AUTOMATED VERTICAL HYDROPONIC DRIP SYSTEM

Jacob Reichle, Max Gomer, David Babcock, Marco Bogani

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

***Abstract* — The objective of this project is to create a microcontroller and client-oriented mobile application for the purposes of monitoring and maintaining a hydroponic drip system. Sensor information on system water-level and pH will be used to alert the client and administer pH adjustment fluids appropriately. The mobile application will be linked to the microcontroller so that system can be controlled and monitored remotely over Wi-Fi connection. Our group chose this project as a method to integrate software design and computer engineering for the purposes of improving small-space hydroponics in an increasingly remote society.**

***Index Terms* — Agricultural products, Client-server systems, Device-to-device communication, Electronic Circuits, Microcontrollers, Mobile applications.**

I. Introduction

Yard sizes of the median American have shrunk more than 26 percent since 1978[1], and increasingly industrialized agricultural practices leave citizens with not many options in growing their own food in their homes. However, people can be hesitant to grow food due to cost and time of maintenance. Even with a standard user-controlled hydroponic system, pH levels must be maintained, and water levels must be checked daily to ensure that a system does not go dry and kill the plants. To adjust pH, a user would normally need to dose the reservoir with adjustment fluid by hand as well as take measurements with a sensor until the desired pH is reached. These are time consuming activities for someone that may not be able to monitor their system closely, so our microcontroller and mobile application alongside hardware like a system pump, dosing pumps, and an array of sensors aim to make it simple, straightforward, and as hands-off as possible to grow food in your home with optimized time between the need for user intervention. The primary function of this system is to try to maximize the time to a 2-week interval.

II. Reasons for Hydroponic Control Unit

Hydroponics is the art of growing plants without soil. The main advantages of hydroponics are its very low water and space consumption, higher plant yields, and its ability to grow plants in harsh environments at the cost of electricity, pH monitoring, and nutrient dosing. The soil is often replaced with another physical medium such as rockwool for the roots to take hold. These roots are then required to be soaked with a nutrient solution indefinitely to maintain proper health.

Hydroponics plants need frequent maintenance and monitoring to ensure the plants grow properly. This means that automation in a complex system can help reduce the amount of human-interaction it will take to keep up with. Even seemingly less important factors in agriculture such as lighting can have a detrimental effect on plants if they receive too much or too little, so being able to control light cycles automatically or from a distance further reduces the chances of light bleaching plants. Nutrients also have to be mixed in water before being delivered to the plants. An uneven mixture can be toxic to hydroponic plants if the concentration of one element far outweighs another, so the system's water must be replaced every two weeks, which a control unit can keep track of and remind a user when it is necessary. Lastly, a control unit can monitor the current state of the hydroponic system with a variety of sensors and keep record of it. By having a record of pH balance in the nutrient solution, the amount of the light the plants received, and the amount of water the plants are getting, a control unit can give users the data to make informed decisions on how to take care of their plants.

III. Requirement Specifications

Fig. 1 shows the demonstrable requirements for this system. It is of note that the cornerstones of this project are the pH rebalancing range, and the steady communication between mobile application and hardware.

Pump Height Minimum	5.5 feet
pH Accuracy	Within 5% error margin
Sensor reading intervals	1 hour
Flow Rate	~80-100 GPH
Hardware commands transmitted to microcontroller within	1 second of posting
Sensor data posted to database within	1 second of reading
Mixing Fan intervals and frequency	1 min every 45 mins
Frame Dimensions	5' x 3' x 1.5'

Fig. 1. Requirement Specifications

IV. Technical Approach

To achieve these goals, our system will be centered around a main controller unit (MCU) fitted with appropriate sensor modules to make accurate readings of the pH and water level in the recirculation reservoir. The controller unit will be able to transmit data across a Wi-Fi connection to a database that is used for a mobile application, allowing for remote monitoring of the system. Recirculation pumps, nutrient dosing pumps, lights, and a mixing fan in the reservoir will be actuated by relays controlled by the MCU when needed. The user will need to top off the recirculation reservoir when it gets below a minimum fill line and completely replace the water after a couple weeks' time. The MCU will make water level readings to send alerts for replacement, and a start/stop button will allow the user to cut power to the pump for water replacement, while the nutrient dosing pumps and mixing fan take care of pH adjustment and nutrient dispensing when the water is completely replaced.

