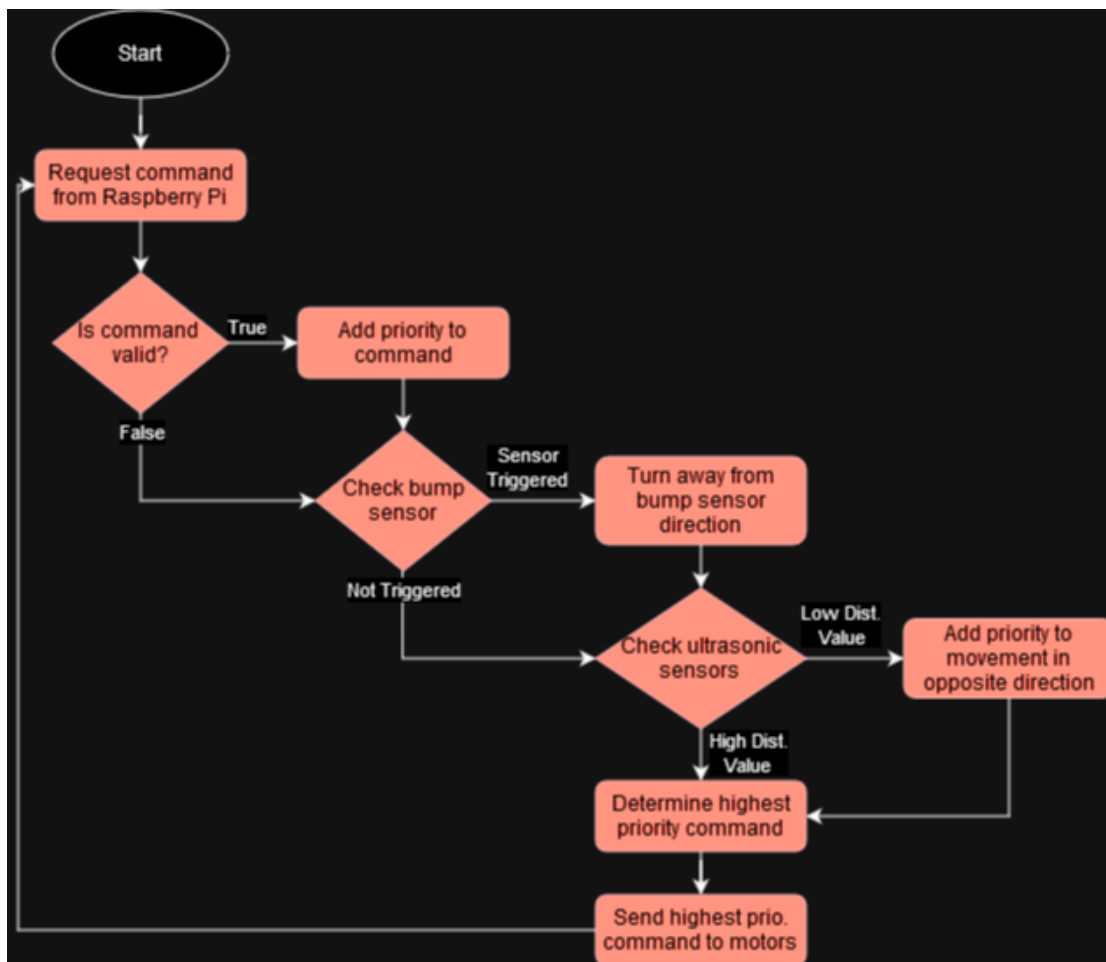


Figure 6.2.1.1 Main Controller Software Flowchart

The goals of the software of the solar powered autonomous tennis ball collector are, generally speaking, to sense the world around it and react within constraints. The most important things to detect for the robot are the tennis balls and any other miscellaneous obstacles to avoid, like walls, fences, or people. Depending on the information gathered about these objects of interest, the robot is expected

to react almost entirely with navigation. Obstacles being detected should result in movement away from that obstacle and tennis ball detection should result in movement towards the ball.

There are a few other systems that involve software, though they are not the core focus of the design. The computer vision system is significantly dependent on software to function but interaction with the main controller board is simplified as much as possible to act like another sensor. The structure of the computer vision algorithm will be discussed in more detail in the section concerning tennis ball detection. The other component that had software written for it is the solar panel charge controller, which uses a smaller, less powerful MCU to monitor incoming power from the solar panel and control its flow to the battery with PWM signals. This board is completely separate from the main controller and runs independently from the rest of the system. Further detail on this implementation can be found in the section titled Charge Controller. Below is a use case diagram showing the responsibilities of the main controller and the Raspberry Pi that handles computer vision.

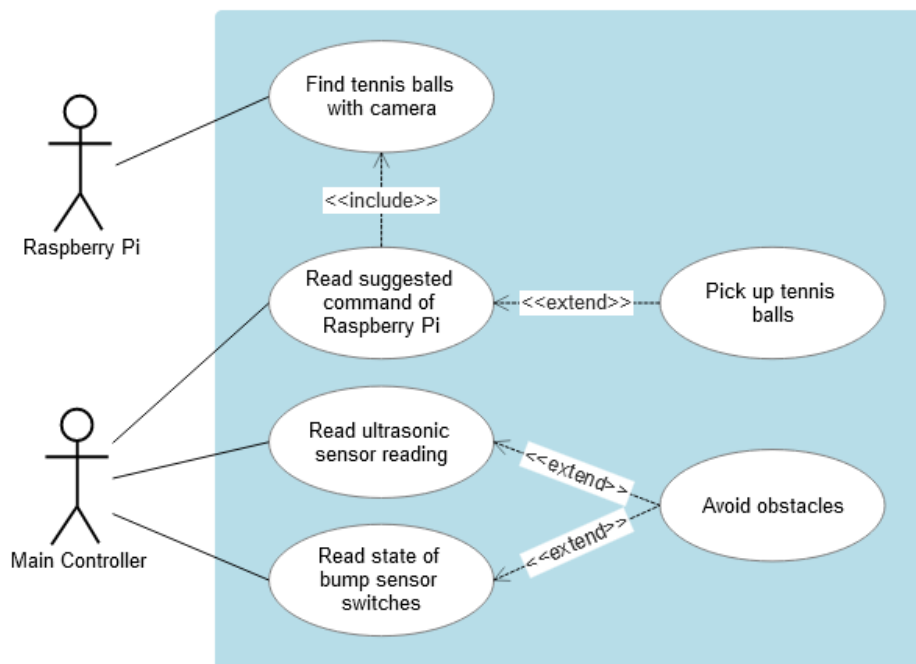


Figure 6.2.1.1 Use Case diagram for control of system

## 6.2.2 User Interface

While the ball collector is expected to work with people present, the software is designed to work as autonomously as possible. This means that there is very little that users are expected to do to operate the collector save for emptying the storage compartment when it is full. This is, of course, by design since one of the

goals of the system is to allow tennis players more time to play or practice and reduce time spent picking up loose balls. Ideally, the only interaction the user is expected to have is starting the robot and emptying its storage when full.

### 6.2.3 Robot Control Architecture

Autonomous systems are often expected to take in input of some kind, process it, and then react accordingly. This series of steps is often referred to in robotics research as “sense, plan, act”. These steps are often separated into different dedicated systems that are then put together into one body. Sensors, microphones, cameras, and other input devices make up the “sense” part of the robot. “Plan” often refers to the processing and problem solving abilities of the robot’s central controller. What can be described as the output of the robot, which is often a sort of action or reaction to complete the robot’s goals, makes up the “act” system. This last system often consists of limbs, motors, servos, speakers, lights, or other controlled or output devices.

In some earlier robotic systems, this philosophy of robot control led to robots with heavy emphasis on the planning system to create more intelligent designs. The most notable early example of this planning based design philosophy was Shakey, a robot developed at the Stanford Research Institute around 1966. Shakey was expected to solve relatively complicated problems involving navigation and object manipulation by utilizing a dedicated planning algorithm called Stanford Research Institute Problem Solver (STRIPS). This planning based system requires two important aspects to work well: a strong planning processor and a saved world model representing the operating environment. This world model would have to be updated often to ensure an accurate model and in turn allow for well functioning plans. In more complex systems, the planning algorithm demands mapping and positional information from the world model. Generally speaking, a heavier focus on planning and problem solving results in greater demand in processing and sensing.

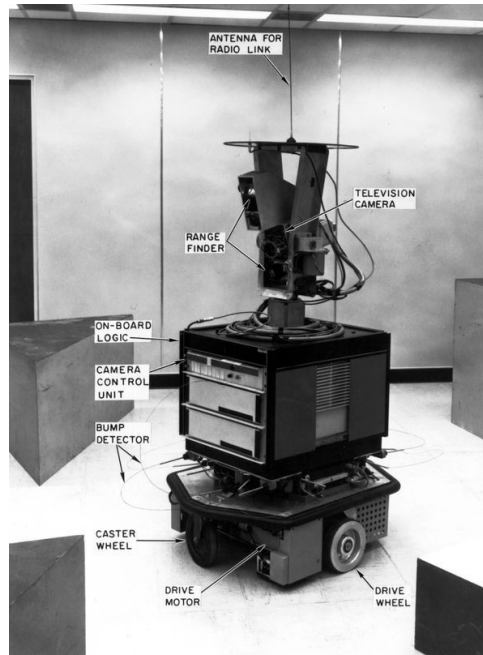


Figure 6.2.3.1 Shakey and its individual components. Reference from <https://www.computerhistory.org/revolution/artificial-intelligence-robotics/13/289/1241>

On the other hand, many simpler robotic systems were created that did not rely on any processing or planning for operation, creating more reactive systems. The design philosophy behind these robots were often based around specific sensor readings having a set reaction without any deliberation or processing. This means that reactive systems react much faster to significant changes in their environment than deliberative systems would.

