Green Steel Garden

A Smart Hydroponics System

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Abstract – The primary goal of this project is to design and develop an automated hydroponics system that will house and grow a variety of plants in an indoor environment. The system will be automated with the purpose of requiring as little physical user interaction as possible. The features that are automatized are all attributes that the end user would otherwise spend time monitoring manually. The use of a mobile application to enable remote viewing of system statistics will appeal to the target audience of potential hobbyists who wish to grow plants locally, but do not have the prerequisite knowledge, time, or effort required to do so efficiently. The grow chamber contains an assortment of sensors to measure the most important parameters for growing plants. Such sensors detect ambient temperature & humidity, reservoir water level, grow enclosure light intensity, fluid pH, fluid nutrient content, total dissolved solids in fluid, and fluid salinity. The data pulled from the sensors will be used to determine if any regulatory fluid pumps need to be activated to maintain system homeostasis.

Index Terms – Hydroponics, Nutrient Film Technique, light intensity, electrical conductivity, pH, water pump, temperature and humidity sensor, Wi-Fi module, power supply

I. INTRODUCTION TO HYDROPONICS

Fundamentally, hydroponics revolves around growing and harvesting plants without using traditional soil-based techniques. This is often done through the use of a nutrient solution in an aqueous solvent. There are a variety of methods to achieve this goal, but for our design purposes, we selected the Nutrient Film Technique (NFT). A NFT system, similar to other hydroponic systems, features a reservoir tank filled with a nutrient solution and an aerator providing consistent oxygenation. The grow tray is in the form of sloped channels that the nutrient solution is pumped through via a robust water pump also located in the reservoir tank. Excess solution is fed through the downward slope into the reservoir, passing through all the plants. Due to all excess nutrient solution being sent back into the main reservoir tank, there is a great amount of reusability with a given set of nutrients and water. A growing medium is required to aid in root stabilization and plant growth. For this system, Rockwool is used to secure the plant roots in the growing tray. Figure 1 displayed a typical NFT system setup.

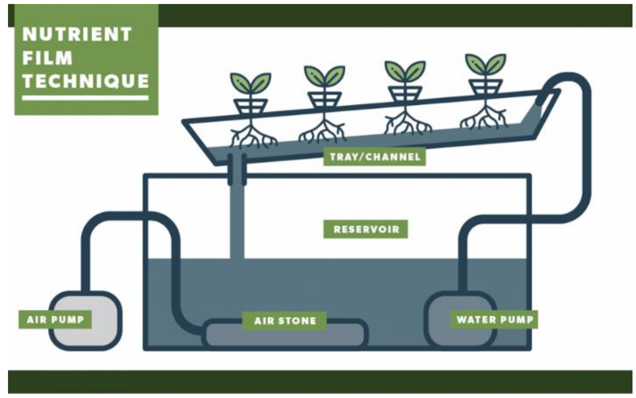

Figure 1. Diagram depicting a Nutrient Film Technique hydroponics system that closely resembles project design

II. PROJECT INTRODUCTION

Despite the benefits that hydroponics presents, setting up such a system still requires a fair amount of knowledge and research in the field itself. The main purpose of the Green Steel Garden will be to fully automate all necessary features to keep the hydroponics system running in ideal conditions. By continuously monitoring the pH levels, nutrient content, humidity, and temperatures within the garden, appropriate feedback can be generated and sent to the subsequent control systems. When required, the Green Steel Garden can control the lights, pumps, fans, and bubblers to ensure that all monitored data is within adequate ranges. In addition, the plant enclosure will feature internet connectivity to provide a direct link to the Green Steel Garden mobile app. The Mobile app will provide many metrics that the user can analyze to determine overall plant health.

III. SYSTEM DESIGN

Automating an NFT system requires a few subsystems that must work in tandem to ensure that homeostasis is met and that growing conditions are always in an optimal state. The Green Steel Garden can be divided into several different subsystems.

A. Enclosure Design

The Green Steel Garden was aptly named because our choice of enclosure frame was to use 1/8” steel square tubing welded together with angle iron. The bottom of the frame has caster wheels attached to allow for ease of transferring. The size of the bare frame and wheels is 36” wide, 36” long, and 72” tall. Plywood was used to cover the gaps in the frame to create a fully enclosed chamber. The result is a sturdy, robust, and moveable enclosure.