A. Microcontroller Unit

The Microcontroller Unit (MCU) is the driving force behind automating the hydroponic system. The MCU is a low-power computer with systems to allow it to interface with external devices. It should be able to control turning the lights, pumps, fans, and sensors on and off. Ideally, the MCU will have multiple power settings and ways to bring it in and out of low power modes. The MCU should have software libraries that make it easy to program.

We chose the CC3220MODASM2MONR for the automated hydroponic system. The CC3220 class of microcontroller units from Texas Instruments has SimpleLink™ technology, which has two processors in one chip. One is the main processor that drives the application environment as any other MCU would do, and the second is a network processor that handles the Bluetooth and Wi-Fi connection environments. Having both processors in one chip will save on board space at the cost of more restrictive board space requirements.

B. Dosing Pumps

Considering the nature of the automated growth system, correct content mixture plays a key role in the plant's overall health. Additionally, another feature of the system is to provide plant type flexibility. Considering these two aspects we need a mechanical chemical dosing system that can provide different amounts of mixture elements according to the user's inputs. In addition to transferring chemicals from a local chemical tank into the main mixture tank, the dosing pump also needs to provide the correct amount of liquids with small deviation due to minute mechanical constraints. This can be achieved through laboratory-grade purpose-specific peristaltic dosing pumps as they are made for accuracy and ease of integration with different types of systems. The reason behind choosing a peristaltic pump instead of another popular type of pump such as the diaphragm pump was due to the peristaltic pump's advantage for our specific situation.

C. Recirculation Pump

The water recirculation pump is one of the main elements of the system itself as its purpose is to move the main mix throughout the drip system. Hence, the drip system will deliver nutrients to the pants in a uniform manner. To achieve the best type of performance different pump designs and placement were researched. For best lifetime and efficient functionality, we decided to place this pump within the lower tank. Placing the pump in the tank will help the pump thermally and ensure proper priming.

Fig. 2. Vivosun 800GPH Pump

The pump in Fig. 2 is the selected model for the purposes of the project due to its high GPH rate and adjustability in flow. This will allow for the project to meet the minimum pump height requirements so that the system doesn't fail, and water will reliably be delivered to the tops of each hydroponic drip tower without risk of clogging.

D. Water Level Sensor

To effectively monitor water-based nutrient quantity inside of the recirculation reservoir, a sensor that will be able to detect if the solution is below a minimum level will be required to alert the user when to refill the system back to its fill line. Either an analog or a digital sensor would suffice for the purposes of the project since the only requirement of this sensor is that it can tell when the water is below the minimum fill line, which will be when the tank is only at 60% capacity; however, a digital sensor will be chosen to save costs and simplify this component's application.

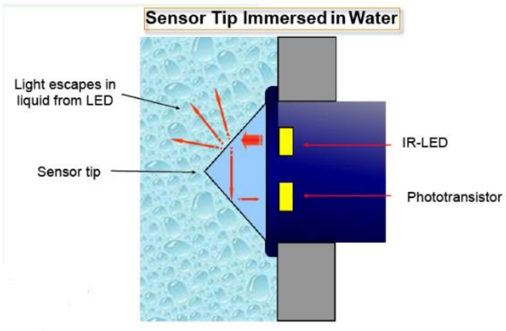

Fig. 3. Optical Liquid Level Sensor[3]

The optical liquid level sensor that is used in this system provided by Optomax saves on space, since the bulkier types of liquid sensors like a floating magnet sensor or capacitive electrode strip are not necessary. As shown in Fig. 3, when the optical sensor is submerged in water, the infrared LED cannot reflect off the triangular tip back into a phototransistor due to escaping into liquid. This causes a signal to be output from the sensor, allowing the microcontroller to sense the presence or absence of liquids at the tip of the sensor.

E. Liquid pH Sensor

The pH of a hydroponic nutrient solution is the essential component to ensuring liberal nutrient intake of the plants contained in the system. If a solution is overly alkaline or acidic, the plants have a difficult time absorbing the nutrients provided in the water-based solution. Therefore, a cornerstone of the hydroponic system being created is accurate and rapid pH adjustments, which will require a reliable sensor that can relay information to the database efficiently and accurately.

