Solar Tennis Ball Collector

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***Abstract* — The Solar Tennis Ball Collector is a robotic system that has been designed to improve ease and comfort in people's lives. With the help of solar energy, brushless electric motors, sensors and computer vision, our robot is capable of identifying and collecting scattered balls around the tennis court. Presently, lots of tennis players are dissatisfied with the task of manually collecting tennis balls after their tennis session. The Solar Tennis Ball Collector has been designed to address this problem, offering a safe solution that minimizes people's waste of time, and allows them to engage and focus on different activities instead of collecting tennis balls manually. The robot operates with a 30W monocrystalline solar panel connected to a 12V lithium ion battery. It senses tennis balls, collisions, and distances with the help of sensors and computer vision. The Robot moves with two 7 inch wheels, two brushed electric motors and a wire rack that keeps it balanced while it gathers tennis balls in the front end.**

***Index Terms* — Brushed Motors, Computer Vision, Safety, Sensors, Solar Power**

I. Introduction to the Solar Tennis Ball Collector

Tennis is a pastime for some people, a profession to others. It depends how the individual sees the sport. Most individuals pursue this activity to be in good health and wellness. Furthermore, people love to play tennis to reduce stress, depression, and anxiety. Playing tennis started in ancient Greek culture. As time went on, it gained popularity worldwide, and nowadays there are famous tennis competitions being held, such as Wimbledon, the US Open, the French Open, the Australian Open and others.

The first tennis ball had been made by rags and strings. Periodically, it changed to a yellowish green tennis ball with an average of 2.7 inches in diameter and 2 ounces of weight. Today's tennis balls are being made of rubber which is being covered by colored fabric.

Presently, after a practice session, it's tiresome to collect tennis balls, especially after long sessions. It is understandable. Not everyone might get tired, but when they do, picking up tennis balls becomes the least appealing task that people want to complete. When people pick up scattered tennis balls, they have to walk around and visually look around first to find where the scattered tennis balls are. After finding them, they typically have to bend down to get them. Some older generations might not be able to bend down and get the tennis balls every time at that time. it is also possible we can overlook and lose some tennis balls. For these reasons, we created the Solar Tennis Ball Collector.

The Solar Tennis Ball Collector consists of sensors, a camera, a solar panel, printed circuit boards, frame, two wheels, two motors, a wire rack, a battery, and software. Each individual component had been chosen or substituted with another component that had been chosen before. We created a 3D model of the project with real-life measurements, and we used it as a guide for the assembly of the robot. We used the 'OnShape' software system to create a 3D model. This helped design the real version, reducing costs (Fig. 1)

Figure 1: Image of Frame, Panel, Wheels, and Wire Rack

We have two 7" wheels and 1 wire rack which keeps the robot on the ground. Using these wheels, wire rack and motors, the robot is able to roam around. The wire rack is one of the main components. It is located at the front end, and it is the part which collects tennis balls while it rolls when the robot moves. Frame's size is 15.5" x 15.5" x 10.5" where the height is 10.5". Wheels are mounted 6.75" after the start of the frame. Meaning it is not in the mid-point of the frame, which is being supported by a wire rack in the front end. The electric components are going to be inside the frame. On top, we have a 30W monocrystalline solar panel which is secured in place by two 3” supporters. It has been mounted on top of the lid. Upon opening the lid we have access to all electrical components and wires, such as: motors, PCBs, sensors and more. The upper and lower arms are installed to assist the robot in two ways. The lower arms are aiding the wire rack in gathering the tennis balls, while the upper arms serve the additional purpose of housing bump sensors to detect obstacles in case of a collision.

II. System Components

The Collector requires important components that are essential for its functionality. Our system components require careful consideration and selection of electrical components. For instance, to sense a tennis ball, it requires sensors and computer vision. To Power it, it requires a monocrystalline solar panel, and a 12V lithium-ion battery. We modified certain components periodically. For example, we changed the infrared distance sensor to Raspberry Pi Camera for improved image capturing. Thoughtful assembly of all system components is important for smooth functioning and success in our project. The following sections highlight major components that are being used in our project.