The enclosure is split into two main segments. The first area will be referred to as the grow chamber, as it hosts the grow tray in which the plants will rest on. The grow tray was built out of PVC pipes with cutouts for the Plants to rest in. The dimensions of the grow chamber are 35” tall with a square area of 36” x 36”. A side panel is fixed with hinges to allow ease of plant access. The ceiling of the grow chamber is fixed with one exhaust fan and 10 LED light bars. Towards the bottom of the grow tray has strategically placed lux, temperature, and humidity sensors for monitoring purposes.

The second segment is the reservoir chamber as it holds the main reservoir tank. The PCB, microcontroller, relays, peristaltic pumps, EC & pH sensors, water pump, aerator, and chemical solution tanks are all housed in the lower reservoir chamber. The dimensions of the reservoir chamber are 28” tall with a square area of 36” x 36”. There is a second fan located between the grow chamber and the reservoir chamber that pulls cooler air from the bottom into the grow chamber. There is a side panel for ease of access to the main reservoir tank and the chemical storage tanks.

Figure 2: 2 Segment Enclosure Design

B. Water & Nutrient Delivery System

The most important subsystem in regard to plant health involves the delivery of water and nutrients to the plants themselves. The reservoir tank can hold up to five gallons of water. As the water level in reservoir slowly drains due to evaporative and plant consumption losses, a water level sensor is placed in the reservoir tank that will provide an accurate measurement of the water level. Located within the reservoir tank is a 5 Watt submersible water pump that will pump the mixed nutrient solution through the downward sloped grow tray, passing through the plants and back into the reservoir tank through an exit drain. Due to the nature of an NFT system, when the system is powered on, the water pump will be continuously active, never stopping. As a facet of the automation features, the user should not have to actively manage the nutrient content of the reservoir tank. Secondary chemical reservoir tanks will house the nutrient solution along with pH buffers. The use of these external chemicals provides the ability to balance the overall nutrient content of the reservoir tank to ensure optimal plant health. Due to the concentration of the chemicals used, precise amounts must be dispersed to the reservoir tank whenever the system needs. To meet these requirements, 12 V DC standalone peristaltic pumps are connected to both the secondary chemical tanks and the main reservoir tank. Peristaltic pumps allow for extremely precise amounts of fluid to be pumped into the reservoir tank when activated. Refer to figure 2 for a block diagram of the water and nutrient balancing and delivery system.

C. Nutrient Monitoring System

Another major design system involves the actual monitoring and control of the chemicals being dispersed into the reservoir tank. When setting up a new System, fresh distilled water should be used to eliminate potential contaminates. With this being the case, the reservoir should have an extremely low electrical conductivity level and a pH of around 7. The electrical conductivity level is directly affected by the nutrient content of the solution in the reservoir tank. After adjusting for the baseline electrical conductivity of the water, any nutrients added should increase the EC levels. The only situation where the EC levels will decrease is when the plants in the grow tray absorb them, necessitating eventual dispersion of more nutrients. The pH of reservoir tank can change for a variety of reasons, so it is vital to ensure it remains within a growing range close to 6-7 pH. The pH levels of the system can fluctuate up and down, thus in order to effectively balance the pH the use of both a pH up buffer and a pH down buffer are required.

Since the chemicals used are very concentrated, a precise measurement of reservoir tank solution is required. To accomplish this feat, fully submersible pH and electrical conductivity (EC) sensors are placed within the reservoir tank to continuously monitor the solution status. Different plants logically require different settings for pH and EC levels flowing throughout the system. Both pH and EC sensors are connected to the main PCB and communicate with the microcontroller for an average response time of less than 1 second. When either the EC or pH levels are reported to be out of range for a sustained period of time, the microcontroller then signals peristaltic pumps to activate, releasing a set amount of either pH up, pH down, or nutrient solution. Due to the nature of the solution flow path, dispensing chemical solutions takes a variable amount of time to be thoroughly mixed evenly into the reservoir tank. Whenever the microcontroller signals the peristaltic pumps to release the balancing chemical solutions, there is a 5 minute period delay in pH and EC sensor readouts to allow for sufficient mixing time before the monitoring system resumes.