An ideal pH sensor is one that is accurate and durable. Since our system revolves around the idea of using it in a confined space as a wall decoration on the consumer-end, a sensor that can withstand long amounts of time without needing maintenance or replacement is a large benefit to the overall cost-efficiency of the hydroponic system. Since pH is read on a scale from [0, 14], 0 being the most acidic and 14 being the most alkaline, a sensor that reads in inputs as analog will be required.

Selecting the correct pH sensor for the system is crucial to the idea of building a durable product that could be used for a long period of time. There are not many different types of pH sensing models available electrically besides different types of combination electrodes, so it is necessary to select a model that can withstand being left submerged underwater for long periods of time.

	SEN0169-V2 Industrial Sensor	SEN0161-V2 Laboratory Sensor
Probe Life	24 hours a day 7 days a week for >0.5 years	>0.5 years depending on frequency of use
Cost	$64.90	$39.50
Supply Voltage	3.3~5.5V	3.3~5.5V
Dimension	1.70" x 1.26"	1.66" x 1.26"
Temperature Range	0~60℃	5~60℃
Cable Length	500cm	100cm

Fig. 4. Industrial versus Laboratory pH Sensor

As seen in Fig. 4, the laboratory and industrial electrode pH sensors do not have many significant differences between them other than the probe life; however, this is a vital characteristic of the pH sensor that is to be selected, so it is a top priority of the system to have a sensor that will not fault after being submerged underwater for extensive periods of time. Since an Industrial pH sensor is classified as a much more durable laboratory sensor with combinational electrodes for pH sensing and a polytetrafluoroethylene membrane encasing them, most upgraded laboratory sensors will meet the requirements of the system. DFRobot® offers two versions of their industrial pH sensor, their original model, and an upgraded version. The upgraded version added capabilities to be used with an external ADC module instead of being constrained to only using Arduino libraries, so the DFRobot® Industrial V2 probe is the only selection of the two options that will work with the system.

F. Frame and Support

To properly provide a housing to test functionality of the system's applications, a frame was built to hold the weight of three towers of 9 total hydroponic inserts and a nutrient solution reservoir. Due to material costs, PVC tubing will be used for the frame as well as the hydroponic towers. This will provide plenty of support to bear the load of each drip tower. This frame will remain under the dimensions of 5' x 3' x 1.5' so that it could reasonably fit in a small area like an apartment or patio.

G. Pump Line

To mainline the water-based nutrient solution from the recirculation reservoir to the tops of the individual drip towers, some sort of tubing will be necessary that can attach firmly to the 1/2" pump nozzle. As mentioned in the requirements, it will be necessary to have opaque tube lines to prevent bacterial buildup that happens when water is exposed to too much light. The tubing must also be malleable, because it will need to be able to make gradual turns to distribute water in the system. Since any vinyl tubing fits the necessary requirements, the flexible and inexpensive material will be selected to use as the main pump line. The required diameter for the line will be ½” to fit around the spout of the Vivosun® 800 GPH pump.

H. Growing Medium

The plants in the system will need a medium for their roots to take hold before their roots begin to expand throughout the drip towers. The standard for hydroponic systems and a favorite medium of most growers is rockwool. Rockwool is a combination of basalt and volcanic slag that is spun into a fibrous material. It is known for its use in insulating homes, but the rockwool that is used in hydroponics serves as a base for the roots to take hold; its rough, sturdy, yet fibrous body makes it the perfect selection for any hydroponic system. Rockwool also has great water retention abilities, so young sprouts don’t have to worry about lack of moisture in their adolescent and fragile state.

The rockwool cannot hold plants on its own, however, and it will need a cup-like structure to support it inside of the PVC wye. Mesh plastic cups are another hydroponic standard because they are affordable and offer effective stability for a plant’s root ball, while giving it enough oxygen and space for its roots to branch out into the hydroponic tower. 20-30 generic mesh plastic cups will be used for this system from a local hydroponic store, and they only cost around $0.20 per cup, which is another negligible price added to the bill of materials.

