



UCF

Solar Tennis Ball Collector

SD1 60 Page Document

06.30.2023

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Group 10

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1.0 Executive Summary

2.0 Project Description

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 the Signal analyzer, the energy storage, and the brushless 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.

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	4" by 4"	Printed Circuit board will be used to show and create all electrical connections
2	Energy Storage	630mAh-680mAh	Energy storage will be used to store energy that is getting from solar panels that is built in on top of the robot
3	Sensors	3 different sensors	Sensors will help robot to detect tennis balls, collisions, and distances
4	Signal Analyzer	At least 4 ft	Signal analyzer will help robot to scan white lines of the tennis court.

5	Brushless electric motor	40 watts-120 watts	Electric motor will help robot to move around tennis court
6	Solar Panel	Up to 50 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

Energy storage, signal analyzer, and brushless electric motor are 3 major requirements of this project. Energy storage will be used to store energy that the robot will consume from the solar panel. It will help the robot to operate better and reach its superior level. Brushless electric motor is going to be the heart of the robot.

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. The robot should keep a distance of at least 4 ft with a tennis court line.

Signal analyzer 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 infrared distance sensor which comes in sensor requirements. Moreover, other sensors such as ultrasonic sensor, and limit switch are going to be useful to detect tennis balls and collisions.

One of the robots' main goals in this project is to avoid getting into the tennis court. That will help players to play safe and joyful games.

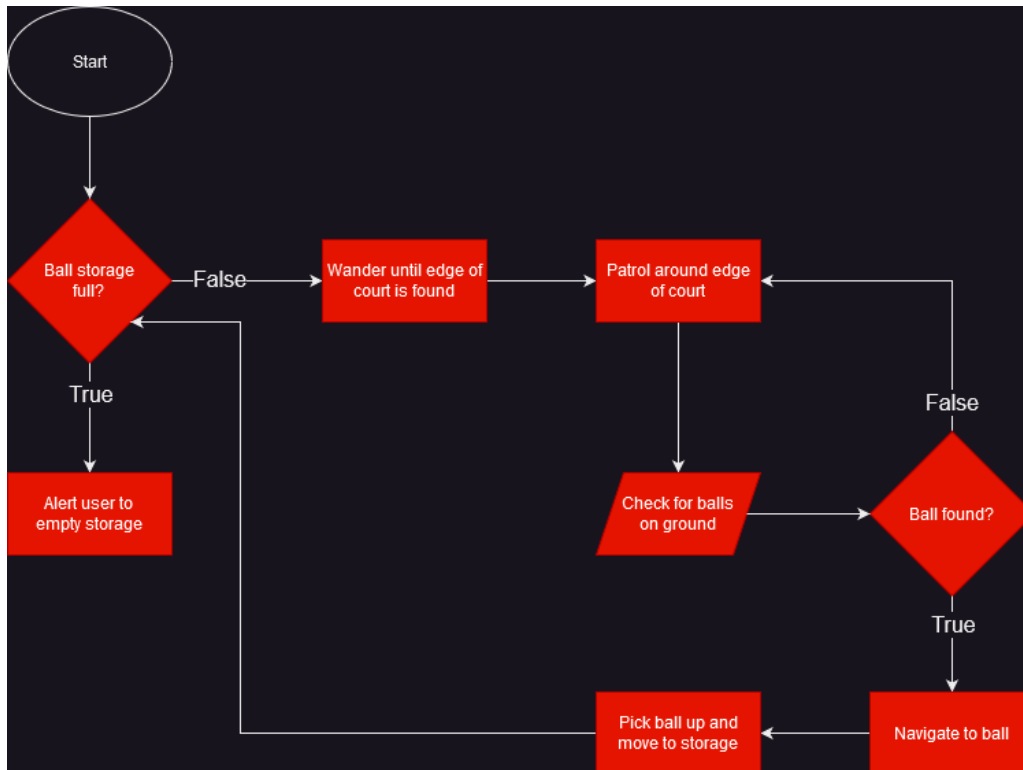
2.5 Hardware Block Diagram



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, court lines 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 Flowchart



The robot is expected to run on an indefinite loop from a software perspective, as the main purpose of the robot is to complete a menial task repeatedly. The above flowchart shows no proper end to the software, but hardware is expected to eventually end the program as the user needs.

