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Green Steel Garden (Wi-Fi Hydro Garden)

An automated hydroponics system with integrated Wi-Fi that you can monitor with your phone.

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1.0 Executive Summary

As a consequence of living in the Digital Age, all the information about food that you eat can be found online. Unsurprisingly, this has led to a variety of concerns regarding the quality of produce that are sold in grocery stores. Worries about pesticide usage and genetically modified organisms (GMO's) have helped push more and more people to growing their fruits and vegetables locally. However, the act of enveloping oneself in the art of horticulture is no easy task. For the majority of people, the lack of knowledge and experience in this field coupled with the stereotypical back-wrenching labor provides an ample deterrent in attempting to grow produce at home.

The Wi-Fi Hydro Garden seeks to lower the amount of skill required to enter this growing consumerist hobby and enable a wide range of people to yield fruits, vegetables, and herbs all from their own home. While horticulture as a whole involves a variety of methods to grow plants, the Wi-Fi Hydro Garden is a strictly hydroponics-based system. The benefits that exist from using hydroponics include more efficient use of water and space, decreased harvest cycle time, and lack of pesticide usage. Hydroponics also has a variety of quantifiable data that can be measured and used for information regarding the performance of the growing operation. For the most part, using a hydroponic system checks all the boxes when considering simplifying the home growing process.

Despite the benefits that hydroponics presents, setting up such a system still requires a fair amount of knowledge and research in the field itself. Continuing on with the ease-of-use philosophy, the Wi-Fi Hydro Garden will also fully automate all necessary features to keep the hydroponics system running in ideal conditions. By continuously monitoring the pH levels, nutrient content, humidity, and temperature within the garden, appropriate feedback can be generated and sent to the subsequent control systems. When required, the Wi-Fi Hydro 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 Wi-Fi Hydro Garden mobile app. Furthermore, the user will be able to see real-time pictures of the growing process at any point through a camera alongside continuous updates of all data being monitored. All data recorded will be saved through AWS cloud storage, reducing the native memory requirements and providing metrics for performance analysis. The hope is that providing remote access to information about the Wi-Fi Hydro Garden's operational status will create a stronger willingness for users to commit to home growing produce.

Automating hydroponic systems is not ground-breaking science, there are several automated systems that many people own themselves. However, it is important to note that many of these systems are in favor of a do-it-yourself approach. Many automated solutions simply sell a microcontroller and require the customer to build their own enclosure for growing. Removing all the work and effort that comes with growing plants locally is the main priority of the design, and with that involves the setup for automation. The Wi-Fi Hydro Garden seeks to provide a relatively modular and refined system that attempts to have little to no user input outside of initial setup.

2.0 Project Summary

This section will serve as a brief overview of the proposed project idea and cement the fundamental concepts that are core to our design philosophy. The motivation behind the project will be analyzed, with the purpose and goals being explained. To help conceptualize the design, a general schematic of the early design will be depicted in this chapter as well as hardware and software flow charts. In order to provide standards to uphold the project to, engineering specifications will be addressed for each core subsystem required in the design. After the overview, the breakdown of the responsibilities for each group member will be explained to give fair credit to everyone involved.

2.1 Motivation and Background

There is a clear and recognizable consumer base that seeks to get into gardening and horticulture but lack the necessary skills and techniques to do so. The target demographic is also notable for not wanting to put in the time and effort to gain those skills. It is precisely this niche that motivates the development of the Wi-Fi Hydro Garden. The hydroponics system in tandem with our automation features is built off the idea of being easy to use. By lowering the barrier of entry into home gardening to the point where very little time and effort is required from the user, we hope to make home growing more of an appealing prospect.

2.2 Project Objectives

The objective for this project was to utilize the Electrical and Computer Engineering skills the four of us have learned during our time at UCF. We plan to combine the use of embedded systems technology with sensors and probes to produce a fully automated and self-sustained hydroponics grow system. This system will have a custom PCB to include specific sensor inputs, relays to power devices, and a Wi-Fi module to upload sensor data to the cloud.