I. Mixing Fan

The mixing fan located at the bottom of the reservoir will serve a great purpose for this project, because it will be responsible for equal distribution of nutrients and stimulating pH readings. The ideal mixing fan will be small and low in power consumption, because nothing heavy-duty is needed to give a mild stir to 5 gallons of water; however, it is also desirable to get a mixing fan with a negligible cost that will be able to withstand long periods of time submerged in water.

To control the mixing fan, the same relay system used for the submersible recirculation and dosing pumps will be used to switch it on and off. A signal will be sent to a GPIO pin that will activate the relay which will in turn allow current to flow to the mixing fan. This will make it simple to turn the fan on or off without risk of connecting a high-power device to a microcontroller that could be harmed by any short circuitry.

The model selected for the purposes of the system is the SunSun JVP-101A. This model provides exactly what is needed for the nutrient reservoir with the negligible cost of $10.99.

J. Nutrients and pH Adjustment Fluids

The fluids contained in the dosing pumps are vital to proper plant upkeep. pH Adjustment fluids are standardized as “pH up/down” and just contain acidic or basic compounds that, with small doses, can drastically shove the pH of a liquid in a certain direction. Standardized pH up/down fluid for the system will be provided by Atlas Scientific™. The nutrient solution on the other hand can be swapped out depending on the type of plants being grown in the system, but since the system will be demonstrated with spinach, a nutrient that is high in Nitrogen and Phosphorous (which promotes vegetation) will be ideal. For the purposes of the system, a compost tea made with water and molasses will be used a cheap, viable way to test nutrient dosing and keep the plants alive and vegetating properly.

V. Design Flow

To understand the problems that the system aims to tackle by mapping them out visually, block diagrams of software and hardware flow were drawn up.

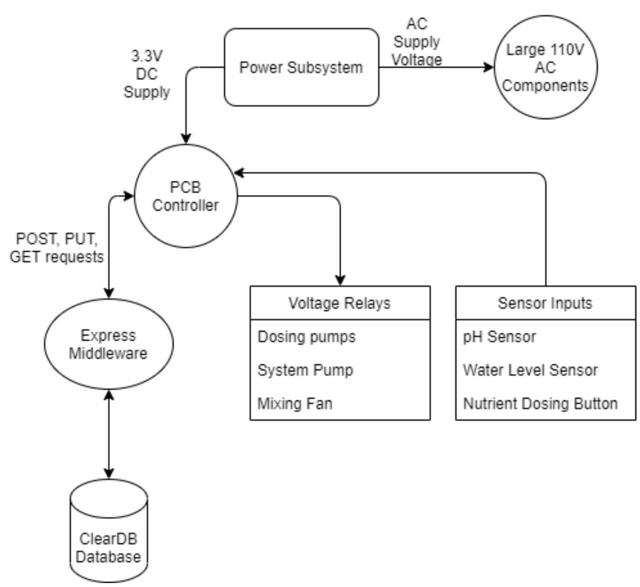

Fig. 5. Overall System Logic

As seen in Fig. 5, the system uses the PCB controller as the central processing center for system logic. The controller will take inputs from each sensor, reports that data through an Express server to the database, then adjusts dosing lines, pumps, and fans accordingly. The power supply is capable of powering both the PCB with 3.3V DC current, and the larger components such as the system pump and mixing fan with 110V AC current.

Fig. 6 details how the hardware logic will be implemented in the power subsystem. All components that cannot be actuated by the 3V output of the TI CC3220MODAS2MONR must be connected to a relay that can actuate the part in question, such as the system pump. The dosing pumps that will dispense pH up and down to the system will each have their own relays to actuate them. This will allow for a precise handling of dosing liquid into the reservoir, rather than dealing with a separate driver for decoding commands to a more involved dosing pump. Also noteworthy is the analog-to-digital converter (ADC) used by the pH sensor. The DFRobot® Industrial V2 probe comes with a built-in ADC, but the voltage output range of [0,5] Volts exceeds the maximum range that the CC3220MODAS2MONR can safely handle, [0, 2.5] Volts. To take care of this voltage division, a simple voltage divider with two 1 kΩ resistors will keep the maximum voltage below 2.5 Volts, so that the MCU can handle the pH sensor's input safely.