This lack of a processing requirement allowed for fully analog systems to be created, meaning some of the earliest reactive robots predate computers small enough to be mobile. While deliberative, planning focused robots were often aiming to emulate human behavior, these reactive robots were often designed to be more animalistic in their behavior. A notable early example of the fully reactive design is W. Grey Walter's Elmer and Elsie, a pair of light-following tortoise robots that used a photocell to detect and follow light and a touch sensor to avoid obstacles.

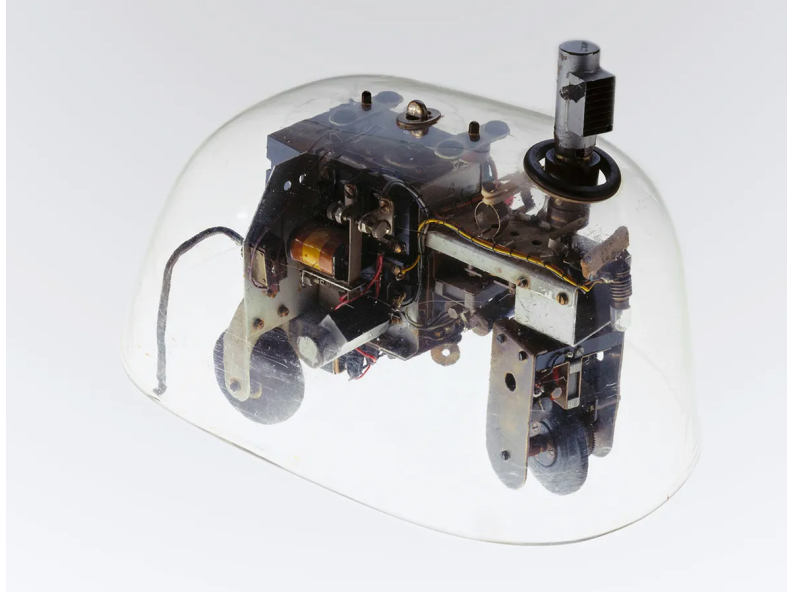


Figure 6.2.3.2 W Grey Walter's cybernetic tortoise. Reference from <https://spectrum.ieee.org/meet-roombas-ancestor-cybernetic-tortoise>

Our system utilizes a sort of hybrid between these two types of designs, using a processor but with very little planning. This is often referred to as behavioral control, something more like how animals are expected to act. Utilizing only simple sensors, keeping an accurate and useful world model for complex planning would be difficult. This naturally pushes us to either simplify the robot's behavior to be more reactive or use more sensors to create a more complete and accurate world model. Since the goals of the robot are relatively simple, we decided on the behavior-based software design.

In the field of study of robot control, what is often referred to as "hybrid" control specifically separates the reactive and deliberative parts into separate subsystems that work independently from each other. In this control architecture, the deliberative system would make plans and act on them without concern for more immediate problems. This responsibility is left to the separate reactive system, which acts only when triggered. Since the two systems are effectively separate, a third subsystem is designed specifically to allow compatibility and cooperation between the systems.

The final architecture used for the control of the robot is only technically reactive, as while inputs trigger specific behaviors, the result of those behaviors are more like suggestions to the reaction the controller finally decides on. The values that are added to the priority list of actions typically ensure that the correct action is taken, but also takes into account simultaneous readings from other sensors with opposite reactions. For example, if the robot only detects an obstacle on its left, it will almost guarantee movement to the right, but detection of objects on both

sides at the same time should not result in movement in both directions. Reactive code will still be incorporated for urgent reactions like immediate collisions, but there is definitely more deliberation and very basic planning involved in this robot's design.

### 6.2.4 Digital and Analog Sensors

Most microcontrollers explicitly distinguish between analog and digital input pins. This difference is significant, as analog signals have continuous values to take into account, while digital signals are a series of predefined discrete values transmitted at a predictable rate. Digital input signals are easier to interpret for computers, which are designed almost entirely as digital systems, so very little translation is necessary for processing the signal on the MCU. Analog signals, on the other hand, need to be converted to a format that can be interpreted by digital systems by discretizing the values and time frames, which often requires a dedicated ADC (analog to digital converter). This difference is significant when considering the expected inputs for an embedded design, since ADCs are limited in the ability to make conversions quickly enough for a real time system. This often results in embedded microcontrollers with less analog capable input pins than digital pins.

To avoid processing delays and a greater need for limited analog capable pins, sensor input should be taken as digital input as much as possible. Luckily for us, most of the sensors we intend to use output a digital signal. For example, the bump sensors are functionally simple switches. While many models of bump sensors have different options for wiring and switch configurations, most still act the way any regular button or switch would. The only expected behavior of a bump sensor is to turn on and off, the simplest of digital signal operations. Distance sensors could be expected to provide an analog output signal due to the fact that they measure distance, a continuous value. Despite this, most of our distance sensors output digital signals since they are designed to work with embedded systems with limited analog processing capabilities.

	<b>Advantages</b>	<b>Disadvantages</b>
<b>Analog Signal</b>	<ul style="list-style-type: none"> <li>- Continuous measurement values</li> </ul>	<ul style="list-style-type: none"> <li>- Limited MCU pins</li> <li>- Takes time to convert to digital</li> </ul>

<b>Digital Signal</b>	<ul style="list-style-type: none"> <li>- No conversion, quick input</li> <li>- More pin availability</li> <li>- Simple signal</li> </ul>	- Discrete values
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Table 6.2.4.1 Comparison of analog and digital input signals for use in embedded systems

### 6.2.5 Loops and Interrupts

Embedded systems are often programmed to run on an infinite loop, only stopping when encountering a fatal error or when the system is shut off. The issue with this method of programming is the fact that it results in a constantly running processor, which constantly draws power, even if nothing is happening. This applies to software delays as well, as wait functions are typically not based on passive clock devices but the clock that drives the central processor. To remedy this, most embedded designs utilize a power save mode on the microcontroller that disables unnecessary clocks and devices until they are reactivated by a hardware interrupt.

Interrupts are functions able to stop the current process being handled by a central processor, execute, then resume the process it had stopped. This allows for simplification of the main loop's operations to only processes that can not be run passively.

Reducing power consumption is an important part of our design due to the fact that we expect to be limited in its availability. While microcontrollers don't consume much power compared to motors, it is still important to avoid excessive power draw, so power save modes should be utilized where possible. For this design, low power modes will not be available for most functions, as most peripherals and sensors are directly driven by the microcontroller.

When input devices are repeatedly checked by the controller device on a loop, it is referred to as being polled. Polling is generally less preferable to use in an embedded design than interrupt based input checks, as it requires dedicated commands in the main loop that take power and delay other essential commands that need to be looped. Interrupting input devices only delay commands when they need to be processed first anyway.

### 6.2.6 Ball Detection

Ball detection is accomplished using a computer vision algorithm and a camera. This camera is connected to the Raspberry Pi board, which runs OpenCV, a library of image processing algorithms used to help computers identify significant

objects in images. For this project, OpenCV runs on a Linux based system and is programmed in Python, running on a loop that is completely independent from that of the main controller board. Every loop, the Raspberry Pi's script stores a value that corresponds to a specific command that it sends to the main controller when prompted. This is handled by an interrupt, temporarily and quickly stopping the current process to send that command. A new picture is taken every loop, ensuring an up to date view as often as possible.

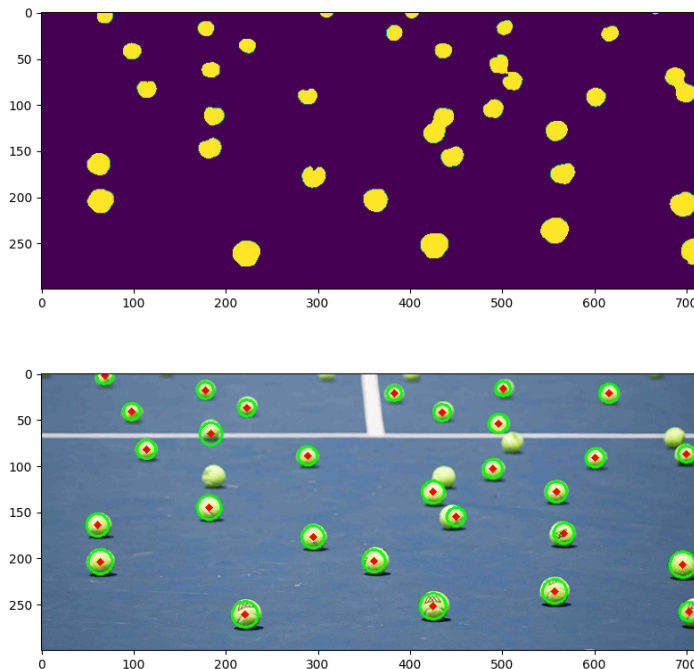


Figure 6.2.6.1 Test image of ball detection algorithm, binary image on top, locations of circles drawn on original image on bottom

The process of object detection using computer vision can be summarized as identifying a notable defining aspect of that object, filtering out any unnecessary information in the image, and finally finding important information about the object you are trying to detect. For tennis balls, we can use their unique color and their round shape to find them in images. The first step of the algorithm is to filter out any pixels that are not the color of a tennis ball. This is done with a function for finding colors within a given range which creates a binary image the same size as the original where pixels that are outside of the range we are looking for have a value of 0 (false) and pixels within that range have a value of 1 (true). To help filter out smaller pixels that may fall within that range and make balls stand out more, the image is blurred before filtering. The binary image is then checked for circles using the Hough Gradient Method, which uses the edges between colors in images to find contours. The result is a list of locations in the image where circles (which can be safely assumed to be tennis balls) are found.