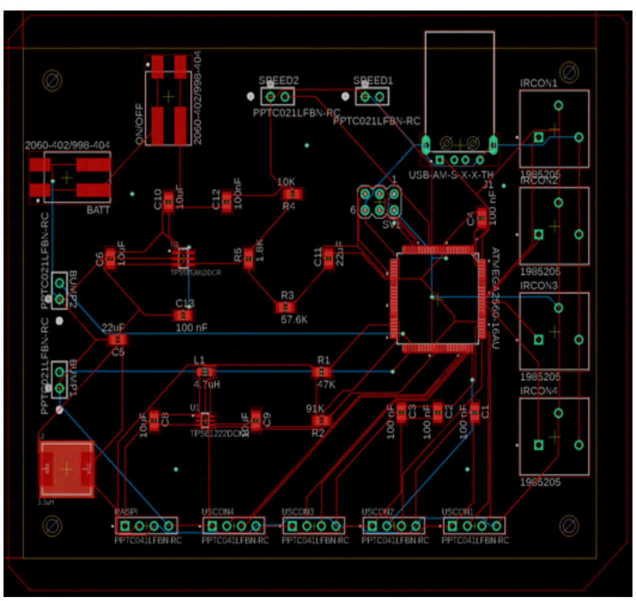


Figure 2: Main PCB design

A. Main PCB

The Main PCB (Fig. 2) is being used to integrate all of our components into one PCB. Here we have all the connections for our sensors and the ESCs, two input terminals for the battery and the on/off switch, we also installed a usb port to power the raspberry pi, In this PCB we also have a voltage regulator that will transform a range 10 to 14.8 volts from the battery down to 5 volts. Then there is a 5 volt to 3.3 volts converter which is used to transfer a signal with UART. We are using everything on this board except the 4 IR sensors on the right side, which from testing, concluded it didn’t satisfy our needs.

B. Motor Regulator PCB

The Motor Regulator PCB (Fig. 3) is a PCB we designed solely to regulate the voltage between the battery and the motors. The motors are rated to work at 2S or 7.4 Volts. This regulator was designed to drop the 12 volt battery voltage to 7.4 volts. Since the battery is 12 volts however it can be discharged at 10 volts to a full charge of 14.8 volts. We used TI WEBENCH to help design this regulator for the needed motor requirements. The output will experience 7.4 Volts as well as 6 Amps of current. Which is 44.4 Watts of power for our motors to move our solar tennis ball collector.

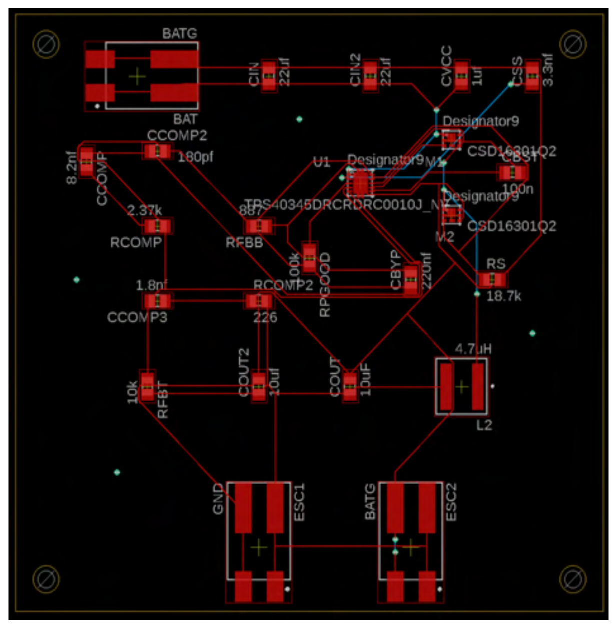


Figure 3: Motor PCB design

C. MPPT (Maximum Power Point Tracking) PCB

The MPPT PCB (Fig. 4) is used for connecting the solar panel to the battery and monitoring power generation. With MPPT, the solar panel is producing the power. However if the solar panel is not receiving a constant stream of light then the power the panel produces fluctuates. The job of this PCB is to track the voltage level of both the solar panel and the battery. Then it will adjust the voltage being provided from the solar panel to the most efficient point to charge the battery. This is achieved by the ATmega328 taking in the information of the current and voltages of the solar panel and regulating it as a DC-DC converter. This PCB features two ACS712 current sensors. It also contains 2 different buck converters.