Generally, the robot starts every loop by checking if it can hold any more tennis balls, and if ball storage is full, it will emit some signal (light or sound) and stop operation until a user empties the ball storage and restarts the system. Otherwise, the robot patrols the edge of the tennis court sensing around for stationary balls. Once it finds a ball, the robot moves to pick the ball up. When the ball is successfully moved to storage, the robot starts the loop again by checking its storage capacity.

2.6 House of Quality

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

		Dimension	Signal Analyzer	Brushless electric motor	Storage Capacity	Energy Storage	Sensors
		-	+	+	-	+	-
Design	+	↑	↑↑	↑↑	↑↑	↑↑	↑
Cost	-	↑		↑	↑	↑↑	↓
Battery Life	+	↓	↓	↓	↓	↓↓	↓
Quality	+	↑	↑↑	↑↑	↑	↑	
Environmentally Friendly	+	↑↑	↑↑	↑		↓	
Targets of Engineering Requirements		24"x20"x10"	At least 4 ft	120 watts	Up to 7 balls	680mAh	3 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 3 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 is 3 sensors. For storage capacity, we have up to 7 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 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
Total		\$ 464

Table 2.7: Cost Estimates

3.0 Research and Part Selection

3.1 Technology Comparison

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 (RC) 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.

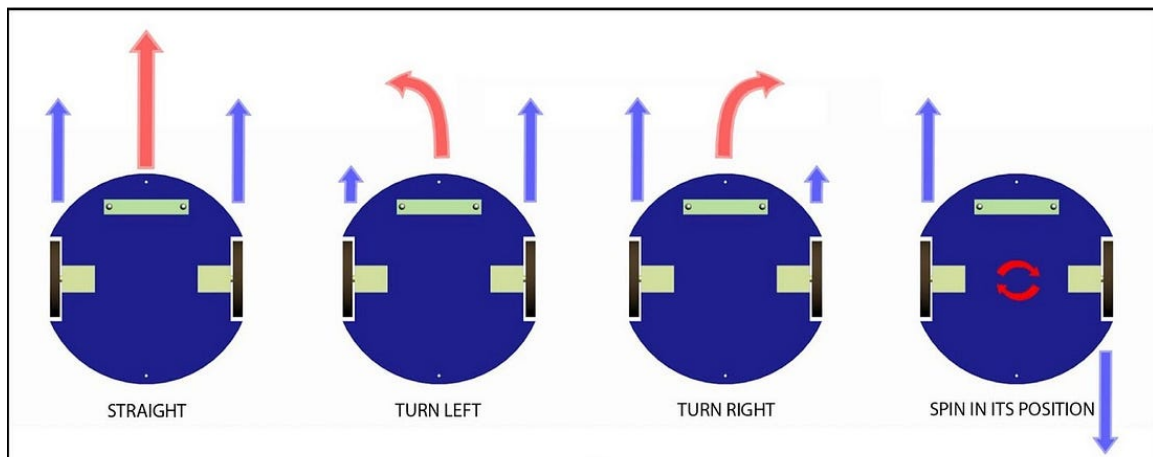


Figure 1: Steering Method of Differential Drive Robot. Reference from <https://medium.com/manual-robotics/drives-76c2b2dac97c>

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. This allows for completely forgoing the need to steer, as this configuration can move in every direction without much rotation of 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.

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

Table 3.1.1.5: 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 an 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.

	Advantages	Disadvantages
Conveyor Belt	Fully controlled ball transportation	Mechanically complex

Flywheel Launcher	Can launch into open basket	Hard to control launch speed
Manual Collector	Simple, complete design	Forced to design around existing collection device

Table 3.1.2.3: 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 the boundaries of the court to avoid interrupting or harming players. We took this into account in deciding on the original constraints of the tennis ball collector by ensuring that it stays four feet away from the edge of the court. This means that the robot not only needs to see the edge but also detect its distance away from the edge. The robot would also need to be able to do the same with the small tennis balls in order to find and navigate to them. There is a notable difference between these two objects in their physical shape, where the lines would be flat and stationary on the ground below the robot while the balls would have at least some height and can have their position shifted. A separate but related requirement is the ability to detect walls and people to avoid unexpected collisions in the operating environment.

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.

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.

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. 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. This is especially dangerous as it breaches one of the constraints we defined for the robot to operate safely and runs the risk of interfering with the players while they play.

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.

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

Table 3.1.3.2: 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.

	Advantages	Disadvantages
Large Battery	Long intervals between needing to recharge	Heavy and large, demands more motor power
Charging Dock	Automatic charging	Requires other power source

Solar Power	Smaller battery, constant power	Requires sunlight which fluctuates in intensity
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Table 3.1.4.3: Power Design Comparison

3.1.5 Programming Language

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. 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.