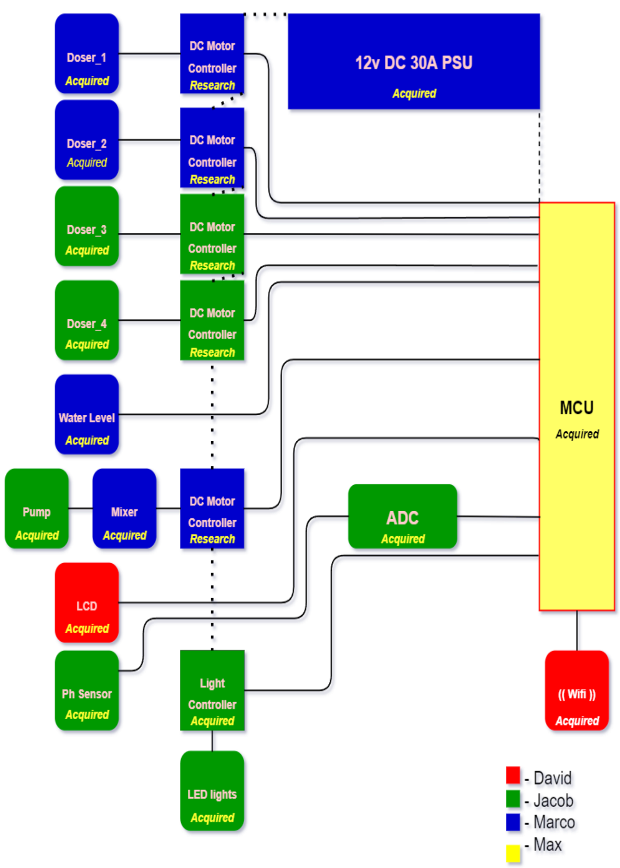

Fig. 6. Hardware Logic

VI. Data Transmission

A. Transmitting Sensor Data

One of the main challenges of interfacing the Hydroponics Unit and the web application is in how data transmission between them is handled. As per the design requirements, the data traffic must be facilitated over Wi-Fi and not rely on any cable connection. Two main types of communication will need to occur: the transmission of sensor data from the Unit to the database, and the transmission of hardware commands from the mobile application to the Unit. Each form of communication will use different implementation methods and will be discussed in more detail in the following sections.

For the uploading of sensor data, ideally, the Unit's system controller would be able to perform POST operations directly to the database without requiring its data to be fetched by an outside software routine. However, the CC3220 does not support PHP scripting and is unable to upload data to the MySQL database directly. The solution involves setting up an HTTP client on the MCU to make POST requests to the web application. Through the POST request, the MCU will send its sensor data payload to the web application. The web application, acting as the HTTP server, receives the requests and makes another POST request to the database to deposit the sensor data payload. Thankfully, Texas Instruments has several libraries of functions available that are compatible with the CC3220 that perform HTTP requests, as well as an example software project that demonstrates the use of these functions. The flow of the sensor data transmission process from the MCU to the database may be better visualized through the following diagram in Fig. 7.

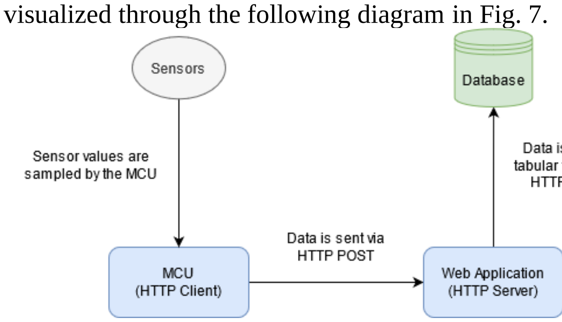

Fig. 7. Sensor Data Transmission Flow

B. Transmitting Hardware Commands

The method in which hardware commands will be sent from the mobile application to the Hydroponics Unit is like the method in which sensor data is transmitted to the database in that HTTP is used, but the roles of the MCU and mobile application are reversed. The MCU now functions as the HTTP server while the mobile application makes requests to it as an HTTP client. Naturally, this requires the setup of an HTTP server to be always run on the MCU to have it be constantly available for receiving requests. These HTTP requests made by the mobile application function much like any other HTTP request, requiring a URI to reference the API endpoint that fulfills the request as well as the setting of request headers. The requests are received by the MCU and fulfilled through calls to internal API endpoints, which interact with the Unit's hardware and complete the user's desired tasks.