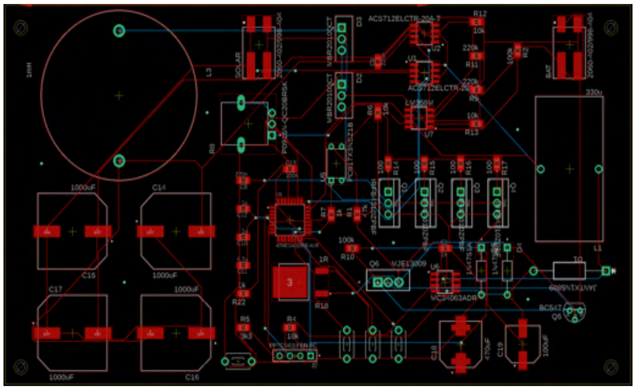


Figure 4: MPPT PCB design

D. Sensors

Sensors are one of the major components in our project. Through utilization of sensors, the robot is able to identify tennis balls and collisions, which are important aspects of a solar tennis ball collector.Ultrasonic sensors and limit switch bump sensors are two sensors that are being used in our solar tennis ball collector robot. HC-SR04 being used with a maximum of 5V working voltage and 15mA working current. HC-SR04 sensor is going to be utilized for tennis balls detection by the added capabilities of its features. Designing a robot requires safety aspects. That is why limit switch bump sensor is used to detect any collisions of a robot. Mini bump sensors are used to identify any collision between the robot and tennis court fences.

E. Solar Panel

In this project, we are using a 30W monocrystalline solar panel that runs at 30% efficiency, which is typical. This monocrystalline solar panel is fully waterproof and durable, capable of delivering 18V of maximum power voltage and 1.66A maximum power current. The Solar panel is mounted on top of the lid. Additionally we have crafted PCB design for Maximum Power Point Tracking (MPPT) to enhance the performance of monocrystalline solar panel, but also provide constant flow even when peak outputs occur.

F. Frame

The frame is a very big component of our Solar Tennis Ball Collector. With the frame we wanted to make sure that all of the components inside are protected and kept safe from any collisions and from all the effects of the environment. We also wanted to make sure that the frame was relatively lightweight. Due to these reasons we decided to make the frame out of PVC. We started out by building a skeleton of the frame using out the pipes. After the skeleton was made we then applied PVC Boards around the outside. The frame measures 15” X 15” X 10.5”. The frame weighs just about 10 pounds. Inside the frame will be all of our PCBs, a 12 volt battery, and the motors. On top of the lid will be a metal bracket that will hold the solar panel. We chose 7” wheels for our solar tennis ball collector. We chose the 7” wheels to make the height even with the wire rack. That way the wire rack will roll on the floor acting as a third wheel, being able to pick up the tennis balls and being the third point of balance that we need.

G. Brushed Electric Motors

For the motors we had a very big selection between brushless and brushed motors. We started off with using the brushless motors.We used the Hobby Fans S3650 3500 KV motor. As we began testing this motor everything seemed to be working fine. The only concern was that the motors would be drawing too much current with a full load. However after further testing with just the wheel attached the motor would produce enough speed but not enough torque to move the wheel itself. After this we tried to find a motor with more torque. We eventually decided on the Traxxas 3975R Titan 550 Reverse Rotation Motor. This was a different motor than what we were originally planning to use because this is a brushed motor. After some initial testing we found that this motor produced a bit more torque, but however it had less speed. This is okay, if not ideal for us because we do not want a very high top speed, we just want our solar tennis ball collector to move at a decent pace.

H. Electronic Speed Controller (ESC)

The Electronic Speed Controller is the brain of the motor. An ESC is responsible for controlling the speed of any electric motor. The ESC is what is connected to the PCB to get power. Then by using the PWM pins of the ATmega2560 we send a pulse through to the ESC. We took the motors and the ESC to the lab and using the function generator and the power supply unit we were able to test this. We noticed that the motors would only turn at a certain range of the pulse width. We also learned that the more we increased the width of the pulse the faster the motor would spin.