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

Table 3.1.5.4: 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 brushless 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. [GPTE]

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 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 there 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
Brushed Motor	\$10	\$239
Brushless Motor	\$16.58	\$413.99
Servo Motor	\$7.29	\$588.23
Stepper Motor	\$6.99	\$971.01

Table 3.2.1.4.1. 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

	Advantages	Disadvantages
Brushed Motor	<ul style="list-style-type: none"> • No controller is required • Easy to Control • Good on lower duty cycles • Simple to operate 	<ul style="list-style-type: none"> • Require a lot of Maintenance • Terrible Heat Dissipation • Lower Speed Range • Can be noisy

Brushless Motor	<ul style="list-style-type: none"> • Very Efficient • Very reliable • Longer life Span • Less Maintenance • High Power Density 	<ul style="list-style-type: none"> • Expensive • Can be Very Complex • Can cause a lot of electromagnetic interference
Servo Motor	<ul style="list-style-type: none"> • Great variety for different sizes and powers • Can be very cheap • Good torque at high speeds 	<ul style="list-style-type: none"> • Jitters • Can be limited in their range of motion
Stepper Motor	<ul style="list-style-type: none"> • Easy to Control <ul style="list-style-type: none"> • Precise Positioning and Speed control • Can provide great torque at low speeds 	<ul style="list-style-type: none"> • Not very efficient • Can skip steps • Can be very noisy • Not a lot of torque at high speeds

Table 3.2.1.4.2. Advantages and Disadvantages of Different Types of Motors

Overall, we think our best option for motor choices is the brushless motor. The brushless motor provides the best of both worlds when it comes to electrical and mechanical engineering. They are very efficient and reliable so we will not have to worry about maintaining them like we would in a brushed motor. Since our tennis ball collector will continuously roam until the storage is full, the brushless motor is the best option since it is okay for it to continuously be running. We also do not have a great need for precision since we aren't using GPS or anything like that so we can eliminate the stepper and servo motors from contention.

3.2.2 Solar Panels

The Solar tennis ball collector will get power by solar panels that are going to be attached on top of the robot itself. This renewable energy will be 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.

3.2.2.1 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 rear 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
Thin Film Solar Panels	Amorphous Silicon	7%
	Copper Indium Gallium Selenide	12% to 14%
	Cadmium Telluride	9% to 15%
Crystalline Solar Panels	Monocrystalline	15% to 23%
	Polycrystalline	14% to 18%
	Bifacial Crystalline	20% to 38%

Table 3.2.2.1: 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]

3.2.2.2 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	$P_t = \text{Sum of all overall power consumption. (Sensors, motors, weight, etc.)}$

Power needed from solar panel	$P_n = \frac{P_t}{e}$
Area of solar panel should be same or slightly bigger 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 3.2.2.2: 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 ≈ 29.41 watts if we put numbers to the given equations above.

3.2.2.3 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 2: Thin film solar panel & monocrystalline solar panel. Reference from <https://www.linkedin.com/pulse/incredible-facts-solar-panel-part-ii-amit-thussu/>

3.2.3 Sensors

Solar tennis ball collector robot is going to have a sensor to detect tennis balls and tennis courts. As previously stated, robots cannot approach within 4 ft distance from a tennis court. The purpose of keeping 4 ft distance is the safety of players in the game and to make sure that players are not going to get distracted by robots while they are having their enjoyable tennis experience. 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 are going to use sensors that are related to detect objects and distance. These sensors are ultrasonic sensors, infrared sensors, or proximity sensors. 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.

	Advantages	Disadvantages
Ultrasonic Sensors	Accurate sensing of shape, color, distance, material. High frequency. Not affected from dust, snow, rain	Change in temperature over period of time
Infrared Sensors	Perfect for objects that are in close distance	Frequencies affected by smoke, dust, light
Infrared Distance Sensors	Expanded detection range	Weather conditions

Proximity Sensors	Rapid switching rate	Negative effect of humidity and temperature
Limit Switch	Easy to use with other technological sensors, Costs low	Wear and Tear

Table 3.2.3: 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.

Infrared distance sensors are going to be the best option to keep 4 ft distance between tennis ball collector and court lines. It will detect distance between robot and court lines and it will avoid entering assigned distance.

Ultrasonic sensors are an ideal option of sensor that can be utilized and reach its optimal performance. It can detect a ball while being at an outdoor tennis court. 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.