A successful project will end with the ability to grow 12 plants at once in a fully enclosed grow structure. It will contain all the water and chemicals needed to maintain a desired pH and nutrient level with the ability to auto adjust as necessary. This project will need to be completed by the end of November 2021 to receive full credit and graduate with our degrees.

2.3 Related Work

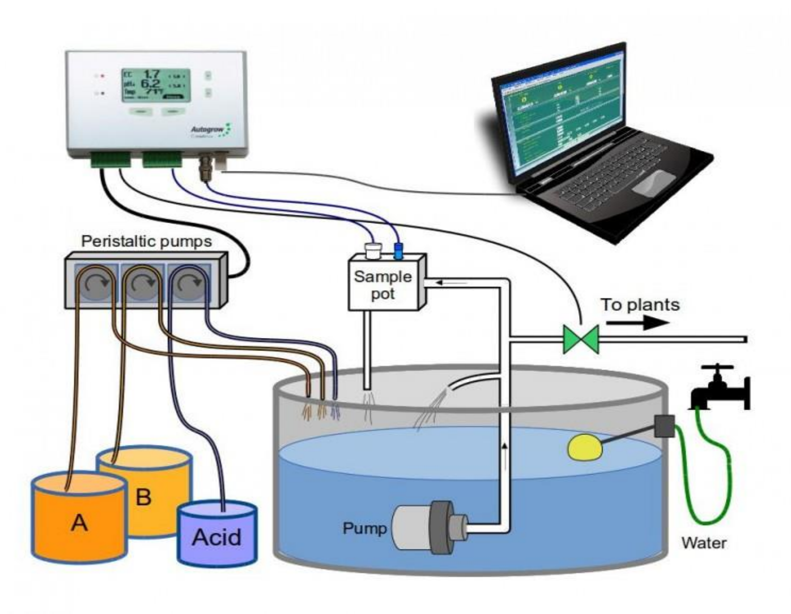
Automated Hydroponic systems are not new to the market, with many companies offering innovative solutions to solve consumer problems. It is important to note that many automated hydroponic systems are offered as generic system controllers that are compatible with large scale growing operations. The concept of an all-in-one automated hydroponic system with a form factor that is space efficient is a relatively new idea.

2.3.1 Autogrow IntelliDose

As per the Autogrow website, Intellidose can automatically manage nutrient and pH levels, set remote alarms, and data log progress with a nutrient dosing system. With these features, Autogrow claims to set the industry standard for small commercial auto-dosing. The IntelliDose product itself is microcontroller with various data inputs and a screen with a few functional buttons. The inputs have connections for a pH sensor, EC sensor, peristaltic pump, and more. If connected to a computer, the IntelliDose system offers the user data logging and scheduling for growing purposes. A partner product known as IntelliGrow provides a cloud-based solution for gorwers to access, set, and manage their IntelliDose systems. Using IntelliGrow in tandem with IntelliDose allows the user to access information regarding the hydroponics system from a mobile app remotely.

Figure 1 shows the complete illustration of a typical IntelliDose system. Using this figure allows for dissection of the issues IntelliDose has when comparing it to the Wi-Fi Hydro Garden. First and foremost, IntelliDose does not offer any actual enclosure or any actual hydroponic subsystem other than the micronctroller itself. IntelliDose is effectively a “plug-n-play” microcontroller in which a user plugs in sensors and pumps to set up their own automated hydroponics system. Since the Wi-Fi Hydro Garden seeks to provide all sensors and subsystems required to effectively automate the growing process, there is a big difference in target audience. With a hefty price of shy of $1300, the IntelliDose is evidently marketed at industrial and commercial clients who already own existing hydroponic setups.