After this list is compiled, it is sorted by vertical location, lowest to highest. This is to prioritize balls that are closer to the robot and would show lower in the image. The top 10 circles are taken from this list to further prioritize closer balls. From here, the horizontal locations of each circle are tallied, counting whether balls are located in the left, right, or center of the frame. The direction with the highest value is taken and used to determine the direction command the robot stores to send to the main control board.

### 6.2.7 Obstacle Avoidance

Obstacle avoidance in our design has two stages. The first consists of ultrasonic sensors facing in the direction of each side of the frame. The expected response from each of these sensors depends on their location and the distance they sense. The forward facing sensor will add priority to movement in any direction but forward, and prioritize turning in place if it detects anything too close. The side sensors will add priority to slight movement in the opposite direction of their position (for example, the left sensor will trigger movement to the right). The back sensor only discourages turning in place, reducing priority value for doing so. This is because the robot primarily moves forward and doesn't fully reverse.

While we theoretically could solely rely on these sensors for obstacle avoidance, they have limited fields of view and specific limitations on what surfaces can be detected accurately. For example, ultrasonic sensors rely on sound waves reflecting off of hard surfaces, so netted or wire barriers like fences are difficult to detect for these sensors. Another hard to detect surface for ultrasonic sensors would be very soft materials that dampen sounds, like wool, though these would be rare to encounter in our expected operating environment.

To compensate for the limits of the first stage sensors, the second stage consists of bump sensors on the front of the tennis ball collector that will signify immediate contact with an obstacle. These bump sensors are expected to sense hard collisions on or near the collector arms meant to guide balls into the wire roller as the robot drives over them. This means the two stages will have different necessary reactions from the robot when they are triggered as well different levels of priority. While the distance sensors will show objects to be wary of and cause the robot to attempt to avoid them, the bump sensors show objects that need to be moved away from immediately.

When a bump sensor is triggered, the robot will immediately stop and turn in place away from the side where the sensor is located. The robot will then try to move forward and resume normal operation. If the robot has not moved away enough to avoid collision, the bump sensor should reactivate, restarting the maneuver. This reaction is triggered immediately as opposed to at the end of the loop after priorities have been calculated due to its urgency. Ideally, this would have been triggered with an interrupt, but due to a hardware design mistake, this was not possible to implement in our final design.

## 6.2.8 Motor Control

When controlling an electric motor, a separate driver device is often utilized to manage the power signals sent to the motor. In a sense, the motor isn't the device being controlled, it's the driver. In the case of most DC electric motors, drivers are commonly made up of pairs of MOSFETs, each controlled by pulse-width modulation (PWM) signals.

PWM signals are similar to periodic square wave signals but instead of a set and equal length of time for high and low signals, high signals can vary in time length, or their "pulse width". The number of pairs of MOSFETs is dependent on the number of "phases" of magnets used in the motor, which are controlled separately with the same frequency and signal, but phase shifted. That is to say that a magnet phase is meant to activate and deactivate in sequence with the others to properly turn the motor.

Since not being able to keep up the precise timing needed to drive the brushed motor results in reduced power efficiency and possible damage to the motor, it is very important to be able to keep that timing. One way to simplify this process is to implement an electronic speed controller (ESC) which manages timing and motor driving on its own. The ESC is itself controlled by a single PWM signal, which becomes much more efficient and convenient than the multiple required by the driver alone. To control the speed of the motor, the pulse width of the input signal is increased or decreased to make the motor turn faster or slower, respectively.

It is important to note that while directly controlling the driver allows us to change the motor's direction, this is not possible with only an ESC, which only allows for changing speed in one direction. To have the motor change direction, the ESC must be specially capable of changing direction or a relay must be utilized to swap signals of the wires leading from the ESC to the motor, essentially reversing the phase activation sequence. In ESCs that are capable of driving forward and backwards, there are ranges of pulse widths that denote neutral, forward, and backward control. For the ESCs we worked with, reverse was triggered at pulse widths less than 1.45ms and forward at widths higher than 1.55ms, with the range in between reserved for "neutral."

With any method of driving the motors, it is very important to note that when working with motors, especially electric motors, there are many warnings and constraints that need to be considered to ensure that the motor does not become damaged. One of the most important constraints for our design is the fact that the motor can not change direction immediately, it must slow down and come to a complete stop before attempting to turn the other way. This must be highlighted in designing software, as an unchecked error of this kind will not be apparent until the motor has already been damaged and needs to be replaced.

### 6.2.9 MPPT Charge Controller

The charge controller is only technically connected to the rest of the system via power management, so the software is completely disconnected from the control systems discussed in sections above. The software design for the charge controller concerns efficiently and safely charging the battery by monitoring and controlling the current sent to it. Implementation of this software is relatively simple but absolutely necessary due to the volatility of lithium batteries and the inherent fluctuation in power provided by solar power. In short, the program needed for this function of the project involves taking the measurements from the panel's output and directing it as needed to increase or decrease the operating input for the battery.

## 6.3 Hardware and Software Closing Statements

Overall, This project to sum up quickly is divided into two components, Hardware and Software. These two main groups work together as one, and the result would be our prototype. The moving pieces, the code, the electricity, being drawn from the sun, all need to interact smoothly for a good operation of the robot. To ensure that our hardware and software do so, we will be conducting tests for every subsystem mentioned in this section. We will be conducting mini tests before implementing each part. This will go into further detail, and the next section. We have already had many versions drawn up, each surpassing the prior.

When speaking about hardware we are talking about the solar energy being converted into electricity, being stored into the battery, which then goes to a voltage regulator, which then the sensors can now operate and the MCU. This voltage regulator ensures the system doesn't get overloaded and burnout.

We ended up with 2 PCB's, one as the Main, and the other to act as the Charge Controller. We made 2 more prototype boards to regulate the voltage to each motor. The software will account for each case, and in theory, the robot will react accordingly and decide its next course of action, whether it's picking up the balls or running into an object or when it's at its capacity, the robot will have a function to perform.

## 7.0 Overall Integration, PCB and System Testing

This section explains planning and testing systems using equipment that a robot requires. The major components for solar tennis ball collectors are motors, solar panel, sensors, microcontroller. These components have a critical role in our robot's functionality. We are going to test each equipment to get its best outcome for the final product. Each component has to operate as needed. If one of the components fails, the robot is not going to be able to function as desired.

Our main goal is to complete each testing successfully so we can construct each part effectively. That will lead us to a more accomplished product. We are going

to start testing electrical components first. For instance, we are going to start with solar panel testing first since solar power is the main source to get the robot to perform at its best. After that, we are going to move on to sensors. Sensors are going to be number one components for detecting objects, distance, and collisions. Our brushed motor is one of the major equipment that robot will have. After testing all these components, we are going to start testing PCB. PCB is going to be the principal part of this project. With a failed PCB we are not going to be able to get the outcome that we need. That is why we are going to be more attentive to PCB testing in comparison to others. Lastly, wire rack, wheels, and frame components are going to be our last systems that we are going to test. Some tables show what are the main goals in system testing in specific component models below.

## 7.1 Solar Panel Testing

As we mentioned, we decided to use a monocrystalline solar panel in our project. Before using solar panels on robot, we have to test solar panels and see how much power we will get. Since our PVC frame is going to be 15.5"x15"5x12.25" we are using a panel that isn't much bigger than the frame..

Solar Panel model	Main Goal
Monocrystalline	Provide energy for performance

Table 7.1.1 Solar panel model and main goal.

This part of the testing was a breeze when thinking of all the amount of testing that was involved throughout the project. All we needed was to see if the panel was working. The panel we specified came with a charge controller already so we hooked it up to that to test the reading and proper function. It was, so the next step was to hook it up to the battery with the MPPT PCB also connected. To simulate a Solar Panel we had a DC Supply hooked up to it first in the lab. After ensuring the input/outputs were reading correctly, it was time to take it outside. Once the system was all connected, it was outputting and inputting how we thought it would. Connecting the red probe to the positive terminal and connecting black probe to the negative terminal will give us output of current and voltage. Overall power will be voltage multiplied by current. After getting output voltage, we were outside in different weather conditions. For example, if the weather is sunny, we are going to measure outputs based on sunny weather and shade or cloudy weather. We are going to measure both conditions to make sure if there is a slight or high increase or decrease depending on the weather.