The following diagram in Fig. 8 depicts the transmission flow of hardware commands from the mobile application to the MCU over HTTP, where the MCU's internal API handles HTTP requests and parses them internally to perform the correct command that the user is instigating from their mobile device.

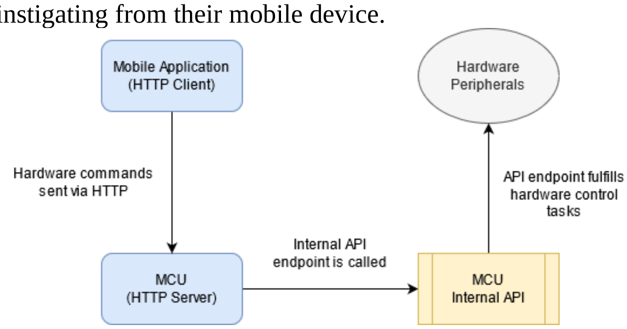

Fig. 8. Mobile App hardware Command Transmission Flow

As with the process of making HTTP calls from the MCU, example projects from Texas Instruments exist that demonstrate proper setups for running an HTTP server from the MCU and implementing internal API endpoints. These will be invaluable to the project's software team, as the concept of running a server from a microcontroller is unfamiliar territory. One small consolation in the implementation of the MCU's internal API is that each supported hardware command and use case is unsophisticated. Most hardware commands will simply toggle a hardware system on or off, which involves setting the status of a single GPIO pin or call an already defined software routine to be performed outside of its regular schedule, such as requesting a sensing cycle to take place immediately.

VII. Prototyping

To properly ensure that the system will function well, prototypes were made for each major section: the frame, the mobile application, and the PCB.

A. Vertical Drip System

As per the requirements of the project, a 5' x 1.5' x 3' frame that is capable of delivering nutrient solution to plant roots was prototyped then constructed successfully. Figure 9 shows an early prototype sketch of how the drip system was modeled after, with a lower reservoir housing pump, encased in a frame equipped with lights.

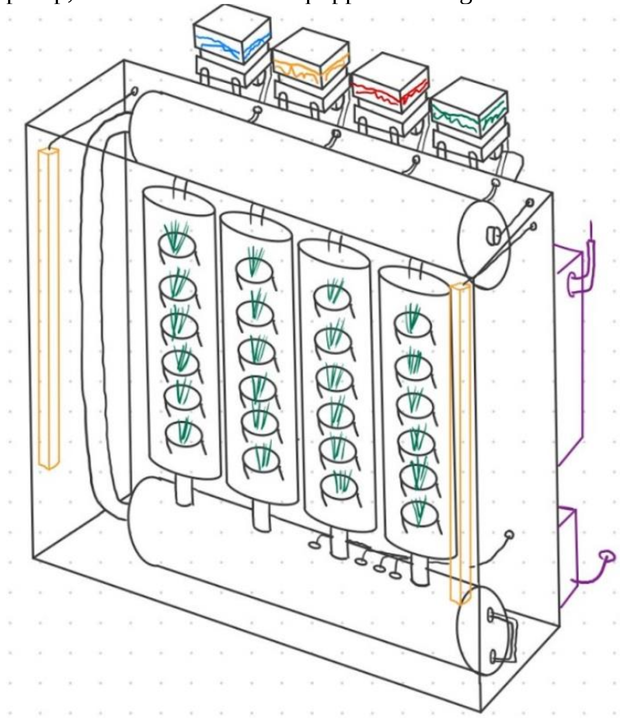

Fig. 9. Frame Prototype

B. Mobile Application

Figure 10 shows a sketch of the system landing page model that the final mobile application will be based on.

Fig. 10. Mobile Application Models

C. PCB Design

Due to supply chain issues at the time of this system's development, we felt it necessary to create two different

PCB controllers with our selected MCU: one with simple pin breakouts for testing and another with more involved circuitry such as voltage step up circuits. Figure 11 shows the “Breakout Board” for testing, and Figure 12 shows the Final PCB design for the improved board equipped with a 5V step up circuit and pull up resistor options for components.

