Automated Rotating Solar Plant Rack with Self-Care Capabilities

Brian Geibig, Abigail Michael, Christina Quinones, Melissa Rose

Dept. of Electrical Engineering and Computer Science, University of Central Florida, Orlando, Florida, 32816-2450

***Abstract* — Plants require plenty of care from their owner to assure they receive enough water and sunlight for survival. This task can be daunting for some people as they lead hectic lives with little time for plant care. This project aims to provide a system that will autonomously care for a house plant without the need of human assistance. It will regularly monitor the water and sunlight levels within the pot and assure that the plant receives the correct amount of both. The system will require little assembly and will run unattended for long periods of time.**

***Index Terms* — Light sensor, moisture sensor, temperature sensor, WiFi module, shading system, rotation system, irrigation system, power supply, solar panel, solar charge controller, rechargeable battery, voltage regulator, PCB, website.**

I. Introduction

Gardening is a wonderful hobby that not only provides comfort and food to billions but also enriches the Earth by reducing carbon output. However, plant maintenance can be time-consuming and easy to blunder. Each plant requires a specific care process for a successful growth which can be hard to achieve for those with a busy schedule and those with a lack of experience in gardening. However, with the designed Automated Rotating Solar Plant Rack with Self-Care Capabilities, it will be easier for everyone to have a small/medium house plant without worrying about its maintenance. This project design aims to provide a house plant with the required conditions for it to grow autonomously through the help of different subsystems and sensors. The designed system will provide the plant with the required amount of water and sunlight depending on the type of plant selected. It will also assure that the plant grows straight up rather than towards the light source. While working together, all these subsystems will provide the plant with optimum condition to grow by itself when a person cannot be present to do so. However, each user will be able to monitor the system from wherever they are via a website to adjust the setting based on the type of plant selected.

II. System Design

The system is responsible for handling different functions to take care of a plant and provide it with essential conditions to grow without much human interaction. This system design is divided into different subsystems. These include the irrigation system, shading system, rotation system, power system, and communication system. The irrigation system measures the moisture levels of the soil and determines if the plant needs more water. The shading system covers the plant based on the amount of light measured by the light sensor and temperature sensor. The rotation system rotates the plant into a different position to ensure the plant receives the same amount of light and makes it grow straight up rather than towards the light source. The power system is responsible for powering all the electromechanical subsystems and sensors using a solar panel and rechargeable battery to ensure they can work together with the required amount of power. Finally, the communication system ensures that the overall system and PCB communicate with the website, database, and server using a Wi-Fi module. All these systems together will provide the automated caring process required to grow a plant.

All the subsystems and sensors are placed together in an enclosure that is divided into different sections to ensure they are protected, and the overall system operates at optimum conditions. In the bottom, the water pump, water storage, and the rechargeable battery are placed together since they are the heaviest components of the overall design. On top of this, the PCB and different connections will be placed to provide enough space for it and avoid short circuits and connection issues. The motor for the rotation system is placed in this section along with the PCB to operate the turning table that is placed above. These sections are enclosed with a metal piece to protect them. On top of the turning table, the plant pot is placed. It is a separate piece since it will be easier for the user to change the plant without transplanting it. Finally, the shading system is placed on top of the plant. This system is attached to a supporting structure that is affixed to the bottom base.

III. System Summary

The project design consists of different subsystems and sensors that work together to provide the plant with the required conditions to grow without much human interaction. These subsystems include the irrigation system, shading system, rotation system, power system, and communication system. Among the sensors included in the design are the temperature, light, and moisture sensor. Each subsystem and sensor has its own role within the project and provides necessary functionality for the project's ultimate success.

A. *Physical Design*

The physical design includes all the enclosures, supporting structure, and components to ensure a proper functionality of the designed system. The design is divided into different sections to provide each component with required operational and safety conditions.