We have had to test a variety of ESCs throughout our project. We started off by using *Hobby Fans Upgraded 80A Brushless ESC*. This ESC worked well, the only drawback was it consumed too much current. Then since we switched to brushed motors we had to change the ESC. The second ESC we tried was the *Redcat Racing Hobbywing 1/10 Brushed Waterproof Electronic Speed Control* with this ESC we were not able to get the motors to turn on a PWM frequency that was going to be provided by the ATmega2560. After various rounds of testing we even had one of the ESCs combust. So after this we decided to switch ESCs once again. The new ESC we are using is the *Hobbywing Quicrun 1080 G2 ESC*. With this is ESC as it has a lot more for the different ranges of PWM frequencies accepted. We hope that it will be more than enough to people our motors at the right speed and torque that we want them at.

I. Microcontroller

The microcontroller used on the main PCB is an ATmega2560, initially chosen for its many usable pins, something we considered necessary when initially designing around many sensors. It is a low power microcontroller that is used mainly to process simple input signals from sensors and convert them to control signals for the motor drivers. This microcontroller is also notably natively capable of various serial communication protocols, which are used to communicate with other peripheral devices such as the Raspberry Pi. Specific use and control of this component is described in more detail in the sensor and software chapters of this paper.

The microcontroller used on the MPPT controller is an ATmega328, a similar model to the one used on the main board but with noticeably less pins. This allowed for programming with the same methods and environment while allowing for more space for other components on the board. The use of the microcontroller on this board is less demanding than the main MCU, which also incentivises us to use this smaller model.

J. Raspberry Pi and Camera Module

The Raspberry Pi (Model 3 B+) is a mini-computer that runs a lightweight version of Linux and designed to be used in a variety of applications too demanding for low power processors but with space and cost limits. The camera is connected to the Raspberry Pi board with an extended flex cable over the CSI-2 interface. This camera is specially designed for use with the Raspberry Pi, which has a dedicated port for the camera and its unorthodox interface. These components are used to do the software heavy image processing required for computer vision and then pass only necessary information to the main microcontroller.

K. Wire Rack

The wire rack is the component where all tennis balls will be stored and collected. It is shown in the first figure of the document. It is designed in oval shape with the stainless-steel elastic wires that go from one end to the other. Elastic wires help tennis balls to get inside of the actual wire rack while it rolls. The size of the wire rack is 9” of height and 13” of length.

III. Sensors and Computer Vision

We decided to use Ultrasonic sensors and limit switch bump sensors. HC-SR04 sensors are going to identify tennis balls that are scattered on the tennis court, bump sensors will detect collisions between robot and barriers that are surrounding the tennis court. It is important to prevent solar tennis ball collector from entering the tennis court area where people are engaged in the game. For that reason, we decided to keep the distance between the solar tennis ball collector and tennis court line. 4 ft of distance is enough to provide safety for individuals who play tennis in the tennis court. The Raspberry Pi camera with its perfect computer vision capabilities is the component that we rely on to maintain 4 ft distance between robot and tennis court lines.

A. Ultrasonic Sensors

HC-SR04 (Fig. 5) is the ultrasonic sensor that we used, to contribute detection of tennis balls. We are going to have four ultrasonic sensors attached to the frame from front, right, left and rear side. Each ultrasonic sensor uses a maximum of 5V working voltage and 15mA maximum working current. Ultrasonic sensors are going to have a maximum of 0.075 watts per sensor and 0.3 watts overall for four sensors. The HC-SR04 has a measuring distance from 5 to 400 cm. However, since the robot will always be in a moving position, we do not have to be concerned about distance measurements, because when an ultrasonic sensor detects a tennis ball, the robot will promptly move towards the tennis ball. The sensor calculates distance in a simple way. Calculation of distance is

$$\frac{time * speed\ of\ sound\ wave}{2}.$$

Approximate speed of sound is $29\frac{uS}{cm}$. HC-SR04 sensors have transmitter and receiver parts. When an ultrasonic sensor detects a tennis ball, the transmitter immediately sends a sound wave back to the receiver.