We are going to measure all the output powers that other equipment are going to provide. Efficiency of monocrystalline solar panel will be 17% and solar irradiance is going to be 1000 watts per square meter. Panel size is going to be  $0.145 \text{ m}^2$  (15"x20"). Output power should give us approximately 24.7 Watts. Table 3.2.2.2

shows more detailed equations about solar panel calculations. All other equipment combined should be less than given output power. After getting output power, we can demonstrate work based on solar power. Thin film solar panels will not give as much output power as we are going to have in monocrystalline solar panel, because of its efficiency.

## 7.2 Ultrasonic Sensor Testing

Ultrasonic sensor is a major component of the solar tennis ball collector project. We are going to use an ultrasonic sensor to detect obstacles. If the ultrasonic sensor fails, we have the bump sensors as a backup.. We gained knowledge about ultrasonic sensors in our junior design course. It gave us enough knowledge on how to use ultrasonic sensors.

Ultrasonic Sensor Model	Main Goal
HC-SR04	Avoiding obstacles

Table 7.2.1: Ultrasonic sensor model and main goal

One of the most recognizable ultrasonic sensors is HC-SR04. This sensor contains 4 pins. These pins are VCC, TRIG, ECHO, and GND. Trig stands for trigger. Echo pin's role is to receive reflected sound. Which means it is the receiver part of the ultrasonic sensor. We are familiar with this ultrasonic sensor and we used it in our junior design project before. We are going to test ultrasonic sensors on a public tennis court. It will be used as the first line of defense and will avoid obstacles. The sensors should detect the obstacles up to four meters and minimum of two cm. The approximate speed of sound is going to be 29 uS/cm at room temperature. However, outdoor tennis courts are not going to be the same temperature as an average room. To get the best output of ultrasonic we have to test it outside since solar tennis ball collector is planned to be used outdoors. We cannot end our testing only using it in clean and sunny weather conditions. Our target is to use an overall of 6 ultrasonic sensors on the solar tennis ball collector robot.

After the testing phase was over, we ended up using 4 Ultrasonics in total. Front, Left, back, and right. They are placed at the top of each side, facing directly outwards at 90 degrees. This layout covered most of the space and also provided simplicity for wiring and setup.

## 7.3 Testing Tennis Ball Detection

After testing ultrasonic sensors, we have to test the detection of the tennis balls. That is where the Raspberry Pi camera comes in. Testing the ball detection algorithm is first done using test images with ideal lighting (typically stock images found on the internet). Testing this way provides a baseline for what to expect

from the images taken by the camera and helps determine a range of colors to filter to find the correct color. Next, single images are taken on the camera we intend to use and individually tested with the algorithm. These results are used to tweak parameters further to reduce false positives and ensure that most, if not all, tennis balls can be seen by the algorithm. Sample images should vary in angle, lighting, and background to ensure consistency with the algorithm.

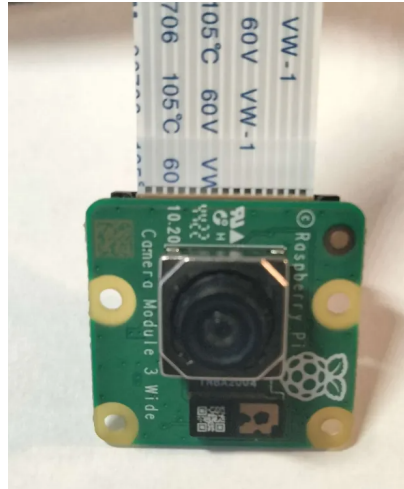


Figure 7.3: Raspberry Pi Camera Module 3

When the software is confirmed to work properly, testing can be conducted with the camera in its intended position on the collector robot. Before establishing communication with the main control board, outputs are monitored remotely to ensure they read correctly. In this case, we place tennis balls in various configurations on the floor in front of the robot and check the direction they read and the quantity of balls that it sees. Further testing is done after full installation of components, ensuring that the Raspberry Pi is sending the correct navigation signals to the main control board by having it try to pick up tennis balls on its own. This stage of testing is conducted after the motors, processor, and frame are all tested.

Difficulties in testing this system came more from the library for accessing the camera and communication with the main board. The camera library was being actively developed, leading to difficulties in finding documentation for troubleshooting,

## 7.4 Limit Switch Bump Sensor Testing

The Solar-powered tennis ball collector is not going to give its best outcome if there are not going to be any bump sensors. As we all know, lots of smart vacuum companies use bump sensors to avoid vacuum cleaners getting stuck with an object or obstacle. Tennis courts are enclosed with specific barriers. The most well-known barrier for tennis courts are fences. Robot will face challenges

or will not perform their best outcome if there are not going to be any bump sensors. There are going to be ten sets of limit switch sensors. These ten sensors are going to be located in the front end of the robot. The front left arm and the front right arm each have five bump sensors tied together respectively.

Limit Switch Sensor Model	Main Goal
MS0850502F030P1A	Detecting Collision

Table 7.5.1: Limit switch model and main goal

MS0850502F030P1A is the limit switch that we are going to use. This bump sensor is the most suitable product for our project to avoid collisions. Limit switch has two pins which are COM, NO, and NC. If the switch is triggered, the NC terminal will be open circuit stop connection. It will happen when the robot will get in contact with a barrier. NO switch helps current to go through the switch when it is getting triggered. It remains open when the limit switch is not being activated. We are going to mount bump sensors on the right and the left side of the front end. Bump sensors are going to be the first equipment when the robot encounters an obstacle. These sensors cannot be mounted at a lower level of the robot because we are trying to prevent sensors from hitting the tennis balls. If it hits the tennis ball it can read it as an obstacle and can change direction. To prevent that, we mounted them at designated height to avoid hitting tennis balls. Best place to mount them was the upper arms. With that, a wire rack can collect the tennis balls without any issues. Figure 7.5 shows where some of the bump sensors are located on the robot's upper arms.

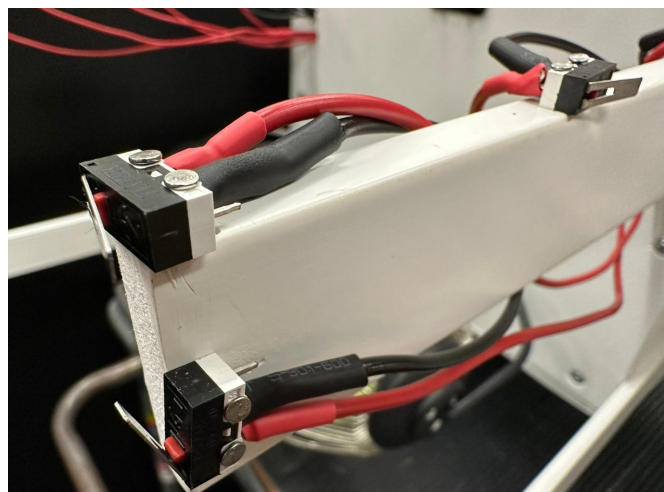


Figure 7.5: Bump sensors

To test bump sensors, we are going to have to apply light physical force to see if the sensor will detect collision. After detecting collisions, it has to send information to axles and motor. Robot will change its direction in a designated way to find an empty area so it can move without hitting any obstacles. One wheel will slow down and the other wheel keeps rolling. It all depends which upper arm detects collision first. We are going to test physical contact on bump sensors multiple times. We have to be sure that the bump sensor functions as it needs to. We cannot forget about the weather condition too. As we are planning to test all sensors in different weather conditions, bump sensors are going to be tested in good and bad weather. After finalizing results in different weather conditions and force application on the sensor, we are going to be able to approve the sensor.

## 7.5 Wire Rack Testing

The wire rack is the only equipment that is going to gather scattered tennis balls in the tennis court. It is designed to collect circular shaped objects, such as tennis balls, golf balls, nuts, pecans, and other objects that can be scattered around. The wire rack comes in oval shaped form. There are multiple elastic wires that let objects get inside of the wire rack while it rolls.

Wire rack ball gathering equipment comes with handles to make it user friendly for people. The handle is designed for people to not bend while collecting objects in their backyard or anywhere else. We are not going to use the handle part for our project, because we need only the oval shaped wire rack part from the item. Firstly, we are going to test the product with the handle to make sure how easily it can collect circular-shaped objects. After that, we are going to remove the handle and keep only the wire rack.

Material of the Wire rack	Main Goal
Stainless steel	Collect 3 balls

Table 7.6.1: Material of the wire rack and main goal.

We tested it with 3 tennis balls. Our goal was to see how elastic wires are going to act on the process of collecting tennis balls. If elastic wires are going to have a hard time collecting the tennis ball, we have to open a little bit of a gap between elastic wires. That is what we ended up doing. We taped 6 elastic wires to each other to give the wire rack easy gathering time. With that, tennis balls can get inside the wire rack easily without falling out. Reason for using tape is to improve the robot's performance based on outdoor environmental conditions.

## 7.6 Frame Testing

The frame of our tennis ball collector is one of the components we have with the least number of restrictions on it. When it comes to the frame we only have constraints. The first one is that it has to be big enough to store the PCB, Motors, wiring, batteries, etc. inside of it. We believe that the frame will be the heaviest component. This leads us to our second constraint that we cannot make it too heavy. With this in mind we have started off with some preliminary designs.