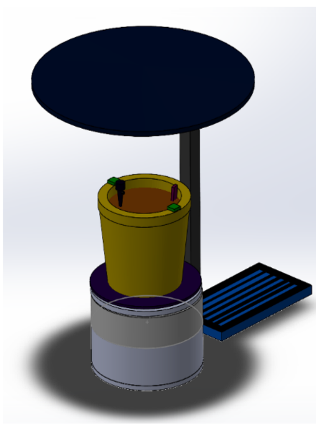

Fig. 1. Model of the system physical design

The bottom base of the physical design is divided into two sections. The water storage, water pump, and rechargeable battery are placed at the very bottom with a separation layer to avoid the battery from being in contact with water. They are placed at the bottom since they are the heaviest components of the overall system. This allows the system to be balanced and sturdy. Also, it will prevent other electrical components from being in contact with water in case of any leak. On top of this section, a separate and enclosed space is designated for the PCB, electrical connections, and motor of the rotation system. This design provides enough space for the connections to avoid short circuits or touching cables. Also, it isolates the main board from any water leakage and provides an easy-access space to fix any connection issues that may occur. On top of this section, the rotation system is placed. Here, the motor is connected to a wheel that allows the plant pot base to rotate. The shading system is placed on top of the plant pot. It is attached to one of the sides of the main base through a supporting structure affixed to it. Here, the motor is placed in the middle of the shading system to allow it to open and close depending on the data received from the light sensor. The solar panel is attached to the supporting structure with an angle to ensure it receives enough sunlight.

B. *Irrigation System*

The irrigation system is responsible for keeping the plant and soil moisture within acceptable ranges depending on the type of plant selected. This system is composed of a water storage or reservoir that can hold up to 2.5 gallons of water. To irrigate the plant, a 3.6W 12V pump powered by a DC brushed motor is added to the system. This provides the required amount of water to the plant via a ¼ inch tube connected to the water pump and drip emitters. The tubing will allow for an appropriate flow of the water and will allow the user to set up the potted plant so that each area may be evenly doused. The emitters on the other hand, have an adjustable flow rate feature so the watering rate may be adjusted. Once this level is adjusted, the new watering rate can be calculated, and the input can be set by the application to water the plant appropriately.

This system depends on the moisture level measured by the moisture sensor. Depending on the readings of this sensor, the irrigation system will or will not operate. Every two minutes, the moisture sensor will be polled to compare the readings with an established threshold. If the reading is higher than the threshold, the timer will be set for two minutes. Once this timer ends, a new reading will be compared. If the threshold is higher, a signal will be sent to the water pump to water the plant. In this case, the timer will be set for thirty seconds. After this period elapsed, the water pump will receive a signal to turn it off. This is a continuous process to ensure the plant is well hydrated throughout the day.

In addition, the user is able to control the irrigation system via a website app where he can select different options and settings depending on the plant selected.

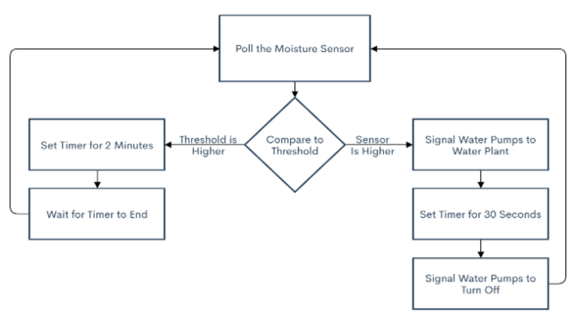

Fig. 2. Irrigation System Flowchart

C. Shading System

The shading system is responsible for monitoring and regulating the amount of sunlight the plant receives. The system consists of a light sensor, a motor, and a shading mechanism. With these components, the shading system is able to accurately regulate the amount of sunlight the plant receives.

The process begins with the light sensor which will measure the lux level of the air surrounding the pot. The value will then be sent to the CPU where it will be processed and compared to the threshold. Once the light reaches its threshold, the CPU will signal the motor to rotate which will cause the shading system mechanism to deploy. The shading system will remain in its deployed state until the next day when it closes and starts the process all over again.