3.2.3.1 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.

An ultrasonic sensor will be 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]

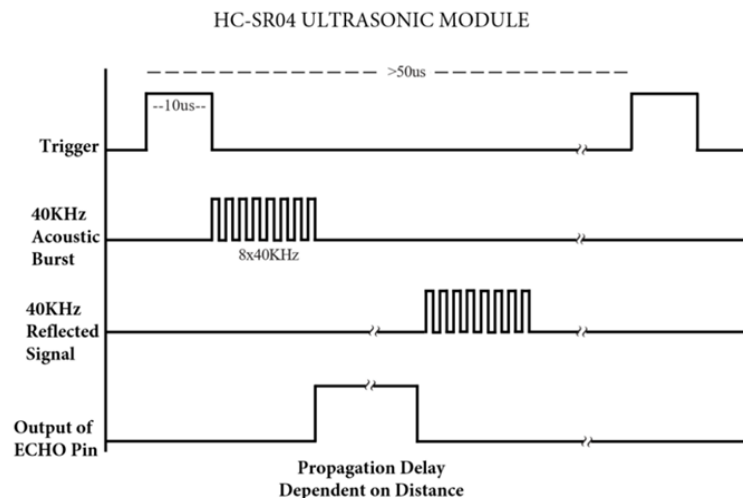


Figure 3: Representation of Ultrasonic pins. Reference from <https://www.microcontrollertips.com/principle-applications-limitations-ultrasonic-sensors-faq/>

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

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

Table 3.2.3.1. Main specifications of Ultrasonic Sensor (HC-SR04)

3.2.3.2 Calculations of Ultrasonic Sensor

To calculate distance, we simply do $\frac{\text{time} * \text{speed of wave}}{2}$. 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.

Time of flight	μ S
Speed of sound wave	μ S/cm
Range	$\frac{\text{time of flight} * \text{speed of sound wave}}{2}$

Table 3.2.3.2. Calculations of Ultrasonic sensor

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

In figure 3, we can see how an ultrasonic sensor sends and receives waves back. There are transmitters and receivers built in ultrasonic sensor. When the sensor detects a tennis ball, 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.

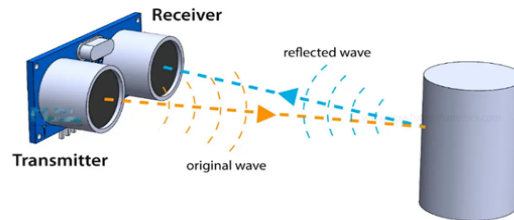


Figure 4: Ultrasonic sensor detecting object. Reference from <https://howtomechatronics.com/tutorials/arduino/ultrasonic-sensor-hc-sr04/>

3.2.3.3 Infrared Distance Sensor

Infrared distance sensors are one of the best and well-known sensors to determine distance between robot and designated object. These sensors transmit infrared lights to an object or assigned object, and it reflects back. Sensor calculates distance similarly to an ultrasonic sensor. However, ultrasonic sensor will not be used to determine distance between robot and court lines. It will detect tennis balls. Infrared distance sensor will receive output of court lines by ultrasonic sensors, and it will measure distance between robot and court lines. If the robot is close to or exceeds 4 ft distance it will avoid moving forward and it will change direction to not enter the specified distance. An infrared distance sensor is going to be placed on top of the robot with a specific angle to see and measure distance between robot and court lines. Active infrared distance sensors will be used in solar tennis ball collector.

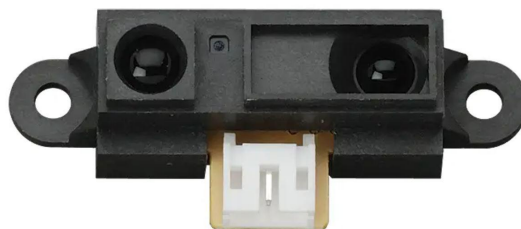


Figure 5: Infrared Distance Sensor. Reference from <https://www.parallax.com/product/sharp-gp2y0a21yk0f-ir-distance-sensor-10-80-cm/>

As we can see from figure 4, there are 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. The detection range of the sensor can be adjusted by potentiometer.

3.2.3.4 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 will send 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 given degrees. An actuator is the part where it physically touches an object. It is in circular shape. Circular shape actuator model comes with an operating head. 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? We will adjust the sensitivity of the limit switch to make sure it does not trigger collision when it will get in physical contact with tennis balls. It will allow robot to push tennis balls around and it will not cause any collision while getting in physical contact with tennis balls.