Our first design we have decided to go with the dimensions of 15.5 inches x 15.5 inches x 10.5 inches. We believe that this will give us ample volume and space to fit all the components we need inside and have some room to spare. Since the dimensions are relatively small we believe that this will not make the frame too heavy. We estimate that the frame itself at this size should be about 10 pounds.

We also have visualized the process of how we are going to build the frame. We will start by Taking two ½ inch 10-foot PVC pipes and cutting them. We will have 12 sections cut to 15.5 inches and then we will have 4 sections cut to 10.5 inches. Using 8 side outlet elbow pipe fittings, we will connect the 4 10.5-inch sections and 8 of the 15.5-inch sections together this will form a cube. The remaining 4 sections of 15.5 inches will be connected forming a square by the 90-degree elbow pipe fittings.

The next step will be to cut out the outside of the frame by using the flat PVC sheets. Here we will have 2 cuts of 15.5 inches x 15.5 inches and 4 cuts of 15.5 inches x 10.5 inches. Those cuts will be for the outside of the frame. For the lid we will have 1 cut of 15.5 inches x 15.5 inches and then we will have cuts of 2 inches x 15.5 inches for the borders of the lid. We will then take the 2 cuts of 15.5 inches x 15.5 inches and the 4 cuts of 15.5 inches x 10.5 inches and nail them to the corners of the cube we made from the pipes. The 1 cut of 15.5 inches x 15.5 inches and the borders of 2 x 15.5 inches will be nailed to the square shape we built out of the PVC pipes.

The next step will be to attach the hinges to the lid to the outside frame of the box. We are hoping that the hinges could allow us to open the lid at least a minimum of 90 degrees. This will allow us to open the lid whenever we want so it would be similar to a chest. This allows for easy access whenever we have to work with a component that is located inside of the frame itself. The last step would be to apply some caulk to all the edges of the frame to make sure they are uniform and sealed so they do not allow any water inside the frame itself, keeping our components dry and safe.

This is how we visualize to build our frame early on in Senior Design 2. We are confident that this method of building the frame will keep our components safe from all outside elements. Whether that is the weather itself or any collision that might occur. We believe that this frame will be lightweight enough to not require

us to get even more powerful motors, but be strong enough to not be at the point where any simple wind could blow it over.

<b>Material type of the frame</b>	<b>Main Goal</b>
PVC	Protection

Table 7.6.1: Material type of the frame and main goal

Since the frame is a very important part of our solar tennis ball collector, we wanted to get started on it as quickly as possible. We thought since the frame was going to be the heaviest component of the project, we needed to prototype it to visualize how everything else would work. The weight of the frame was such a big deal because all the other components are going to be bought. You can easily find the weight and the dimensions for these components on the website you are buying them from.

However, the frame had to actually be built for you to be able to find the exact weight and measurements. So, we were trying our best to be able to solve this issue as quick as possible to have a better idea of what we were building and what was needed

One of our group members had some extra materials from a previous project. We took this as an opportunity to prototype our frame. We took the spare materials and made a prototype of the frame. The prototype of the frame is missing a few key components such as the hinges for the lid, the caulk to seal the edges, etc. However, this gave us an idea of the size and weight that we would be using for our actual frame that we are going to build during senior design two. With this information in hand, we can plan for what size components we need to buy, how powerful the motors should be, what size wheels, etc.



Figure 7.6.1: Prototype Frame Open lid

In Figure 7.6.1 we have the frame with the open lid. Since this is the prototype, we did not want to spend any extra money designing a prototype that would not work. We had to have someone physically holding the lid up since there are no hinges attached to the top of the lid.

The edges are also a bit uneven due to the cuts we had to make. For our final design we will use caulk to even out all the edges but to most importantly seal them. This would prevent any water from trickling its way down and into the inside of the frame.

Both the panels and pipes are PVC. As stated this was the first iteration of the housing for components. This was more to see the dimensions and how things would be distributed.

In the figure below, it shows how the lid would close. The Solar Panel would go on top, and the sensors all around the sides.



Figure 7.6.1: Prototype Frame Closed lid

## 7.7 Wheel Testing

The wheel testing is one that we believe we can do with simple measurements before we buy the actual wheel itself. The final design is having our solar tennis ball collector run on only two wheels with a third point of balance being the wire rack for the tennis balls. We chose to design it this way to help collect the tennis balls. For the balls to be collected into the rack you have to apply a little bit of force downwards for the ball to get through the wires. By having the rack at the front, it will be rolling along the floor as the tennis ball collector roams around. As it is rolling around this in theory should allow for enough force to be applied to let the tennis ball go through the wires.

Model of the wheel	Main goal
B0821QN7X2 (7" Mower Wheels)	To allow the robot to move

Table 7.7.1: Wheel model and main goal

We have also come up with a backup plan if we need to add more balance to our solar tennis ball collector. The idea is to attach a third wheel to the back. However, this wheel will not have a motor connected to it. It will be a free wheel very similar to the one you can find at the bottom of your typical office chair (Castor Wheel). As of this moment we will not be needing it. This would give us the balance if needed and it will help us a bit with turning. However, the only two real downsides to this is that it will add money to our very limited budget and

it will also add weight to the total build itself. This might cause us to have to reconfigure which motor we choose.

As of right now we have chosen to go with wheels that have a diameter of 7 inches. This should be big enough to let the wire rack roll on the ground. The size of the wheels would also depend on how far up the frame we decide to drill the holes to connect the wheels to the motors. We didn't really need to test these wheels due to the fact that we specified ones that are used on push lawn mowers. When the robot was resting its full weight on the weight it was fine and moved freely. Therefore it was strong enough and good for our use.

## 7.8 Motor Testing

The motors are one of the most difficult components we will have to work with in this project. As we are not mechanical engineers this part of the project will require a lot more research and testing. We believe that the motors we chose in our budget will be more than enough to be able to drive our solar tennis ball collector. Mathematically speaking every one watt translates to 0.00134102 mechanical horsepower. The motors we chose can deliver up to 100 watts of power. This means that our motor can produce 0.134102 mechanical horsepower. Now with this in mind, one horsepower can move up to 550 pounds. So, if we multiply our horsepower by 550 pounds you will receive 73.7 pounds. This means that theoretically and mathematically speaking as long as our solar tennis ball collector does not exceed 73.7 pounds, we should be able to move it just fine. Now this is just the calculation for a single motor, we are planning to have two brushed motors. So, we should have no issues.

Motor model	Main Goal
Brushed	Drive to each ball

Table 7.8.1: Motor model and main goal

At the beginning we tested this by using a string/paper like material to prove the motors spun according to the code given. Next we moved on testing various speeds and see what would work for us. After those tests we moved onto installing them to the frame. Each motor has a bracket to hold the motors in place. There is a slight camber but it doesn't really affect the design much.

We did run into a problem though, once the robot was fully assembled the motors would withstand and run with having the full load on the ground. Which led us back to the drawing board and ended up getting the Gearboxes for each motor. This allowed the torque to exist. Before we were drawing too much current and the start up had zero torque, therefore the robot would not move. After testing a couple of Gearboxes, we found one that worked and the motors now spun with purpose.

## 7.9 Processor Testing

When it comes to the processor, we had a variety of different options to choose from when we did our initial research. We had the choice of MSP430 boards, Adafruit boards, and Arduino. After debating the topic in our group, we ultimately decided to go with an ATmega microchip commonly found on Arduino boards for a variety of different reasons.

Arduino is very common in RC cars. Our whole project stemmed from wanting to build an RC car of some sorts, so we want to stay true to the components that make up an RC car. Arduino is also known to be very user and beginner friendly. They have a huge library that we would be able to access, like example code and premade functions for common peripheral devices. There is also a huge community behind Arduino so if we ever need help with troubleshooting, we would be able to ask for help. Another benefit is that Arduino has the ability to read and process multiple sensors at once. This is very important for us because we have 4 ultrasonic sensors and many bump sensors. We know that the Arduino has models that can handle this. A couple of our group members also have some experience using Arduino and this only even more solidified our choice to choose this microcontroller.

Model	Main goal
ATmega2560-16AU	Control all components

Table 7.9.1: Processor Model and main goal

Arduino has a big line of different boards to choose from. We had narrowed it down to be either the ATmega328P or ATmega2560. We decided to go for the ATmega2560-16AU for a variety of different reasons. The first reason we decided to go with ATmega2560 over the ATmega328P is because there were a lot more input and output pins available to us to use. The ATmega2560 has four times more RAM and eight times the flash memory than the ATmega328P. Our solar tennis ball collector is a complex project involving multiple sensors, drivers, and motors that need to be read or controlled by the ATmega2560. This is why we chose the ATmega2560-16AU chip. We believe it will be able to handle the demands of our project.

Initial testing of code for the microcontrollers was first conducted using their respective Arduino prototype boards. When the algorithms showed acceptable results, they were flashed onto our custom boards. Since these were different chips, they were first tested with a basic blinking LED loop to ensure nothing was wrong with the chip itself. This was a struggle because we realized that it needed

an external oscillator that was excluded in initial PCB design. After that was soldered directly on, it flashed the code and worked.