The threshold for the system will be set by the user through the app. This data will be sent through the Wi-fi module to the CPU and will change the value of the threshold. The CPU will use this new number when deciding whether or not to deploy the shading system.

In addition, the user will have manual control of the system through the app. The app will feature a selection box that will allow the user to manually deploy or close the shading system with the press of a button.

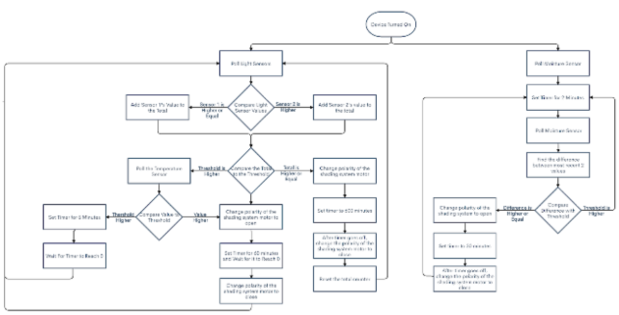

Fig. 3. Shading System Flowchart

D. Rotation System

The rotation system ensures the plant receives an equal amount of sunlight on all sides and grows in an upward direction. This system counts with a 12 V brushed DC motor attached to a wheel that rotates the disc and base of the plant pot. This motor is set to rotate in two directions with an angle of 180 degrees to avoid cables from being entangled. To operate this system, a variable for the direction of the motor rotation is established. The value of the variable is then analyzed. If this value is zero, the polarity if the motor is changed to positive and the variable is changed to one. On the other hand, if the variable value is one, the polarity of the motors is changed to negative, and the variable is set to zero. After this, a timer is set to twenty minutes. Once this timer hits zero, the variable is analyzed again to perform the corresponding operation to change the polarity of the motor and make it turn with an angle of 180 degrees. This angle is achieved by setting the corresponding time it takes the motor to rotate the disc and base until they reach the desired angle.

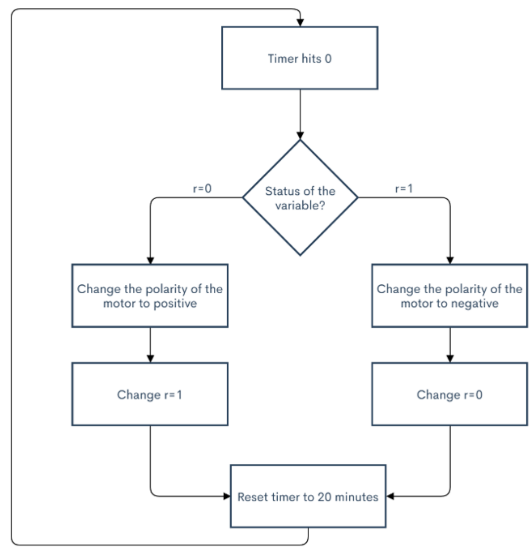

Fig. 4. Rotational System Flowchart

E. Power System

As this project aims to provide an autonomous system to take care of a plant without much human interaction, it was decided to power the overall system via a solar panel. Even though the solar panel selected is rated at 10W and outputs a voltage of 12V, this output is far from being constant due to different environmental factors. For this reason, a solar charge controller was added to regulate the output voltage and current from the solar panel to charge a rechargeable battery in a constant voltage and constant current mode. The chosen rechargeable battery was a 12V 5Ah Lithium LiFePO4 deep cycle rechargeable battery since it can handle more than 2500 charging cycles. This extends the life of the power system and requires less maintenance from the user.

Since the overall system is designed with different components that require specific voltage levels, a voltage regulation must be implemented in the design. The motors used for the rotation, shading, and irrigation system operate at 12V DC which allows them to be powered directly from the rechargeable battery. However, the microcontroller and moisture sensor used in this application require a voltage of 5V, while the light and temperature sensors and the Wi-Fi module require a voltage of 3.3V. To achieve this voltage levels, two voltage regulators were implemented in the design. Both voltage regulations were implemented using the LM2576-ADJ switching regulator from Texas Instrument. This switching regulator was chosen since it is more efficient than linear regulators and they can handle voltages from 4V up to 40V.