3.2.4 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 3.2.4. 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 hopper requires 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 can be 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.

3.2.4.1 Wire Rack

The wire racked tennis ball collector is the convenient, easiest, and most efficient way to collect balls for 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,

Lightweight	Wire Rack weighs only 1 lbs. to 1.2 lbs.
Easy to Customize	Wire racks can be bent into a group formation to access tennis balls to enter easily to the storage.
Material	Carbon Steel
Durable	Rust and water resistant
Function and Performance	Can gather from 3 to 15 balls depending on a size

Table 3.2.4.1. 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 racked 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 racked 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 racked 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 5 to 7 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 5 shows what a wire rack looks like.



Figure 6 Wire Rack. 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 wire rack will start 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.

3.2.5 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.

3.2.5.1 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.

3.2.5.2 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.

3.2.5.3 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.

3.2.5.4 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.

3.2.5.5 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
Wood	<ul style="list-style-type: none"> • Inexpensive • Water resistant to some extent • Easy to find • Easy to build with 	<ul style="list-style-type: none"> • Require a lot of Maintenance • Terrible Heat Dissipation • Lower Speed Range • Can be noisy
Cardboard	<ul style="list-style-type: none"> • Inexpensive • Widely available • No building required 	<ul style="list-style-type: none"> • Biodegradable • Not water resistant
PVC	<ul style="list-style-type: none"> • Water Resistant • Widely available 	<ul style="list-style-type: none"> • Can be very heavy
3D Printed	<ul style="list-style-type: none"> • Many different materials to print from • Let's us build to exact specifications 	<ul style="list-style-type: none"> • Expensive • Requires knowledge of software to be able to design and build

Table 3.2.5.5.1. 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'X4')	\$2.75
Cardboard (10x6x6)	\$1.10
PVC (6"x12")	\$14.49
3D Printed (cubic inch)	\$7.00 + \$40 per hour (lab manager)

Table 3.2.5.5.2. 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. 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.

3.2.6 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 the of all 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 3.2.6. 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.

3.2.7 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.

3.2.7.1 Arduino

Arduino is a very common and popular microcontroller. 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.

3.2.7.2 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.

3.2.7.3 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.

3.2.7.4 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.

	Advantages	Disadvantages
Arduino	<ul style="list-style-type: none"> • Platform available on multiple operating systems • Able to handle multiple sensors and drive motors at the same time • Large community • Open-source libraries • Simple programming language 	<ul style="list-style-type: none"> • No scalability • Not good for real time responses • Not precise with analog to digital conversion
MSP430	<ul style="list-style-type: none"> • Variety of different memory sizes • Very Efficient on energy • Very reliable • Excellent peripherals • Prior knowledge and usage • Simple programming language 	<ul style="list-style-type: none"> • Limited in memory • Harder learning curve • Not enough open-source material • Very self-reliant learning about the board and programming
Adafruit Feather	<ul style="list-style-type: none"> • Customizable so you can pick exactly what you need. • Energy efficient • Open-source platforms • Multiple simple programming languages 	<ul style="list-style-type: none"> • Can get very expensive with customization options. • Low processing and memory • Limited pin outs • Small community

Table 3.2.7.4.1. 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	\$5.51	\$27.60
MSP430	\$1.24	\$23.20
Adafruit Feather	\$11.95 + \$\$\$ for each Wing	\$39.95 + \$\$\$ for each Wing

Table 3.2.7.4.2. 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.

3.2.8 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

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 robot's 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.

8.0 Administrative Content

8.1 Milestones (UCF imposed dates in blue)

6/02 - Divide and Conquer

Write ~5 pages a week each group member

6/25 - Progress meeting for 60 page

6/27 - Finalize 60 page Draft

6/30 - 60 Page Draft due

Write ~5 pages a week each group member

7/20 - Finalize 120 - page draft

7/25 - 120 Page Draft due and start ordering parts

8/21 - Fall Semester starts and start Building Robot

8/29 - Testing & Troubleshooting Phase

9/25 - Finalize Testing

10/20 - Finish Project (TBD)

8.2 Contribution Table

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

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 are glad to try and help out wherever Jorge may need us to lighten his load.

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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

Declaration: We hereby declare that we have not copied more than 7 pages from the Large Language Model (LLM). We have utilized LLM for drafting, outlining, comparing, summarizing, and proofreading purposes.