To test the ATmega2560-16AU we tested it alone with one other main system at a time. First was getting the main pcb which had this component to function and upload code to it. Next was the ATmega with a simple LED circuit to test functionality. Then came to testing the Motors and sensors one at a time.

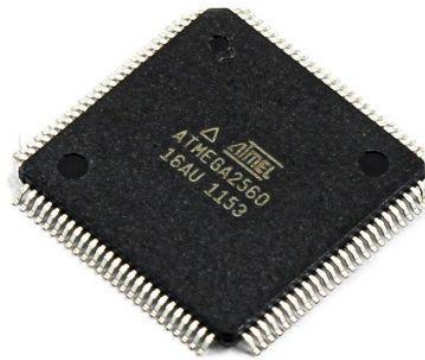


Photo by ElectroPeak

Figure 7.9.1: Image of ATMEGA2560-16AU. Reference from <https://electropeak.com/atmega2560-16au-chip>

## 7.10 PCB Testing

The testing of each PCB was extensive and time consuming, as each board had many components and tiny ones at that. While soldering the components, it required much patience as the parts were so small. We ended up using a whole package of solder. Throughout the soldering process, we measured each component to ensure reliability and prove to ourselves it was functioning as designed. Each PCB was reading the input and outputting the correct Voltage and Current.

The PCB is a massive part of our project. It is essentially the heart of our solar tennis ball collector. The PCB will house all the information and connections needed for our battery, motors, drivers, sensors, microchip etc. The PCB is crucial for the connection between mechanical parts and electrical parts. Without it there would be no way to link the different subsystems. With the PCB we can incorporate multiple small components that would take up a lot of space if they

were not Printed on the PCB itself. PCBs also make it super simple and easy to test our different electrical circuits.

We took the time to design a preliminary PCB. We started off by doing the schematic we wanted to see and making sure that what we're envisioning was possible. Designing the PCB was a struggle at first, we were trying to remember all the work we completed in Junior design. The first issue we faced was finding all the parts we needed on the *Autodesk EAGLE* software. However, we used websites such as *SnapEDA* and *Ultra Librarian* to find the libraries and the footprints of the parts we needed. We used these two sites to find the Ultrasonic sensor, IR sensor, Bump Sensor, Motor Driver, On/Off switch, and the ATmega2560-16AU microchip. We placed all of their footprints on the schematic. This is when we realized there was an issue with our planning. We planned to use a 12-volt battery. This is fine for the brushless motors, but this amount of voltage would fry the ATmega2560-16AU microcontroller. So, we used *WEBENCH-CIRCUIT-DESIGNER* by *Texas Instruments* to design a voltage regulator. The job of the voltage regulator would be to drop the 12 volts down to 5 volts. This would allow the ATmega2560-16AU to operate at a safe voltage level. Then using the pin out diagram for the ATmega2560-16AU and the several different datasheets for each part we connected all the parts together.



by placing the VIAs, adding the ground layer, and adding some drill holes in the corner to be able to secure it to the frame.

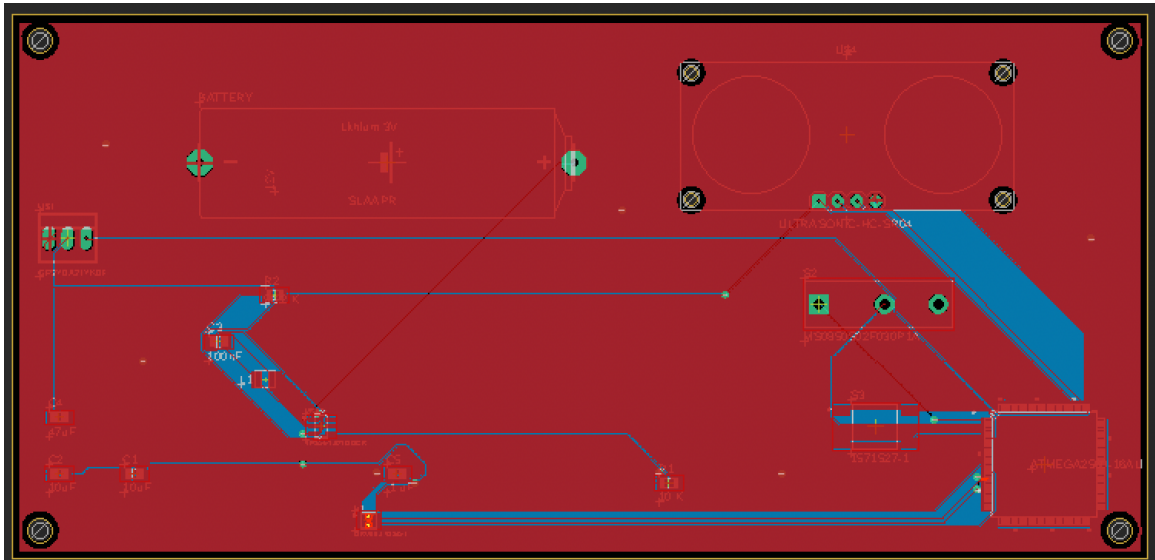


Figure 7.11.2: Preliminary PCB Board

This is a preliminary version of our PCB board. First things first we only used one of each sensor and one motor driver. For the final design we are going to have to have two motor drivers, 6 ultrasonic sensors, 2 bump sensors, and 4 IR sensors.

Secondly, we have to fix the issue we have with the air wire that we cannot connect. We plan to see all the other motor drivers we can use and implement them into future designs. Hopefully this will fix the issue and we will be able to move forward with our PCB design.

During Senior Design we finalized our PCB. It is now 3 PCB's. One as the Main PCB, which houses the brain of the robot. Another PCB for regulating the Solar input to provide a constant feed to the battery. And the Third was the Voltage regulators for the motors.

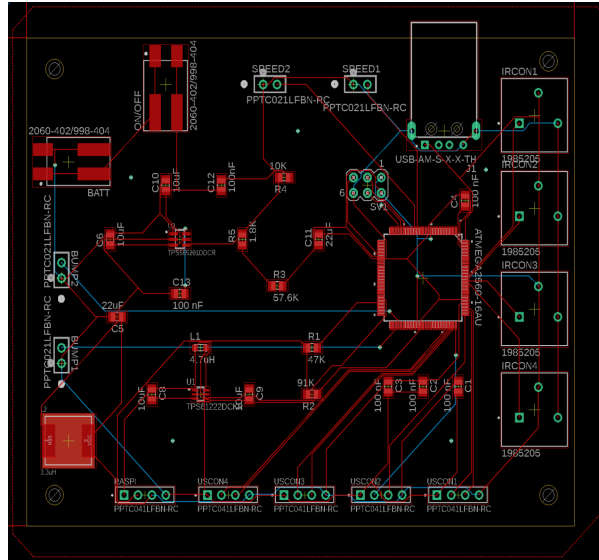


Figure 7.11.3.1 Main PCB

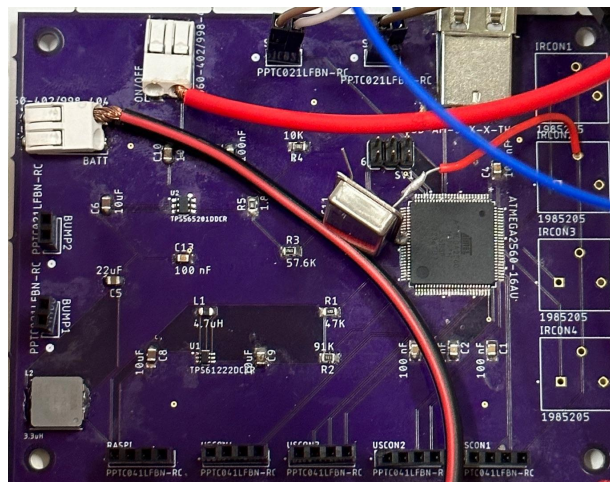


Figure 7.11.3.2 Final Built Main PCB

This PCB is what houses the main components of the Robot, it contains all of the connections for the Sensors and Camera, It houses the ATMEGA which is the brain of the robot. The Connection to the battery and more. After completing this MAIN PCB, we ran into a software issue we had missed when designing the PCB in the first place. It was assumed that the internal clock in the MCU component would work fine with what we needed. But when connecting it to the computer to flash the code onto the board, it was reading the MCU. That is when we figured out it was a clock rate issue. The solution to this was to buy and install an External clock. I had to directly mount it onto one of the pins of the ATMEGA, connect it to ground with as little distance as possible, and to Vin. We actually ended up connecting it to one of the IR Sensors through holes that was free since we didn't use them. Ended up connecting a few unutilized pins with solder

to provide a bigger node to connect the clock. For Ground it worked out using the pin the clock came with to a nearby grounding point, so it all worked out perfectly in the end and got the code to flash and the main PCB up and running properly.