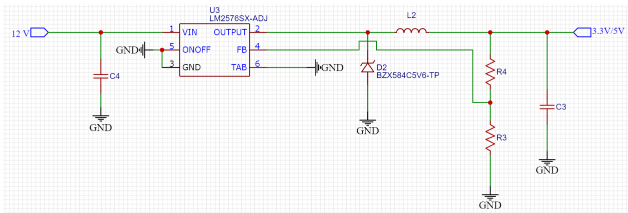

Fig. 5. Voltage Regulator

Another component of the power system is a motor driver module. The chosen module was the L298N module. This module can drive DC and stepper motors and can control up to four DC motors, or two DC motors with directional and speed control. This motor driver module was selected to change the polarity of the motors for them to rotate in both directions. The L298N driver chip is based on a double H Bridge configuration which allows motors to operate at different polarities. To control the spinning direction of the motor, two direction control pins are set for each channel. Pins IN1 and IN2 control motor A, while pins IN3 and IN4 control motor B. Either a logic HIGH (5V) or logic LOW (ground) must be applied to the inputs of each motor to make it spin in both directions. If both inputs are LOW or HIGH, the motor is OFF. If input 1 is HIGH and input 2 is LOW, the motor spins in a forward direction. If input 1 is LOW and input 2 is HIGH, the motor spins in a backward direction.

F. Communication System

The communication system is responsible for communication between the overall system and the app. The system consists of a web application that will allow the user to insert data about the plant, have manual control over the system, and receive updates about the current state of the plant. It will provide an easy-to-use experience for the user.

The communication system consists of several components. To start, we have the CPU itself. This is the ATMega328P which will be responsible for not only implementing the inputs sent through the app but also sending live updates regarding the system. This includes the things like the current moisture level and the state of the shading system. The CPU will send its data via the Wi-Fi module.

The chosen Wi-Fi module is the ESP-12F. This device is soldered to the PCB and communicates with the CPU using I2C where the Wi-Fi module acts as the master and the CPU the slave. The code for the communication system has been implemented in such a way to assure that the data is updated consistently and is always up to date. When sending data to the CPU, the Wi-Fi module will send a request to the CPU via the I2C lines which will in turn be processed and implemented in the plant's care routine or the output systems. When retrieving data from the microcontroller, the Wi-Fi module will send a request to the CPU via the I2C line. The CPU will retrieve said data and send it back to the Wi-Fi module over the same line. This data will then be sent to the database which will be uploaded to the app.

Next, we have the application itself. The app is web-based and can be accessed by any device that has Internet capabilities. The prototype was designed in Adobe XD and the website itself in Adobe Dreamweaver. The app is user-friendly as it is easy to navigate and has little learning curve. The app will allow the user to have full control over the system.

All data regarding the inputs and outputs will be stored in a database. For this project, we are using MySQL. This database will store all values as integers which can be easily transmitted to between the Wi-Fi module and CPU for processing. A PHP file was created to dictate these interactions. The PHP file also transfers the user submission in the database. It will be referenced in the code for the Wi-Fi module which will allow it to send and receive data to the CPU.

Finally, the application will be uploaded to a server. For this project, 000webhost was chosen. This server will allow the website to be accessed from any Internet capable device in the world.