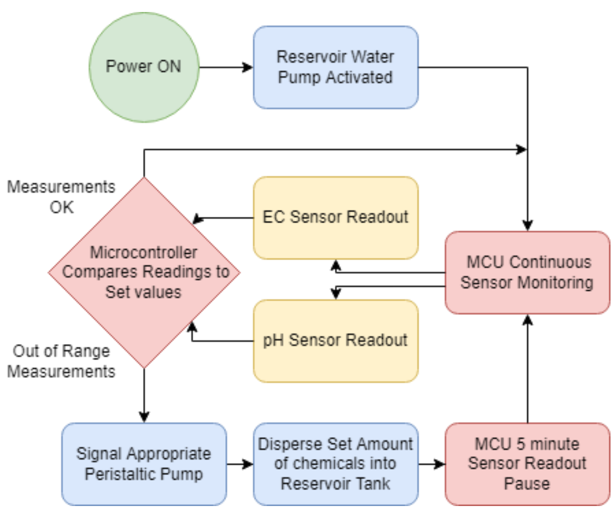

Figure 3. Block Diagram of Water & Nutrient monitoring and delivery system.

D. Light System

Getting the correct nutrient solution to reach the plants in the grow tray is not the only operation required to ensure successful automated plant growth. The amount of light that the plants receive are crucial to development and growth. While there exist full spectrum lights that are specifically meant to target the wavelengths that plants need, the actual need of these are questionable when comparing the cost efficiency.

Our solution utilizes 10 separate 2 feet 20W LED lightbars attached to the interior ceiling of the grow chamber. These lightbars are rated for an LED efficiency of 125.4 lumens per watt. The number of lumens required for healthy growth of plants varies depending on what is being grown. To fully accommodate and give the end user freedom of choice, the lightbars can be remotely set on or off via mobile app to ensure optimal lumen output. To verify the output of the lightbar configuration, a lux sensor is installed inside the enclosure a few feet away from the lightbars themselves. The lux sensor will report to the MCU and send the metrics to the mobile app for viewing. Should any one lightbar fail, the lux sensor will be able to immediately tell the difference in light production and notify the user.

E. Temperature & Humidity System

With the grow chamber being fully enclosed, there is concern for potential high temperatures and over humidification. Similar to the lumen output of the lightbars, various plants require different levels of temperature and humidity. The Green Steel Garden is a hydroponics system meant for indoor usage, so the only temperature fluctuations should come from the lightbars above the plants, while the humidity percentage should gradually rise as water is evaporated from the grow tray.

To ensure proper temperature and humidity values, a dual temperature and humidity sensor is installed in the grow tray within the enclosure. The temperature and humidity sensor readouts are reported to the MCU and then uploaded into the cloud server for mobile access. Should either value be dangerously out of range for plant growth, there are built in climate control fans included in the grow chamber. For optimal cost and design efficiency, we opted to use standard 120mm 12V computer fans. These fans are quiet, efficient, and run off the same voltage as the peristaltic pumps, ensuring simple power management.

The 120mm fans chosen have to ability to move 118.2 cubic feet in one minute. In order to have more control over the temperature and humidity requirements, a two-fan push/pull configuration was deemed to be most effective. One fan will pull cool dry air in from the bottom and the other would exhaust warm humid air from the top. With a two-fan push/pull configuration we can completely replace the air in the chamber in approximately 54 seconds.

F. Power Delivery System

With all the aforementioned systems operating on various different voltages, considerations for the simplest possible power system were made. The solution for this problem was to simply use two separate power plugs. One power plug will be connected to a 12 V DC adapter and the second will be a direct 120 V 60 Hz AC connection.

Since the peristaltic pumps and climate control fans both operate on 12 V DC, we decided that the input voltage of the entire PCB should be 12 V. The adapter chosen supplies 12 V DC to the PCB through a female DC jack barrel connector that is a standard 5.5 mm x 2.1 mm. The adapter chosen can supply 12 V DC and 5 Amps at max output. Due to the lower voltage requirements of some components, 2 voltage regulator circuits included on the PCB were used to match the appropriate voltages required. The list below depicts all devices powered by the 12 V DC adapter.