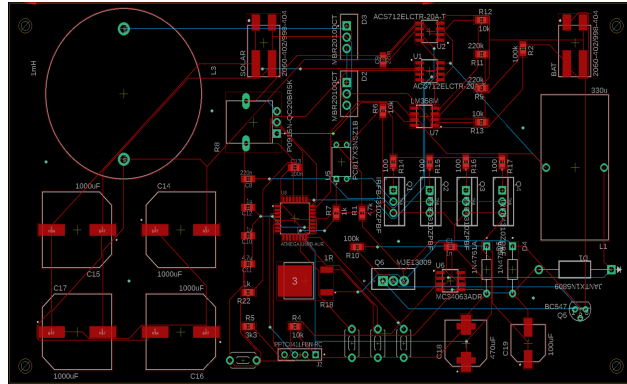


Figure 7.11.4 MPPT PCB

This PCB is designed and built as a Charge Controller. This is a midway connection between the Solar Panel and the Battery. This regulates the fluctuating voltage output from the Panel due to its reading from the sun at a given moment. It takes that as input in the PCB and converts it into a steady, constant output to the Battery so that it doesn't burn up or kill the battery, while charging it. Once the soldering was complete we ran into an issue. The LCD Display was not reading anything on it. After ensuring all the solder joints were functioning properly many times, the screen wouldn't display correctly. After some research we thought maybe it was the wrong Arduino Library in the code. We tried many, but no success. After looking into the schematic we had found the problem. The LCD wasn't connected to the right pins on the ATmega within this board. So what I had to do was directly solder two of the pins from the ATmega to the connection port of the LCD Display, and this was very difficult to accomplish but it worked out and the PCB was finally working properly.

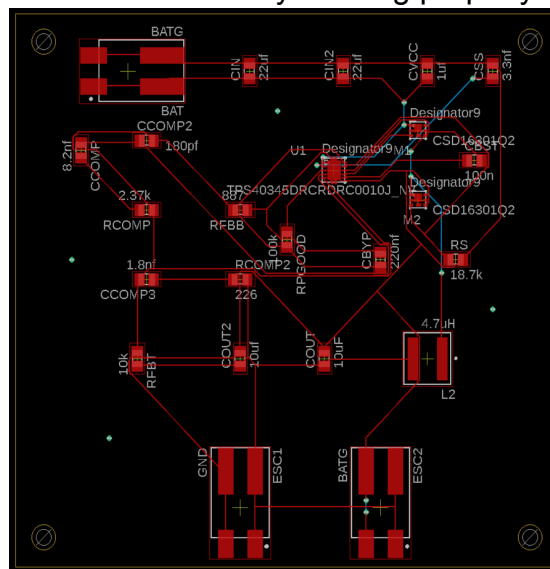


Figure 7.11.5 Motor PCB

This Motor PCB was printed and tested, but during testing it had to be scrapped and we had to use a new voltage regulator for the motors. This was done using a Prototype Board for each, and I made the traces using Copper tape. And most of the components we already had because of another class we had taken, Electronics 2. So it ended up weren't as intended and the motors spun. Section 6.1.3.4 gives more information about that specifically.

## 8.0 Administrative Content

In this section we plan to go in depth into the logistics part of our project. When working in a group project it is very important to get everyone on the same page about everything. In these sections we want to discuss our timeline, finances, and total work contributions for the whole project. This will help us stay on the same page with the most important and crucial parts of designing and building our solar tennis ball collector.

### 8.1 Milestones

Planned Period for Senior Design 1	Description	Dates
Divide and Conquer	Write 5 pages a week for each group member	June 2
First Progress Meeting for 60 page	Brainstorming session for 60 page	June 10
Last Progress meeting for 60 page	Proofreading session of complete 60 page	June 28
60 Page Draft due	Last day of submission	June 30
First Progress meeting for 120 page	Brainstorming session for 120 page	July 3
Part orders	Ordering some parts	July 14
Last Progress meeting for 120 page	Proofreading session of complete 120 page	July 23
120 Page Draft due	Last day of submission	July 25

Table 8.1.1: Senior Design 1 planning.

<b>Planned Period for Senior Design 2</b>	<b>Description</b>	<b>Dates</b>
Fall semester starts	First day of Fall semester	August 21
Solar panel	Mounting solar panel to the lid	September 21
Finishing Frame	Finishing finalized design of the frame	October 2
Finishing PCB design	Finalizing PCB design	October 18
Motors and Wheels	Mounting wheels and motors securely to frame	October 19
Part orders	Ordering all missing parts	October 20
Testing and Troubleshooting	Testing all components	October 31
Implementing PCB	Installing and integrating PCB inside of the frame	November 10
Finish wiring	Finalizing all electronic wires on the robot	November 26
Final Demo	Finalizing and testing the robot	November 30
Revision	Revision for Motor/Camera	December 4
Finish Project	Final product	December 8

Table 8.1.2: Senior Design 2 planning.

With any project you begin it is always beneficial to have a schedule in place. You want to keep track of important deadlines so that you never miss them. It is also very beneficial to set smaller goals along the way to make sure that you are on track to hit all of your major deadlines. That is what we did. All the deadlines above in green are the major UCF deadlines. The other deadlines in black are our small goals. These can be flexible and it all really depends on how long the parts take to arrive. We hope to finish our project about a month away from the last deadline. This allows us to prep any paperwork we might have to do in senior design 2. It also gives us time to make and perfect our final presentation.

## 8.2 Contribution Table

	Primary	Secondary
Hardware	Adil, Emmanuel, Juan	Jorge
Software	Jorge	Adil, Emmanuel, Juan

Table 8.2.1: Contribution Table

For our group, since Jorge is our only computer engineer, we will be relying on him to do most of the software work for this project. To compensate for this Jorge will not have to worry about any of the hardware work on our solar tennis ball collector. Juan, Emmanuel, and Adil have very minimal to no experience in coding and programming. We tried and helped out wherever Jorge needed us to lighten his load.

	Tasks
Adil	<ul style="list-style-type: none"> <li>● Bump Sensor</li> <li>● Ultrasonic Sensor</li> <li>● Solar Panel</li> <li>● PCB Design</li> </ul>
Emmanuel	<ul style="list-style-type: none"> <li>● Motor Drivers</li> <li>● Ball pickup &amp; Storage</li> <li>● Frame</li> <li>● PCB Design</li> </ul>
Jorge	<ul style="list-style-type: none"> <li>● MCU</li> <li>● Raspberry Pi and Camera</li> </ul>

	<ul style="list-style-type: none"> <li>● Software Design</li> <li>● PCB Design</li> </ul>
<b>Juan</b>	<ul style="list-style-type: none"> <li>● Solar Panel</li> <li>● Voltage Regulator</li> <li>● Battery</li> <li>● PCB Design</li> </ul>

Table 8.2.2: In Depth Contribution Table

At the start of the project, we decided to split up the project into multiple parts or tasks. With the help of the bootcamp assignment we were able to establish each other's specific strengths and weaknesses. This helped us to practically create roles for one another that we thought would be the best fit. The separate tasks do not mean that they will only be completed by a single person; however instead it means that that person should excel and somewhat lead the way in a certain category. For example, Jorge is the only computer engineer, so we are counting on him to have a major impact on the programming for our solar tennis ball collector. Another example would be Juan who is in the power track for electrical engineering, this is why he is being focused on the solar panel and voltage regulator. The tasks will not just simply be completed by the person that is assigned to it. It will be a team effort so that they are done and completed in an efficient and time orderly manner.

### 8.3 Finances

Finances play a big part in designing any project. As engineers we want to provide the most cost-effective solutions. This way products are not too expensive to the consumers and thus provide a good profit margin. When you first draft or start to research a new project it is very important for you to evaluate the total budget that is available to you before you start building. The more information you collect on materials, price points, alternatives, measurements, etc. can help you cut down on the total cost of your project.

As professional engineers you can have a lot of people backing your work. Whether that is the company you work for, a sponsor, grants, the government, etc. There are a lot of different ways to secure funding for different types of projects. For Our project we do not have someone to sponsor our project. All the funds for our solar tennis ball collector are coming out of our own pockets. Due to this being the case we have set our initial budget to be \$600.

As we began testing and actually realizing our solar tennis ball collector we realized that this low budget was unachievable. There were certain items that made our budget higher such as switching types of motors and ESCs, custom work done to a screw to mount the wheels, etc. This slowly added up and we eventually had to double our initial budget.

Item	Unit Price	Total Spent
Charlotte Pipe 1/2-in 90-Degree Schedule 40 PVC Side Outlet Elbow (x8)	\$2.58	\$20.64
Charlotte Pipe 1/2-in 90-Degree Schedule 40 PVC Elbow (x4)	\$0.70	\$2.80
Silver-Line Plastics 1/2-in x 10-ft 600 Psi Schedule 40 PVC Pipe (x2)	\$4.71	\$9.42
RELIABILT 0.25-in x 24-in x 4-ft PVC Trim Board (x2)	\$26.98	\$53.96
Hickory Hardware Surface Mount Black Self-Closing Overlay Hinge (2-Pack)	\$5.11	\$5.11
DAP Alex Plus 10.1 oz. White Acrylic Latex Caulk Plus Silicone	\$3.58	\$3.58
Teks #8 x 3/4 in. Zinc Plated Steel Philips Drill Truss-Head Point Lath Screws (200-Pack)	\$11.87	\$11.87
Set of 2 Wheels Kit for Push Mowers (7" Inch)	\$21.99	\$21.99
Yangbaga Tennis Balls Pickup Ball Retriever Adjustable Tennis Ball Roller Collector	\$40.99	\$40.99
Penn Championship Tennis Balls - Extra Duty Felt Pressurized Tennis Balls	\$11.78	\$11.78
Raspberry pi Module 3 wide	\$35.00	\$35.00
Raspberry pi 3 model B+	Already Owned	Already Owned