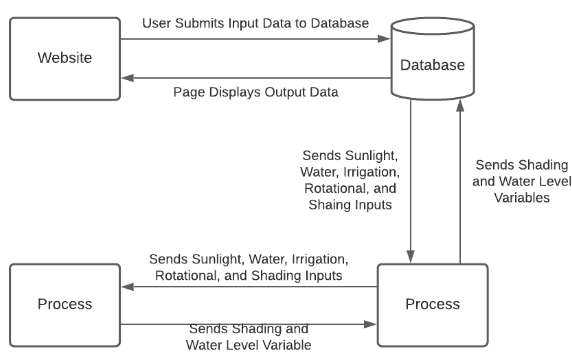

Fig. 6. Communication System Flowchart

IV. Components Summary

The Automated Rotating Solar Plant Rack with Self-Care Capabilities contains different components such as motors, sensors, a pump, a communication module, and a solar charge controller to ensure the overall system provides the plant with conditions that promote its successful growth. Each component is described below along with its main role in the project design.

A. Motors

The overall design requires two separate motors for the shading and rotating system. For both systems, the same motor was selected. The chosen motor for each system was a DC 12V 10RPM gear motor. This makes them able to be connected directly to the rechargeable battery to be powered. This is a high torque motor that can drive 15 kilograms which is acceptable for both implementations of the design.

Both motors are implemented such that they can spin in both directions. The rotation system must rotate in both directions with an angle of 180 degrees to avoid cables and electrical connections to be entangled, and at the same time provide equal amount of light to all the sides of the plant. The motor for the shading system must also rotate in both directions in order to open and close the system depending on the readings from the light sensor which determines the amount of light the plant is receiving.

The polarity for each motor is controlled with a motor driver controller implemented in the PCB which uses the L298N Dual Full-Bridge driver. This motor controller is designed to change the polarity of two motors based on logical HIGHs and LOWs.

B. Water Pump

The chosen water pump was a mini submersible water pump with a power rate of 3.6W and a voltage of 12V DC. Its dimensions are 2.17x1.34x1.61 inches, which make it suitable for the implementation due to space limitations. In addition, it has a maximum flow of up to 240 liters per hour or 63.4 gallons per hour which is acceptable for this implementation. Also, this pump is able to lift liquid to a height of three meters, so it can easily pump the water from the water storage container at the base of the system, to the area above where the potted plant is.

This water pump is connected to a drip emitter via a ¼ inch tubing system which allows for an appropriate flow of water into the plant. The pump is controlled by the readings of the moisture sensor which based on an established threshold will determine if the plant needs more water or not.

C. Light Sensor

The chosen light sensor is the SparkFun Ambient Light Sensor with Qwiic Ports which uses the VEML6030 onboard light sensor. It has an operating voltage of 3.3V, a stand-by current of 0.5 μA, and a maximum power consumption is 50 mW. It conducts digital communication using I2C and has a 16-bit resolution. It has a spectral response between 400-700 nm which is similar to the human eye. The light sensor itself is capable of detecting light from a range of 0 - 120000 lux.

The light sensor will be responsible for periodically detecting the level of sunlight in the area surrounding the plant. This data will be used as an input for the shading system. It will be sent to the CPU using I2C and used to determine the total amount of light the plant has received for the day and when to deploy the shading system.

The light sensor will be placed on top of the shading system. Here, it will be in direct contact with the Sun and will produce the most accurate measurement of the total sunlight possible. It will be connected to the PCB through a SparkFun Qwiic 4-Pin JST Connector. This wire will plug into a port soldered onto the PCB. Because the sensor is placed at the top of the shading system which is significantly far from the PCB, the wire had to be extended to assure that it could reach the sensor as well as enclosed to keep it safe and secure from a wider variety of environmental elements.

D. Temperature Sensor

The temperature sensor chosen for this project is the SparkFun Temperature Sensor with Qwiic Ports which houses the TMP102 temperature sensor. The sensor can detect temperatures within a range of -40°C to 125°C or -40°F to 257°F with an accuracy of 0.3°C or 0.54°F. The sensor operates on a voltage of 3.3V, a low quiescent current of 10 μA, and a maximum power consumption of 36 μW It has a digital output and communicates via I2C with a 12-bit resolution.

The temperature sensor will be responsible for measuring the temperature of the air surrounding the plant in an accurate and efficient manner. This data will be used by the CPU to determine when to deploy the shading system.