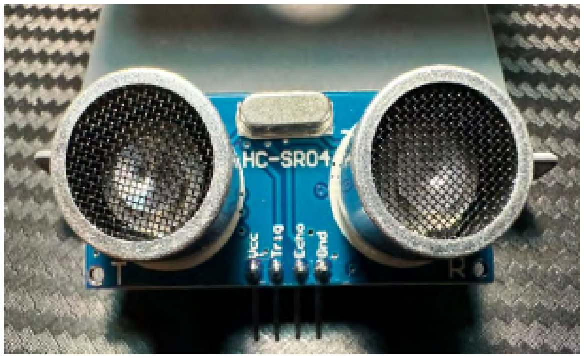


Figure 5: One of the HC-SR04 sensor

Ultrasonic sensors are covered and mounted on the frame facing outward. All of the Sensors' views are clear, ensuring that the wire rack does not overlap with the ultrasonic sensor's view. Right, left and rear sides are going to have one ultrasonic sensor each the same as the front end. It is important to note that it refers to the direction it is facing. The robot has the capability to detect a tennis ball even if the front sensor will miss it. If it is unnoticed by the front sensor and will be left behind, that means the rear sensor will detect the tennis ball and will notify the robot.

The front ultrasonic sensor will not be used for ball detection as that job will be handled by the camera. Instead, this sensor will help with avoiding obstacles, detecting them from far away.

B. Limit Switch Bump Sensor

We cannot forget about the solar tennis ball collector's safety that is safeguarded by mini bump sensors. These mini bump sensor sizes are 0.49”x0.26”x0.22”. We are going to have only two bump sensors located at the upper arms of the Solar tennis ball collector robot. One on each side. These two sensors are going to be located at the front end at the tip of the upper arms. The reason behind this is that the upper arms had to be longer than the measurement of the wire rack. This gives robot detection of the collision before the wire rack comes in contact with the barriers or fence. The lever will be pushed by an obstacle and the robot will change its direction after realizing it. NO and NC pins of bump sensors are being triggered when the lever is in collision with a barrier. NO pin is letting current flow through the pin. Voltage rating for bump sensors can go from 3V to all the way to 125V. However, in our project, we are not going to use high voltage which means minimum voltage works in our project.

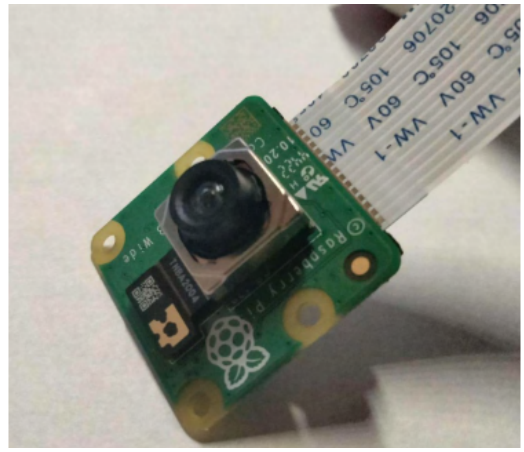


Figure 6: Raspberry PI Module 3 Camera

C. Camera

We decided to eliminate the use of six Infrared distance sensors in our project and replace them with a Raspberry PI Camera Module (Fig. 6). Raspberry PI Module 3 camera comes with 12MP sensor and autofocus[1]. Moreover, our chosen model has a 120-degree wide angle view which allows us to use it over a wider array of sensing applications instead of using several different devices with dedicated jobs.

The camera is mainly used for general object detection, accomplished through computer vision software algorithms. Court lines are avoided as best as possible with distance estimation monitored by the camera, maintaining a distance of at least four feet from the camera. Detection of tennis balls is also accomplished through the camera, using their position in the camera's view to help the robot navigate to collect them.

IV. Power

The Solar Tennis Ball Collector is powered by a 30W monocrystalline solar panel and 12V 30Ah Lithium-Ion battery. The Lithium-Ion battery weighs 7 lbs. It is a lightweight battery compared to its rivals. We designed a dedicated MPPT controller PCB. MPPT means maximum power point tracker. It is a technology that is being used in solar systems to optimize efficiency and consistency of solar panels by adjusting and regulating the power that needs to be used. For instance, if the output of the Solar panel is 17V at a given moment, it will consistently convert it to 12V because our battery is 12V.