Voltage (V)	Component Name
12	PCB
12	3 Peristaltic Pumps
12	2 Computer Fans
5	Microcontroller
3.3	EC OEM board
3.3	pH OEM board
3.3	Lux sensor
3.3	Water level sensor
3.3	Temperature & Humidity Sensor

Table 1. DC Supplied Components

As previously mentioned, there is a second power plug that directly sources power to the components that do not operate off of a DC power supply. These devices were connected by daisy-chaining a 120 V 60 Hz AC power cable into our chosen relay's common line for the following devices.

- Water Reservoir Pump
- Aerator
- Lightbars

With both DC and AC powered devices needing remote controlling, the selection of our relay was important. The relay module chosen was the ELEGOO 8 Channel 5V relay module. This specific relay has a 5 V trigger voltage and can handle a maximum DC current of 10 Amps at 30V DC and a maximum AC current of 10 Amps at 250 V. These relay pins are used for the following control settings.

Pin	Controlled Component
D5	Peristaltic Pump with pH up Buffer
D6	Peristaltic Pump with pH down Buffer
D7	Peristaltic Pump with Nutrient Solution
D4	Reservoir Water Pump & Aerator
TX	2 Push/Pull 120 mm Computer Fans
D0	Led Lightbar ½
D3	Led Lightbar ½

Table 2. Relay Controlled Components

IV. COMPONENT SELECTION

The Green Steel Garden is comprised of many different components that are crucial to success. This section will list all parts relevant to the EECS criteria.

A. Electrical Conductivity (Nutrient) Sensor

In order to effectively determine the amount of nutrients flowing through the grow tray, an electrical conductivity sensor is required. The EC sensor we used ended up being the Atlas Scientific Mini Conductivity probe K 1.0. This probe was chosen despite its high initial cost due to the fact that it is fully submersible, while many other cheaper probes meant for laboratory settings will give erroneous readings and require continuous recalibration.

The Mini Conductivity probe has a readout range of 5 – 200,000 micro siemens per centimeter. The probe can operate within a temperature range of 1 – 110 degrees Celsius, which fits design requirements. The design of the sensor requires an initial calibration using a specialized calibration solution purchased separately, but once initially calibrated the probe does not need to be recalibrated until it reaches its life expectancy. The probe uses a male SMA connector, which connects to our PCB through a female SMA port respectively.

One significant caveat of using the Atlas Scientific Conductivity Probe is that the probe itself does not deliver a valid signal that can be read by our microcontroller. Atlas Scientific utilizes a propriety OEM board that must be used in tandem with the probe for interpretable results. See figure X for board Pinout.

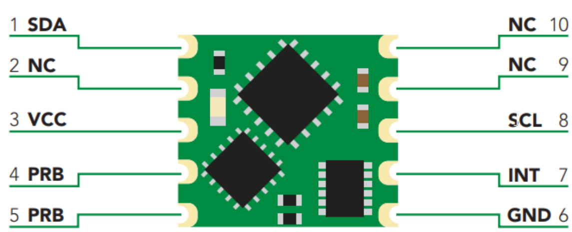

Figure 4: Atlas Scientific EC OEM board

The EC OEM is an I2C slave device that can communicate with the master microcontroller at a frequency rate of 10 – 100 kHz and allows access of 36 different registers for direct control over the probe and sensor readouts. This EC OEM board was soldered onto our main PCB following the design guidelines set by Atlas Scientific. There are 10 pins present on the OEM board, but only a select amount are required for sensor functionality. Pin 1 is the data line bus shared with the pH, lux, temperature, and humidity sensors being fed directly to the microcontroller. Pin 3 is the 3.3-

volt VCC power line, pin 4 is the probe analog data line, pin 5 is the probe ground, pin 6 is the PCB ground, pin 8 is the clock bus shared across the previous sensors connected directly to the microcontroller.

B. pH Sensor

The water mixed with the nutrient solution will be the primary factor in facilitating growth of the plants, so it is vital that the fluid mixture has a stable pH level. The pH level of the water solution can affect the stability of the nutrients and the ability for plants to absorb said nutrients. If the pH levels are outside the expected range, then the nutrients may separate, and the plants may not absorb them properly. The pH sensor we ended up using Mini Lab Grade pH Probe by Atlas Scientific.