The sensor itself will be placed on top of the pot. Here, it will be out of the direct sunlight and will provide a more accurate reading of the temperature of the plant. It will be connected to the PCB through a SparkFun Qwiic 4-Pin JST Connector. The wire will connect directly to the PCB through a port soldered to the board.

E. Moisture Sensor

The chosen moisture sensor is the SparkFun Moisture Sensor. This has an operating voltage of 3.3 V. The moisture sensor produces an analog output and, after ADC conversion, has a moisture sensor range of 0 - 1023 bits.

The moisture sensor consists of two waterproof probes that, in the presence of water, lower their resistance. This change in resistance allows for a reading of the moisture level on the probes.

The moisture sensor holds the responsibility of accurately reading the moisture levels within the pot and sending it to the CPU. This data will then be used to determine whether the plant needs water and if the irrigation system should be activated. The moisture sensor will be placed closer to the bottom of the pot. This will assure that the moisture sensor is within the soil and its readings are as accurate as possible.

The moisture sensor will be connected to the CPU through a soldered port on the PCB. A SparkFun Qwiic 4-Pin JST Connector will plug into the port and will then connect directly to the moisture sensor. This wire allows the moisture sensor to be fully operable for the project.

F. Wi-Fi Module

The chosen Wi-Fi module is the ESP-12F. It operates at a voltage of 3.3V and a clock frequency of 2.4GHz. It consists of 16 GPIO ports, is capable of conducting the 802.11b/g/n protocols as well as I2C communication, and has a 4 MB flash memory. The Wi-Fi module will be responsible for transmitting data between the CPU and database in an efficient manner. The ESP-12F is capable of meeting these requirements and for this reason, was chosen for the project.

As stated above, the Wi-Fi module will be responsible for transmitting data between the database and the CPU in an efficient manner. It will communicate with the CPU via I2C where it will act as the master and the CPU the slave. The Wi-Fi module will take all data received from the CPU and send it to the database using the 802.11 protocol.

The Wi-Fi module has been soldering onto the PCB and will be programmed separately from the CPU. While it will receive power from the same battery as the other components, it will function with its own CPU and work alongside the ATMega328P to transmit data.

G. Solar Charge Controller

Since the main source of power to the overall design comes from a solar panel, a solar charge controller was added to the design to regulate the output voltage and current supplied by the solar panel. The chosen solar charge controller chip was the CN3795 from Consonance Electronics. This is a multi-chemistry battery charger with photovoltaic cell MPPT function. This charger can handle wide input voltages from 6.6V up to 30V and is suitable for single- or multi-cell Lithium ion, LiFePO4, or Lithium Titanate Batteries that require constant current and constant voltage mode. It can have a charge current up to 4A and provides battery overvoltage protection. Also, it can automatically recharge the battery after a certain threshold is reached while indicating the charging status. All these characteristics make it a good fit for this implementation based on the rechargeable battery chosen.

For this particular application, the charging current was set to 2A by adjusting a single current sense resistor, RCS. The regulated output voltage was controlled by the resistor divider composed of R1 and R2 and was set to be around 13.3V which is required to charge the battery.

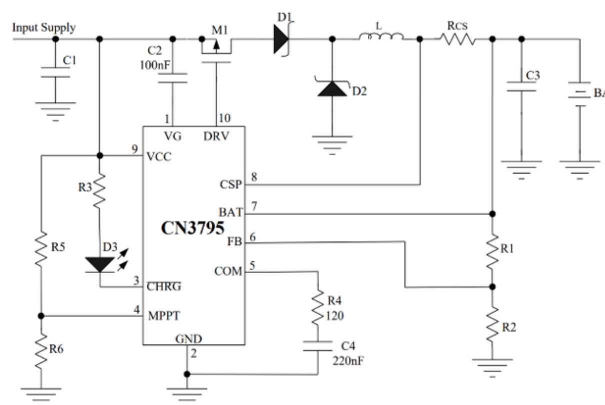

Fig. 7. Solar Charge Controller

H. PCB

All the subsystems and sensors of the overall design must be controlled and maintain an electrical communication for a successful operation of the project design. In order to achieve a controlled system, a printed circuit board (PCB) was designed. This PCB contains all the components to drive the electromechanical systems and sensors of the design. The designed PCB includes the ATmega328P microcontroller, the solar charge controller, voltage regulators, motor driver controller, Wi-Fi module, relay circuit for the water pump, indication LEDs and the pin headers to connect all the components of the overall design.