Figure 1: IntelliDose Complete Kit



2.3.2 Seedo Home Grow Device

According to the Seedo website, Seedo claims to be the first fully automatic growing device for all types of herbs. Seedo operates through hydroponics, but it is unclear which precise method the product utilizes. The company advertises its air conditioning system, hermetically sealed grow chamber, and its automation features.

As **Figure 2** depicts, the Seedo home grow device has movable full spectrum LED light arrays. The ideology behind this patent-pending technology is that there is an ideal distance for the light source to be depending on the growth of the plant. This product also features a built in Co2 enrichment capabilities. By periodically pumping in carbon dioxide when the grow lights are enabled, the overall growth speed is increased. Seedo also includes a modern phone app that offers a 1080p camera for a remote viewing experience. The door to the grow chamber is remotely lockable and the application offers a plant tracking feature to help the user stay on top of their grow cycles. While the Seedo home grow device may seem to do it all, this very small growing enclosure is priced in at $2400. Despite this product doing several things that the Wi-Fi hydro Garden claims to do, the price is extraordinarily high for such a small volume and is not compatible with the target market we are aiming for.

Figure 2: Depiction of Seedo Grow Chamber

2.4 Requirements

- The system will have 3 individual liquid storage containers for pH Up, pH Down, and nutrients.
- The system will have a PCB with an integrated Wi-Fi and BT module.
- The PCB will run on 12 to 3.3 VDC.
- The PCB will control relays to power on and off the lights and pump.
- The system will send sensor data via Wi-Fi to a data storage system in the cloud every 60 seconds.
- The system will send pictures via Wi-Fi to a data storage system in the cloud every 10 minutes.
- The total cost of the build shall not exceed $1300.
- The system will interface with a custom iOS app that will display pictures and sensor data.
- The system will be able to grow 12 plants at one time.
- The system will be able to return the pH balance of the water back to specified levels in less than 1 hour.
- The system will be able to return the nutrient level of the water back to specified levels in less than 1 hour.
- The system will have at least one fan to control temperature and humidity.
- The system will be able to restore temperate and humidity levels to required parameters in less than 30 mins.
- The system will have full spectrum lighting to include 380-780nm wavelengths.
- The Power Supply will receive 120V 60 Hz AC and convert to 12V DC.
- All PCB circuitry will run on less than 500mA of power.
- The microcontroller will operate at a frequency of no less than 16MHz.
- The system will be completely enclosed so that we can control the amount of light the plants will receive.
- The iOS app will notify the user if there is a system malfunction is less than 60 seconds.
- The entire system will run on less than 10A of power.
- The lighting will be no less than 24” above the base of the plant growth.
- The lighting will supply at least 300 PPFD to entire growth area.

Table 1: Project Requirements

Feature	Desired Value
EC Reading Accuracy	<= 7% Error
pH Reading Accuracy	<= 1% Error
Water Capacity	5 gallons
Dimensions	24” x 36” x 72”
Light System Output	>= 10k Lux
Able to read sensor data from iOS app	< 25 seconds
PCB Operating/Regulating Voltage	12/5/3.3 V
Operating Environment	Indoors
Max System Power	10A
Sensor Readings	< 60 seconds

2.5 Project Operation

The operation of the Wi-Fi Hydro Garden will be very straight forward once set up. After all of the fluid reservoirs are filled the system will auto adjust pH balance of the water and add nutrients as needed. Lights, temperature, and humidity control will be automated though the microcontroller. You will be able to monitor the sensors remotely though the iOS app.