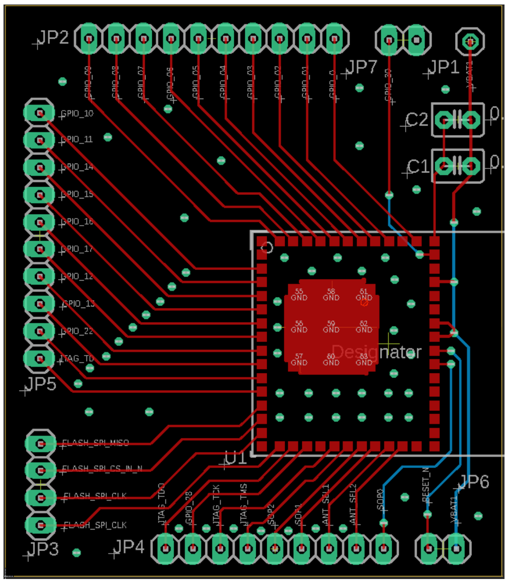

Fig. 11. Breakout Board

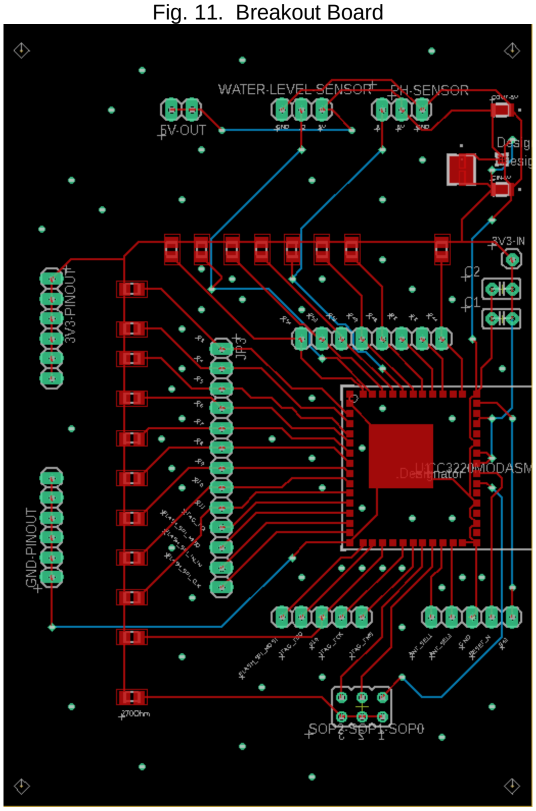

Fig. 12. Final PCB Design

VIII. Implementation

A result our system was implemented based on our prototypes. A setback we endured during the process was a manufacturing error, resulting in our final PCB design to be dysfunctional, and due to the international parts shortage for electronics it was not viable to create a new one. Luckily, the breakout board we created was a good secondary option, and we received the green light from our supervising professors to use it in our system.

Fig. 13 shows the final result of our mobile application. It closely resembles our prototypes in Fig. 10, and it includes the same functionality from the Mobile prototype such as a dashboard and settings menu, with buttons to save user settings and set a custom pH range if desired. It is worth noting that for a user to connect to their device, all they would do is enter the MAC address displayed on the LCD on startup. This was a simple implementation that allowed for the device to be set up for network connection easily.