The Solar panel will be connected to the MPPT controller with positive and negative terminals. Positive output of MPPT controller will be connected to positive terminal of 12V lithium-ion battery and negative output of MPPT controller will be connected to negative terminal of battery.

Power consumption	P
Efficiency	e
Solar irradiance (Orlando FL)	Si=5.59kWh/m^2/day
Total power of robot	Pt
Power needed from solar	Pn=$\frac{Pt}{e}$
Area of Solar panel	A=51.556 inch^2
Approximate Efficiency	Ef=30.01%
Panel size	Ps=21.85"x2.36"
Output Power	Op=Ps*Si*Ef

Table 1: Power Analysis

To figure out what we need from a power standing point, we had to run some calculations using Orlando's Solar Irradiance. This city's solar irradiance is 5.59kWh/m^2/day. Below we can see an analysis for our 30W monocrystalline solar panel (Table 1).

If we convert the area from inch^2 to m^2 we get, 0.033m^2. After converting the area to m^2 , we can calculate output power. The Output power is giving us approximately 0.0557kWh/day or we can say 55.7 Wh/day.

V. Software

A. Main Control System

The main controller handles inputs from all sensors and sends control signals to the electronic speed controllers handling motor control. In other words, the system's inputs are sensor readings and output is robot movement. The Raspberry Pi handles all of the image processing for the camera and sends direction signals to the main MCU, a process which will be discussed further in the following section.

Generally, the control system works on a loop that routinely checks sensor data and adjusts motor speeds accordingly. If a close obstacle is detected by the ultrasonic sensor, motor controls direct the robot away from collision. Bump sensors detect immediate collisions that could not be avoided and direct the robot to stop, wait, and maneuver away if necessary. The response from these sensors being triggered is dependent on the direction that they face. For example, if an obstacle is detected on the left bump sensor, the robot will move toward the right to avoid it. When checking the Raspberry Pi for sensor data, the main controller will send a signal asking for instructions, which the Pi will respond to with a command. Input responses have varying levels of priority based on their urgency. For example, collision detected by a bump sensor will trigger a near immediate response to avoid further damage and take priority over detection of a further obstacle elsewhere that expresses a more lenient need to move out of the way.

B. Computer Vision

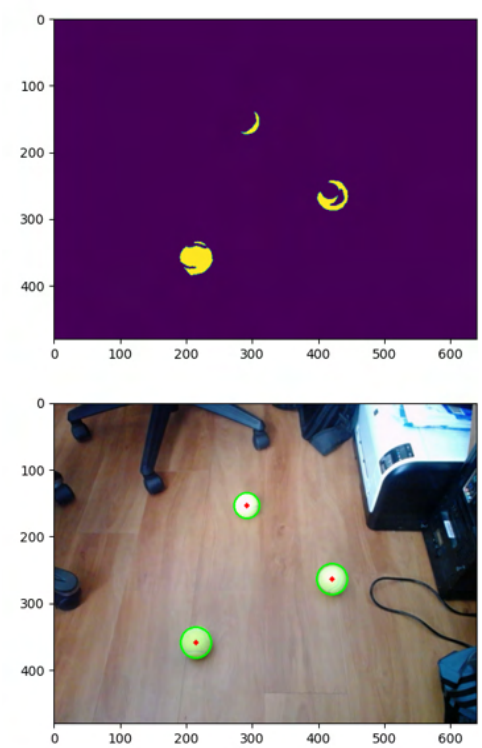


Figure 7: Ball detection software test images

Computer vision processing is handled entirely by the Raspberry Pi, which runs on a lightweight distribution of Linux called Raspbian, allowing for the use of commonly used image processing programs. For this project, our Pi uses OpenCV for detection of tennis balls and court lines.

Tennis ball detection is accomplished by looking for their distinct bright green color. This color is used to make a binary version of the original captured image, which is then searched for circular objects (Fig. 7). The algorithm then makes a list of the balls that were detected and their positions in the frame, listed from closest (lowest in frame) to furthest (highest in frame) with especially high circles ignored. Since the camera also has the ball storage container in view, a similarly functioning algorithm can be used to determine if the storage is full. These two algorithms are differentiated by the area of the frame of view that is ignored, with the general ball detection ignoring anything not at ground level and the ball storage while storage monitoring ignores everything except the ball storage container.