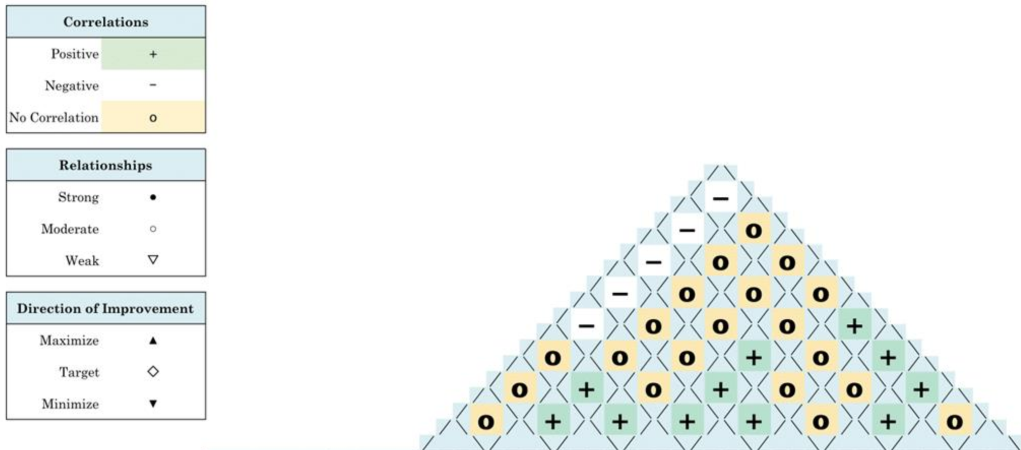
2.6 Safety Warning and Hazards

The Wi-Fi Hydro Garden is not composed of any material that is considered hazardous by the OSHA Hazard Communication Standard, the design involves use of materials that may require some safe handling and proper use. In order to effectively balance the pH of the water solution, the use of pH buffers are required. The user is expected to pour said buffers into the solution tanks located in the Wi-Fi Hydro Garden’s tank storage. Precaution needs to be taken when handling the aforementioned substances, to ensure that it does not reach the users eye or mouth. In addition, the Wi-Fi Hydro Garden will use a nutrient rich solution which when disposing of, should be treated as a substance similar to fertilizer run off.

2.7 House of Quality

The house of quality is a method to associate engineering specifications with the wants and desires of the target market. By providing a visual identification of how the specifications interact with the consumer wants, the house of quality enables analysis on how to further develop a strong product for the audience in question. In addition, the comparison allows for the detailing of which specifications are deemed more important in terms of project success. The house of quality in **figure 3** features a horizontal listing of all design requirements listed in **Table 1**. The roof of the house of quality shows the relation of the specifications and consumer traits.