The PCB design was performed using EasyEDA and was manufactured by JLCPCB. The dimensions of the whole board is 170 mm x 110 mm. The PCB was designed with two layers, top and bottom.

The board design is divided based on each circuit implemented for each controller and module. This method allows to keep all related components to a specific circuit together and keep traces as short as possible to reduce electromagnetic interferences and costs. This will also ensure the overall system operates at optimum conditions creating a more efficient design.

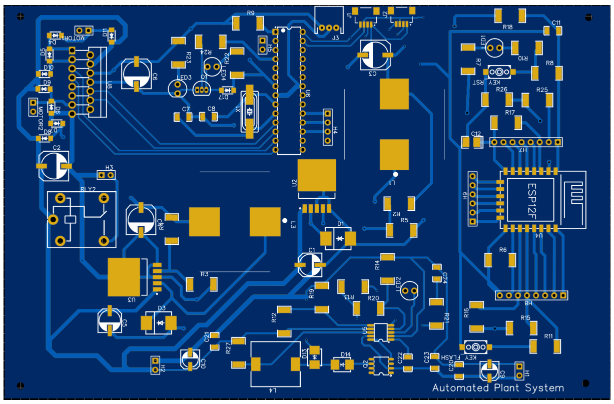

Fig. 8. Project PCB Layout

I. *Microcontroller*

The chosen microcontroller is the ATmega328P. It operates on a clock rate of 16MHz and features 23 I/O pins, 2 8-bit timers, 1 16-bit timer, and 2 external interrupts. The board also houses 32KB of internal storage as well as 32 general purpose registers. The pinout of the microcontroller can be seen below in Figure 9. Most importantly, the MCU is capable of conducting UART, SPI, and I2C communication which will allow it to communicate effectively with all components of the various systems.

Another reason for choosing this microcontroller was its manufacturer. Choosing an Arduino MCU will allow the device to be programmed in Arduino IDE - a program that this group is familiar with. This also allowed for a wider selection of components as much of the market is compatible with Arduino.

The project consists of multiple systems that must work hand in hand without interfering with one another. For this reason, it was important to choose a microcontroller with enough capability to handle such a task. The chosen device meets all requirements. To start, the 16 MHz clock rate plays a vital role. It is fast enough to assure that all lines of instruction are processed without becoming overwhelmed as losing an instruction on the way. It is also slow enough to assure a low power consumption and a more efficient system.

The microcontroller also features 32 KB of storage. With so many components associated with the various systems, the code houses many libraries and functions for setting up. Therefore, it is important for the microcontroller to consist of enough storage to store all of the code required to operate.

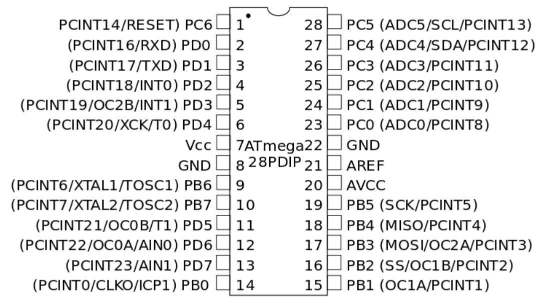

Fig. 9. Pinout of the ATmega328P

J. *Server and Data Storage*

A server and database are components in the communication system. The server houses the application itself and provides a method for users to access it. The database is used for storing data that will be sent between the app and the Wi-Fi module. Both components play vital roles to its successful implementation.