Court lines are detected by the software by taking advantage of their contrast against the rest of the floor and the straightness of the lines. When the court lines are found, the result is two thin lines running parallel with each other. Knowing the width of the court lines (typically two inches wide) and comparing that to a known pixel width of the same line, we can estimate the distance between the line and the camera. Additional checks are done to ensure that the object being detected is actually a court line and reduce false positives.

Much like the main controller, this system also works on a constant loop to ensure updated and accurate environment detection. When the main controller sends a signal requesting instructions, a single, predetermined command is sent to the main controller. This command is updated every loop and is determined after processing the results of each individual detection function. The command can be a direction for the robot to move or another non-directional notification, like letting the main controller know that the storage is full. Generally, movement avoiding the court lines and the full storage notification takes priority over movement to pick up tennis balls.

VI. Testing

The testing was split in parts of the robot. All the main components were tested separately to ensure functionally. The sensors were tested individually on prototyping boards before implementation on the custom PCB. Camera and Raspberry Pi software was tested on a desktop Linux system before being further tested and tweaked on the hardware itself. The Motors were tested first without any load and then with only wheels before eventually attaching to the frame and adding the further weight of all components. During the PCB Assembly, each part was read with a digital multimeter to ensure that it was the correct value we had specified. When running manual tests on the wire rack, we realized it needed to be slightly modified so that it could pick up the tennis balls with more ease. Since the Robot fully assembled is about 30 lb, we needed a lightweight, but sturdy frame and wheels to house. For the framing we choose PVC and for the Wheels we choose ones that would typically go on a lawnmower.

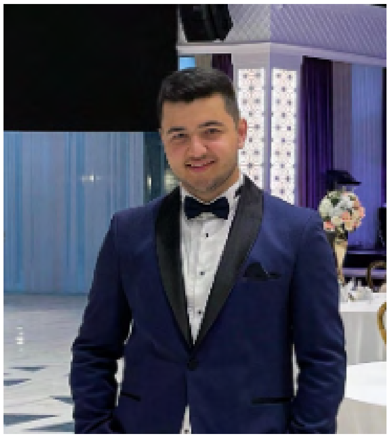
VII. Conclusion

The Solar Tennis Ball Collector is a family-friendly device that is suitable for all.The last thing that individuals want to do after an intense tennis session is to gather scattered tennis balls around the tennis court. It is designed to prevent people wasting time and energy on collecting scattered balls allowing them to use that time for better and meaningful activities in their lives. The primary goal of the robot is to gather scattered tennis balls when tennis players hit them in various directions inside of the tennis court. At the same time, we had to think about safety regulations too, implying that the Solar tennis ball collector is restricted to enter zones where tennis players are engaged in their game. As it was mentioned, computer vision is used for solving particular issues. With the help of the perfect vision of Raspberry Pi Camera, we are able to keep distance between the tennis court and robot. Detecting tennis balls and collisions in the tennis court is employed with sensors.

VIII. Future Improvements

For the next version of this robot, the main hope would be for solar panel technology to be much more advanced such that the battery wouldn't be needed for it to function properly, but rather be directly powered from Solar only, while being more compact. Another Improvement could be Size Reduction, the robot's frame is the size it is because of all the components within it. The next future improvement could be a better, more complex version of the wire rack. Where it involves more mechanical function, which we tried to minimize because our scope was Electrical, and not so much about Mechanical.

IX. The Engineers



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Juan Rodriguez is a senior at the University of Central Florida, majoring in Electrical Engineering (Power & Renewable Energy Track), with a minor in Intelligent Robotic Systems. Who currently has a Full-time Internship since June 2023, and is on track to having a Full-time position shortly after graduating.

Emmanuel Sanchez is a senior majoring in Electrical Engineering (Comprehensive Track) at the University of Central Florida. He is a first generation college student. After graduating he plans to apply for various internships and to see what side of the field he prefers.

Acknowledgement

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