The Mini pH probe has a readout range of 0 – 14 pH. The probe can operate within a temperature range of 1 – 99 degrees Celsius, which fits design requirements. The design of the sensor requires an initial calibration using a specialized calibration solution purchased separately, but once initially calibrated the probe does not need to be recalibrated until it reaches its life expectancy. The probe uses a male SMA connector, which connects to our PCB through a female SMA port respectively.

The pH probe shares many similarities with the EC probe mentioned in section A. In particular a near identical OEM board is required specifically to get pH readouts that are interpretable by the microcontroller through the I2C protocol. See figure X for the similar pinout nature.

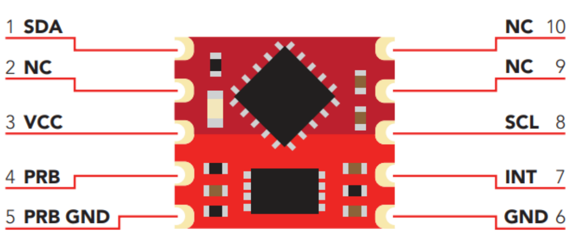

Figure 5: Atlas Scientific pH OEM board

C. Lux Sensor

A Lux sensor was deemed a necessary requirement to test and verify the integrity of the LED lightbars used in our design. Another benefit is that the lux sensor can be used to provide metrics for the end user via the mobile application. The sensor used was the Adafruit VEML7700 I2C Lux sensor. This sensor has a 16-bit dynamic range for ambient light detection from 0 lux to about 120 klux, which fits well within design requirements. The Lux sensor has a basic I2C pinout with a ground pin, SCL, SDA, and 3.3 VCC pin.

D. Water Level Sensor

One of the few manual exercises the user must commit to ensuring functionality of the Green Steel Garden is to refill the reservoir tank with water when it is running low. To manage this, a water level sensor is placed inside the reservoir tank. The water level sensor chosen is an analog float sensor that directly connects to an analog-to-digital converter located on the MCU. When the fluid level is at a maximum level, the voltage level of a resistor connected to the float sensor will be topped out at 3.3 volts. When the fluid level drops to the minimum level of the float sensor, the voltage level will drop to 1.65 volts. This voltage when converted through an ADC can be used as a metric to determine relative water level. The MCU will take this data and upload it to the mobile application so the user can always be aware of the status of the reservoir level.

E. Temperature & Humidity Sensor

As part of the temperature and humidity regulation system, a sensor that measures such values is required inside the grow chamber. The sensor we chose for this was the SHT20 I2C temperature & humidity sensor. This sensor comes equipped with a waterproof probe and contains an amplifier, A/D converter, OTP memory, and a digital processing unit housed within the sensor body. Like the Lux sensor, the pinout for this sensor follows standard I2C protocols with ground, SCL, SDA, and 3.3 VCC connections.

F. Fans

Another vital component of the temperature and humidity system are actual fans used to vent the enclosure. The fans selected for this are 120mm Venturi High Flow computer case fans. Due to the simplicity of setup and cheap cost, while providing an impressive CFM rating of 118.2 cubic feet per minute. With the dual fan setup described earlier we can completely replace the air in the chamber in approximately 54 seconds which is more than enough for temperature and humidity regulations. The Fans run off of 12 V DC power and are directly connected to the relay. The fans can have controllable RPM's, but we opted for a simpler on or off system.

G. Peristaltic Pumps (Chemical Pumps)

A set of 3 peristaltic pumps were required to disperse the pH buffers and nutrient solution into the reservoir tank. The pumps chosen for this task were NKP-DC-S10B peristaltic pumps from Kamoer Fluid Tech. These pumps feature a 12 V DC power requirement and runs off of .25

Amps per pump. Most likely only one pump will be running at any given time, so the current draw fit our DC power supply specifications. The pumps have a variable flow rate from 5.2-90 ml/min. Using the lowest settings provide the most accuracy when attempting to balance the reservoir nutrients and pH. Each pump is individually connected a different relay pin to allow for specific control of chemical dispersion.