The chosen server is 000webhost. This was chosen for its functionality, affordability, and reliability. The server houses the entire website and provides a link for the users to access. The files were uploaded to the server using the FTP server FileZilla. With the use of the server, the web application is fully accessible by any device with Internet capabilities.

The database is used to store all data sent between the application and Wi-Fi module. MySQL was used for the database. This was chosen for its affordability and ease of use. The database will store everything from the most recent measurements from the sensors to the current state of the shading system. All submitted values will be stored as integers which can be transferred easily between terminals.

K. *Website*

A website was created to enhance the user experience and functionality of the product. The website will allow the user insert data about the plant which will in turn be used to care for the plant. The website will also provide insight of the plant's wellbeing to the user. This includes a reading of the system's lighting, temperature, and moisture levels as well as the status of the shading system. In addition, the website provides the user with manual control over the project's three main systems. The website was designed using Adobe XD and Dreamweaver. It was uploaded using 000WebHost to the server and was tested on a group member's laptop. The response time of the website was less than 3 seconds.

The website was designed to be easily accessed by all users. Because the target audience is not traditionally tech-savvy, it is important for the website to be easy to use as possible with little to no learning curve. This requires a simple design with as few components as possible. This was achieved by grouping like functions together and using large, easy to find text. There is little to distract the user from the true functionality of each of the pages of the website.

V. Conclusion

This project has been an extraordinary and challenging experience for the group. Completing a major project in a two-semester time period with the monetary constraints that we had proved to be a challenge for all of us. Not to mention the effects of the COVID-19 pandemic on our ability to meet up as well as access to necessary equipment for the project's completion. This project as a whole has given us real-world experience that we will find in our everyday lives as Electrical Engineers. From initial brainstorming to the final testing of the project, the entire process has provided great insight on our lives in the electrical engineering field. It has provided necessary experience that each of the group members will use in their future careers.

Acknowledgement

Our group wishes to acknowledge our professors and peers who have taught us all we needed to know for the successful implementation of this project. We want to especially thank Dr. Wei, our advisor, for his guidance and professionalism. We are thankful for all that we have learned to allow us to reach this educational milestone and to one day be considered respected electrical engineers within the field.

Engineers

Brian Geibig is a baccalaureate student at the University of Central Florida. His interests include communications and PCB manufacturing. Upon graduation, he plans on obtaining a starting position as an Electrical Engineer with a corporation.

Abigail Michael is a baccalaureate student in Electrical Engineering at the University of Central Florida. Her interests include signal analysis and embedded systems. Upon graduation, she plans on pursuing her graduate degree in Industrial and Systems Engineering from the University of Florida while working towards a career in Industrial Engineering.

Christina Quinones is a baccalaureate student in Electrical Engineering at the University of Central Florida. Her interests include power generation, transmission and distribution. Upon graduating, she will continue her career as an electrical engineer with the Power Delivery Distribution Services Group at POWER Engineers.

Melissa Rose is a baccalaureate student at the University of Central Florida. Her interests include processor design, embedded systems, and sensors. Upon graduation, she plans on working as a Hardware Engineer for IBM in Austin, Texas.

References

[1] "4A, Multi-Chemistry Battery Charger With Photovoltaic Cell MPPT Function CN3795," *Consonance Electronics,* www.consonance-elec.com/pdf/datasheet/DSE-CN3795.pdf

[2] Last Minute Engineers. "In-Depth: Interface L298N DC Motor Driver Module with Arduino." *Last Minute Engineers*, Last Minute Engineers, 18 Dec. 2020, lastminuteengineers.com/l298n-dc-stepper-driver-arduino-tutorial/.

[3] "LM2576xx Series SIMPLE SWITCHER 3-A Step-Down Voltage Regulator." Texas Instruments, June 1999, www.ti.com/lit/ds/symlink/lm2576.pdf?ts=1618779211178 &ref_url=https%253A%252F%252Fwww.google.com %252F.