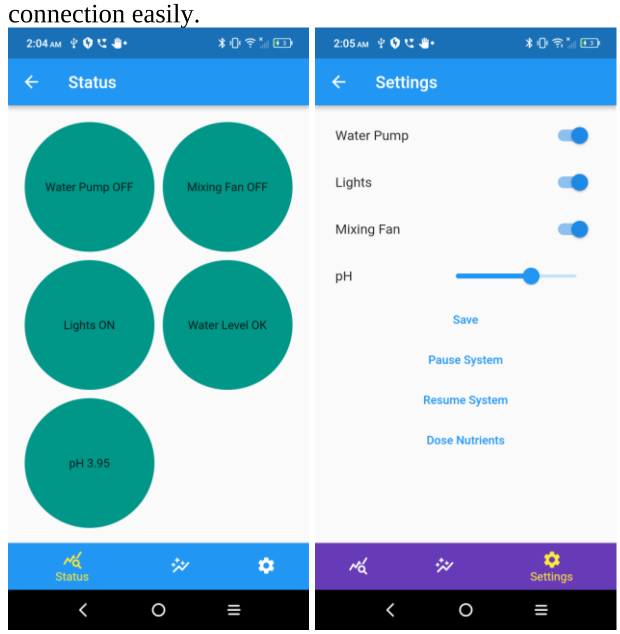

Fig. 13. Final Mobile Application Screens

B. Frame

Figure 14 shows the frame constructed with the 5’ x 1.5’ x 3’ dimensions adhered to from the system’s requirements. The frame is composed entirely of PVC material with a wooden peg board on top to secure the towers. All towers drained into the five-gallon bucket used for a nutrient solution reservoir for recirculation. Near the bottom left of the frame, the dosing pumps are staged to transfer the necessary pH adjustment fluid from containers to the nutrient reservoir. Plants are supported in 2” PVC wyes by their net pots and a rockwool medium. When the nutrient solution is run to the top of the towers, the roots soak and absorb the solution.

Fig. 14. System Frame

C. Power and Microcontroller

Slightly to the left of the frame shown in Fig. 14, the power supply system, microcontroller, and dosing pumps are housed on a side table for easy maintenance and demonstration.

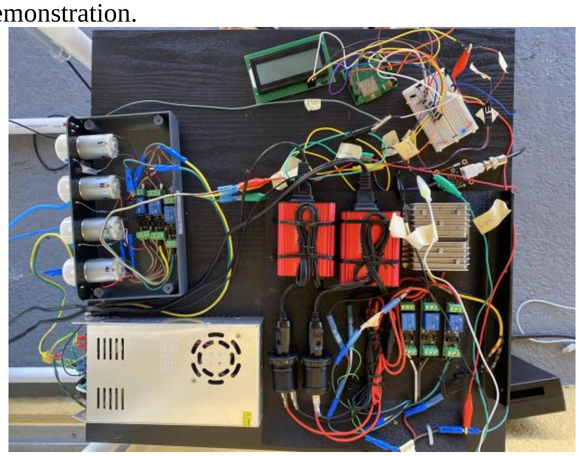

Fig. 15. Power Delivery and Microcontroller

It is well worth noting that our breakout board being used in the system had to be connected via a breadboard only due to the manufacturer destroying our final PCB along with using up all extra parts we purchased. This usage was greenlit by our supervising professor, so our board used for testing ended up guiding the system to implementation when it became impossible to design and order a new PCB due to supply chain shortages; however, the system was able to be implemented in its entirety, just having to substitute our 5V step up converter to direct current from the power supply, SOP pins had to be manually pulled to VCC for programming, and sensors had to be grounded manually on the breadboard rather than soldered directly onto the final PCB.

IX. Conclusion

Much of the inspiration for the project came from the team's personal interest in growing plants in a home environment, as well as the realization that the field of hydroponics allows for the marrying of these interests to the fields of computer and electrical engineering. This made for the creation of a project idea that each team member felt passionate about and motivated to successfully implement, while also serving as an excellent way to demonstrate our knowledge, experience, and research ability.

Most hydroponic units require the manual adjustment of nutrition content and pH levels, were restricted to either tower or rack formats, and lacked software connectivity. By designing a hydroponics unit for in-home use with automated maintenance systems, a mobile application to control and monitor the unit, and a unique physical format, the project team believes that our system created a method that would allow a user to back away from garden maintenance as much as possible, since it takes care of pH rebalancing, and the user can adjust any lighting or pH adjustment settings from the convenience of their mobile device.

Acknowledgements

The authors wish to acknowledge the assistance of our volunteer judging panel consisting of Dr. Tanvir Ahmed, Dr. Rickard Ewetz, and Dr. ChungYong Chan. The authors also wish to thank our supervising professors Dr. Lei Wei and Dr. Samuel Richie, who have both provided critical guidance to us throughout setbacks we experience during the development of our system.

References

[1] McGill, Andrew. "The Shrinking of the American Lawn." The Atlantic, Atlantic Media Company, 6 July 2016, https://www.theatlantic.com/business/archive/2016/07/lawns-census-bigger-homes-smaller-lots/489590/.

[2] The World Counts, https://www.theworldcounts.com/challenges/planet-earth/freshwater/when-will-the-world-run-out-of-water/story.

[3] Image provided by https://sstsensing.com/how-does-a-liquid-level-switch-work/