H. Reservoir Water Pump

The main water pump in our system is the pump that supplies the water and nutrients to the actual plant roots though the PVC tubing that will house the plants. The pump will be fully submerged in the 5 gallon reservoir container. We selected a pump from PULACO which operates off a 120 V 60 Hz AC power supply. The pump consumes 5 Watts of power and is rated for 95 GPH. In order to enable remote controlling, the standard power cable that connects to the pump was spliced into the NC line of the relay. Some constraints are that it has a maximum lift of only 3’ and a maximum line output of 1/4” ID. Both are within required specifications. This pump is less than 2 cubic inches in size which will allow us to drop it into the mouth of the water tank that is only 2.75” wide.

I. Lights

The grow lights used in the Green Steel Garden’s grow chamber are 10 sets of 2 feet long 20W LED lightbars attached to the interior ceiling of the grow chamber. These lightbars are rated for an LED efficiency of 125.4 lumens per watt. The LEDs are powered by via 120 V 60 Hz AC power and are set up similar Reservoir water pump with the power cable being spliced and daisy chained into the NC line of the relay. This allows for equal power to be dispersed amongst the AC powered devices while allowing remote control. Since there are 10 separate lightbars but only 2 GPIO pins on the relay available for use, we decided that dual zone lighting control was the most we could afford for user customization.

J. Aerator

The use of an aerator or air stone allows for the root systems of plants in a hydroponics settings to receive enough oxygen for efficient growth. It was decided to use the HITOP Single Outlet Aquarium Pump. The product includes an air stone, tubing, and pump, and is designed to work for tanks up to 15 gallons. This aerator outputs air at a rate of 1.5 liters per minute and consumes 2 Watts from a 120 V 60 Hz AC power supply. Similar to the lights and reservoir pump, the aerator’s power cable is spliced and connected to the same relay pin as the reservoir pump itself. The logic behind this is that if the main reservoir pump is not running, then neither should the aerator and vice versa.

K. PCB

A printed circuit board (PCB) was designed and tested over several iterations to control the system and meet design requirements. The PCB includes two voltage regulating circuits and pin headers that all DC powered sensors connect to. There are four separate I2C-based sensors that require a shared clock and data line, which is connected all through the PCB. The bottom of the PCB features 2 SMA connectors for the pH and EC sensors. As such only one 12 V DC power input is required to power all required DC sensors. Each sensor that utilizes the shared I2C data and clock lines are all connected through here. The footprint size of our PCB is 90.5 mm x 80 mm. The design was made through EAGLE and manufactured by PCBway.com. The board is a 2-layer design, where the first layer are the red traces, and the bottom layer are the blue traces. The PCB layout can be seen in Figure X.