Cylewet 25Pcs AC 1A 125V 3Pin SPDT Limit Micro Switch Long Hinge Lever for Arduino	\$6.99	\$6.99
ELEGOO 5PCS HC-SR04 Ultrasonic Module Distance Sensor Compatible with Arduino UNO MEGA Nano Robot XBee ZigBee (x2)	\$8.99	\$17.98
3D printed Case for HC-SR04	\$50.00	\$50.00
PCB Printing	\$250.00	\$250.00
Board Components	\$250.79	\$250.79
Voltset 30W Solar Battery Trickle Charger Maintainer	\$74.99	\$74.99
Traxxas 3975R Titan 550 Reverse Rotation Motor (x2)	\$20.99	\$41.98
HOBBYWING QUICRUN 1080 G2 Combo (Combo QR (1080 G2 + 555 13T))	\$62.99	\$125.98
ECO-WORTHY 12V 30AH LiFePO4 Battery	\$99.99	\$99.99
Miscellaneous		\$150.00
<b>Grand Total:</b>		<b>\$1285.84</b>

Table 8.3.1: Materials Itemized list

<b>Legend</b>
<b>Frame</b>
<b>Power</b>
<b>Storage</b>

<b>Circuit Boards</b>
<b>Motors</b>
<b>Sensors</b>

Table 8.3.2: Materials Itemized List Legend

As you can see the table above shows all the materials we plan to buy and use to build our solar tennis ball collector.

- The most expensive portion of our solar tennis ball collector is going to come from the circuit board section. The main expense in this section is our PCBs which had 2 iterations, with faster shipping times.
- The frame is the second most expensive section. This is due to it having the most different components.
- The third most expensive section is the Motors. We had to make sure that the motors would be powerful enough to move our solar tennis ball collector. The motors were one of the cheapest components of this section followed along with the gear boxes. The most expensive parts in this section were the two ESCs.
- The power section is the fourth most expensive section. Here we have the two components that are providing power to our solar tennis ball collector. The most expensive being the battery. The solar panel is a little bit cheaper but not by much.
- This is then followed by the sensors. For the Sensors the most expensive one is the raspberry pi camera. We already owned the raspberry pi itself so this did not have to go in the calculations. The bump sensors and the ultrasonic sensors finished this category
- The Storage section is the cheapest section. The storage only consisted of two components. The least expensive being a set of tennis balls and the most expensive being the wire rack.
- We included a miscellaneous section to cover small inexpensive things such as wires, solder, etc.

Having a list like this is very helpful to us. It keeps us organized and we can easily use it to reference any of the parts. This in turn will keep us being very efficient. Efficiency is going to be key for us. We do not have a lot of room to waste money on materials that we do not need or will not meet the desired specifications that we want to achieve. With these products we are confident that we can deliver our solar tennis ball collector at a great and high level of quality.

## 9.0 Conclusion

Solar tennis ball collector is a device that can be beneficial for everyone that trains or plays tennis in a tennis court. There are a lot of benefits that people can get from this robot device. It is designed to bring people joy, time efficiency, not exerting much effort, and advantageous workout. There can be no doubt that people do not want to collect scattered balls after intensive tennis matches or training, because people might get tired and collecting tennis balls is going to be the least thing that they will want to complete. As we mentioned there are a lot of products that can be helpful to gather scattered tennis balls. However, mentioned products require human engagement. In some products people need to bend and collect tennis balls, and in some products people need to use their force to push specific equipment to gather all tennis balls. The Solar tennis ball collector does not require any human engagement, just emptying when full and turning it on and off. The robot detects tennis balls and moves towards the ball to collect it. It changes directions whenever it comes into contact with a fence or any other kind of barrier.

Tennis is one of the most ancient games that was founded centuries ago. First official tennis game was played in early 1600. After that, people started to get intrigued about tennis games. Time after time people started to play tennis using tennis balls and a tennis racquet which are two major pieces of equipment for a tennis game. Most people see the game of tennis as an engaging and unique sport. After some time and people's love of the game, we can see a lot of tennis courts, tennis clubs, and tennis competitions all around the world.

Imagining a tennis court without a fence is impossible. The tennis balls are bouncy, and it allows them to travel far if there will not be any barriers on the tennis court. That is why we can see fences around the tennis courts. The average overall tennis court playing surface is 120ft in length and 66 ft in width. The distance between the tennis court and the barrier is 27ft and 18ft. Fences or barriers around the tennis court were one of the main concerns in this project as they serve as obstacles to navigation. However, we ended up with bump sensors and ultrasonic sensors that will be beneficial for solar tennis ball collectors. As we mentioned, it will change direction to a given degree whenever it will get into contact with the fence or when a robot will detect an obstacle in the distance. Nowadays, almost every smart vacuum cleaner uses bump sensors to change their direction after hitting a wall, chair, table, human, or any other obstacles that prevent the robot from moving forward. This inspired us to use bump sensors to avoid any collisions between robots and designated barriers at a tennis court. It is the cheapest and safest way to use bump sensors to avoid any damages to the solar tennis ball collector.

As we can see from the robot's name, solar panel is going to be the main power source for the robot. We are also going to use a small battery to store the battery just to be safe. As mentioned before, there are some robots that collect tennis

balls. However, they are not powered by solar panels. There are a lot of advantages to using solar panels in a solar tennis ball collector. It is designed to make people's lives easier. Which means they do not need to worry about charging the robot before going to play their tennis match. Solar panels will give confidence to people without worrying about the robot's battery life. We need to consider weather conditions too since a solar tennis ball collector is an equipment that performs best outdoors.

As widely recognized, solar panels perform their best when they are exposed to sunlight. There can be bad weather conditions when it can stop solar panels from gaining any energy or power. For that reason, we added a small battery to let the robot perform. If thinking logically, people do not recommend playing tennis in rainy, windy, hailstorms, snow and other bad weather conditions. It is understandable that it might be challenging to play tennis in bad weather conditions. That means people prefer playing tennis in sunny and good weather where they can enjoy themselves and have a good time. Having a small battery and a solar panel as a main power source is not going to lead to any problems in a solar tennis ball collector. The Solar panel is going to be mounted on top of the frame's lid and all electrical wires are going to be hidden inside of the body under the lid. With that, the robot will have a cleaner and more visually appealing look.

The wire rack and motor are another main equipment that helps the robot to complete its task. Without a motor, the robot will not be able to move in any direction by itself. The wire rack is the one and only equipment that collects the tennis balls while it rolls. We decided to have two wheels and one wire rack as a third wheel and ball collector in the front. It not only collects balls, also it helps robots to balance and roll in forward and backwards directions. Two wheels are going to lift the frame. So it can have a little bit of distance between the ground and the robot. Also, wheels are going to help wire rack to move easily and not to get stuck to something since two wheels are going to get torque. Which means with the help of wheels torque, the robot can be in movement at a designated power.

The PCB, the main component of our design, will basically act like a heart. Its job will be to control and route power to all the electrical components in our project. It will also take electrical energy and convert it to mechanical energy so that the brushless motors can continue to keep running. It is single-handedly the most important component in our design. Designing the PCB gave us a few issues with all the sensors and motors we are running. However, in the end we made it work and all the systems are functioning.

Nowadays, people prefer products that are easy to use. Solar tennis ball collector is the product that tennis lovers want to see. There are lots of worldwide tennis tournaments that hire young generation kids to be ball boys or ball girls. Their job is to gather tennis balls and give it to professional tennis players when they are asking for it. In our opinion, this kind of job can be challenging for young kids staying under the sun. Moreover, it can be unsafe in some cases. There are

some short videos that show how kids get hit with a tennis ball by a tennis player accidentally when they want to gather other tennis balls. Solar tennis ball collectors can complete tasks that all young generation ball boys and girls are doing. This robot can make practice sessions more meaningful and productive.

Markets prefer selling user friendly, high quality, reliable, environment friendly, and cost-effective products. At present, people prefer cheap but high-quality products to buy. At the same time, they pay attention to quality and how reliable or user friendly the product is. We focused on how lightweight and user-oriented products we can create. With all the sensors and power that a solar tennis ball collector has, it can bring enjoyment and satisfaction to customers.

In today's generation, we can see a lot of products that can help people's lives be easier. Such as, smart vacuum cleaner, self-following luggage, smart phones, smart doorbells, speakers, and other interesting products. The Solar tennis ball collector is a robot that can simplify people's lives a bit. It will get rid of simple and mundane tasks that people do not typically enjoy doing.. The robot's performance and utilization of sensors will bring people joy while they focus on their tennis match.

Our team is delighted to announce the completion of this project. Gathering all the parts together led us to our project's goal. There was a lot of testing of different parts and components. We faced some challenges with specific components. However, we made adjustments to some components. It happened only because some designated components did not function as planned. With our team's critical thinking, problem-solving, and engineering skills and background in the sport, and robotics we declare the completion of this project.

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[GPTA]: Types of Solar Panels

[GPTB]: Ultrasonic Sensor

[GPTC]: Clarifying ChatGPT actual control limitations

[GPTD]: Basic research for Brushed motors

[GPTE]: Basic research for Brushless motors

[GPTF]: Basic research for Servo motors

[GPTG]: Basic research for Stepper motors

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