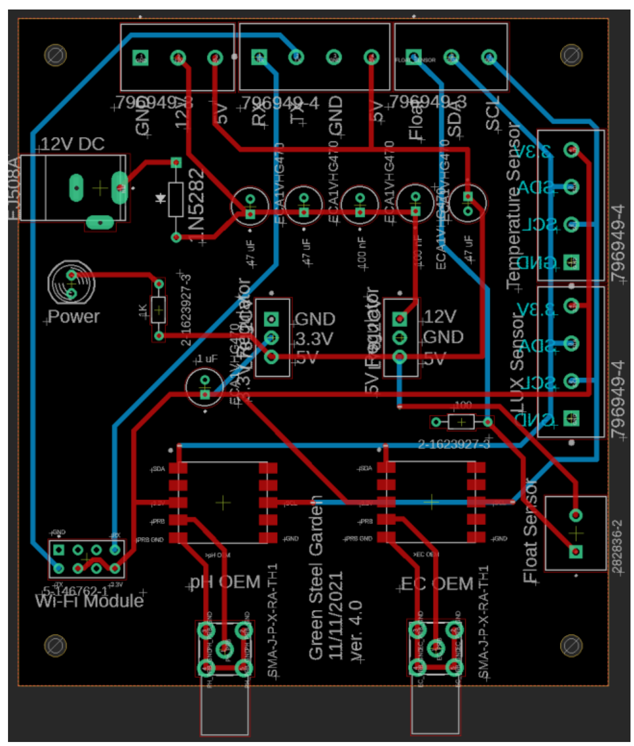

Figure 6: Project PCB layout

L. Microcontroller

Figure 7: Microcontroller

The microcontroller that was selected for the final design was HiLetgo ESP8266 NodeMCU CP2102 ESP-12E development board. This board features a Tensilica L106 32-bit MCU clocked at 80 MHz and has 160M MHz support RTOS. There is a built-in 1-channel 10-bit high precision ADC, which is required for our float sensor to operate. There are a variety of peripheral interface pins allowing for HSPI, UART, I2C, I2S, IR Remote Control, PWM, and GPIO connections. The standby power consumption is rated at less than 1 mW. The main connections required from this microcontroller were the GPIO, I2C, and ADC pins, as displayed in figure X. The microcontroller selected was coded with the Arduino Software IDE. The main benefit of selecting benefit of using this microcontroller is due to the integrated ESP12 Wi-Fi module located on board, this simplified the development process of significantly, as the microcontroller needs active connection to the internet to both upload data metrics to our webserver as well as receive requests to control system functions.

M. Server

In order to store data metrics that the mobile application can pull remotely, we opted to use InfluxDB. This is an open-source database developed by InfluxData and is primarily meant for the storage and retrieval of data for sensors and other monitoring efforts. InfluxDB has no external dependencies and provides a language similar to SQL for setup, it uses port 8086.

N. Mobile App

It was decided unanimously by our group to include a mobile app within our system. This in return would make the sensors outputs readable from anywhere that has Wi-Fi readily available. To accomplish this, the app was coded on the Xcode environment using the swift coding language. This was a language that we had to take some time to learn but once the basic concepts were grasped coding ended up being easy. The App is composed of three different screens; A screen for the homepage, a screen to control the relays, and a screen to view the sensor readings. The structure of the app first starts with the sensor readout information being sent over to the microcontroller. From there, the microcontroller sends the information to the web server. Finally, once that happens the information gets send over to the mobile app. The app itself will check for new information every 2 seconds while microcontroller updates every 20 seconds. This will hopefully lead to the overall update time being less than twenty-five seconds.

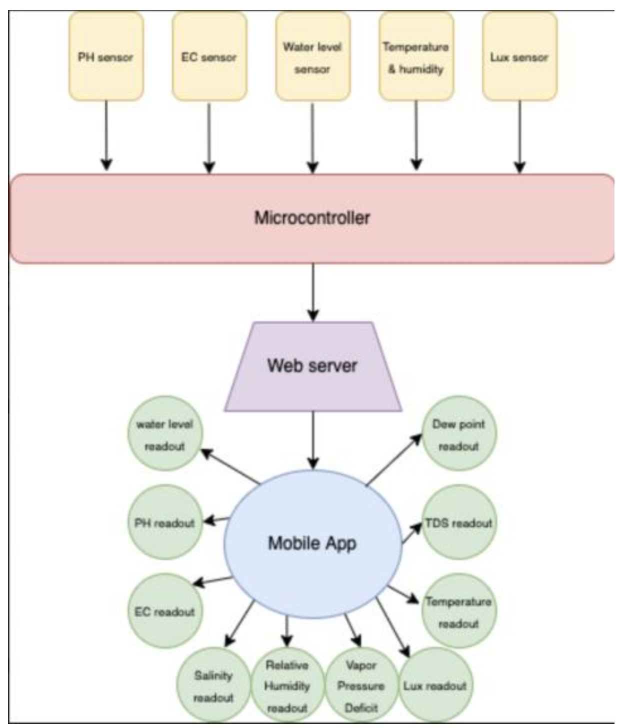

Figure 8: Mobile App Flowchart

V. CONCLUSION

This project has been a challenging yet fruitful experience for us. Challenging because a project like this tested our time management, technical, and communication skills over the course of two semesters in a way which they had not been tested before. Fruitful because even though we struggled early, through hard work and discipline we were able to overcome these challenges and grow. We are grateful for how the project has developed us as engineers and are proud of our Green Steel Garden.

VI. ACKNOWLEDGEMENTS

The Green Steel Garden group acknowledges the plethora of professors and peers who have prepared us for careers as electrical and computer engineers. We thank you for the instruction that you have given us both inside and outside the classroom which has led to the completion of this project and hopefully, a successful career.

VII. ENGINEERS

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