Figure 3: House of Quality

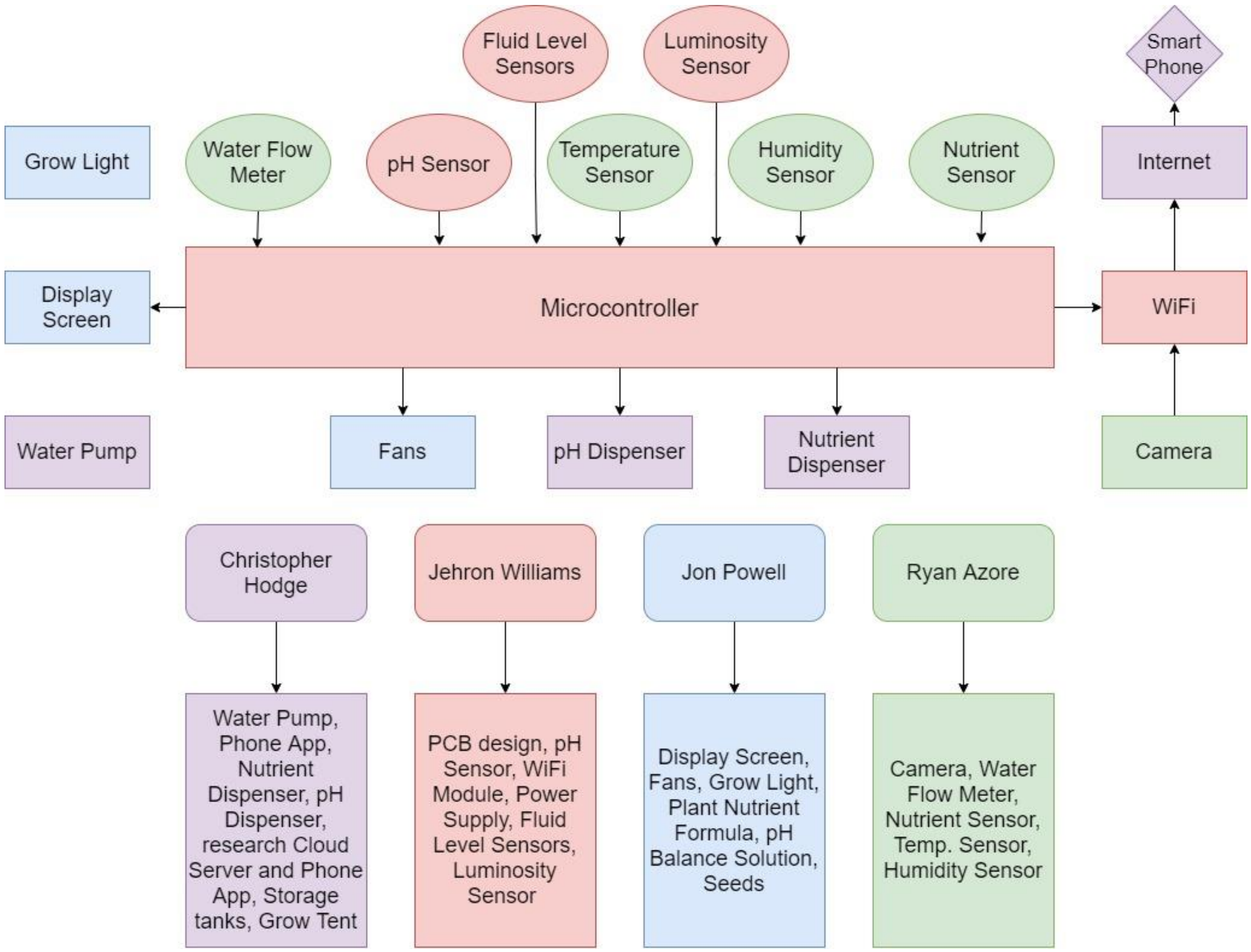


Row #	Relative Importance Weight	Customer Importance (1-5)	Customer Requirements (Explicit and Implicit) / Functional Requirements	Cost	Wi-Fi Connectivity	Cloud Storage	Mobile App	pH Balancing System	Nutrient Balancing System	Temperature & Humidity Control	Frame Construction	Power Effieciency
			Column #	1	2	3	4	5	6	7	8	9
			Direction of Improvement	▲	▼	▼	▲	▲	▲	▲	▼	◇
1	15%	5	Marketing Requirement	●	●	○	▽	●	●	●	○	●
2	6%	2	Modern Design	▽	○	●	○	○	○	▽	●	●
3	9%	3	Concealable Equipment	▽	▽	○	●	●	●	●	▽	▽
4	15%	5	Ease of Operation	▽	○	○	●	○	○	○	●	▽
5	15%	5	Remote System Control	○	●	●	●	○	○	○	▽	○
6	9%	3	Environmentally Friendly	○	▽	▽	▽	●	●	●	●	●
7	15%	5	Mobile App ready	▽	●	●	●	●	●	●	▽	▽
8	15%	5	Cost	●	○	○	▽	●	●	●	●	●
			Target	9	9	9	9	9	9	9	9	9
			Difficulty of Implementation	390.91	536.36	500.00	548.48	681.82	681.82	669.70	493.94	493.94
			Relative Importance Weight	8%	11%	10%	11%	14%	14%	13%	10%	10%

2.8 Hardware Diagram

The following diagram in **Figure 4** visually represents the different devices and how they relate to one another in transmitting data. The arrows indicate that the data from the sensors is interfaced by the microcontroller with the dispensers, fans, display, and smart phone. There are also components like the grow light and water pump which function alone. The colors and the section on the bottom of the diagram indicate which team member was responsible for researching each part.

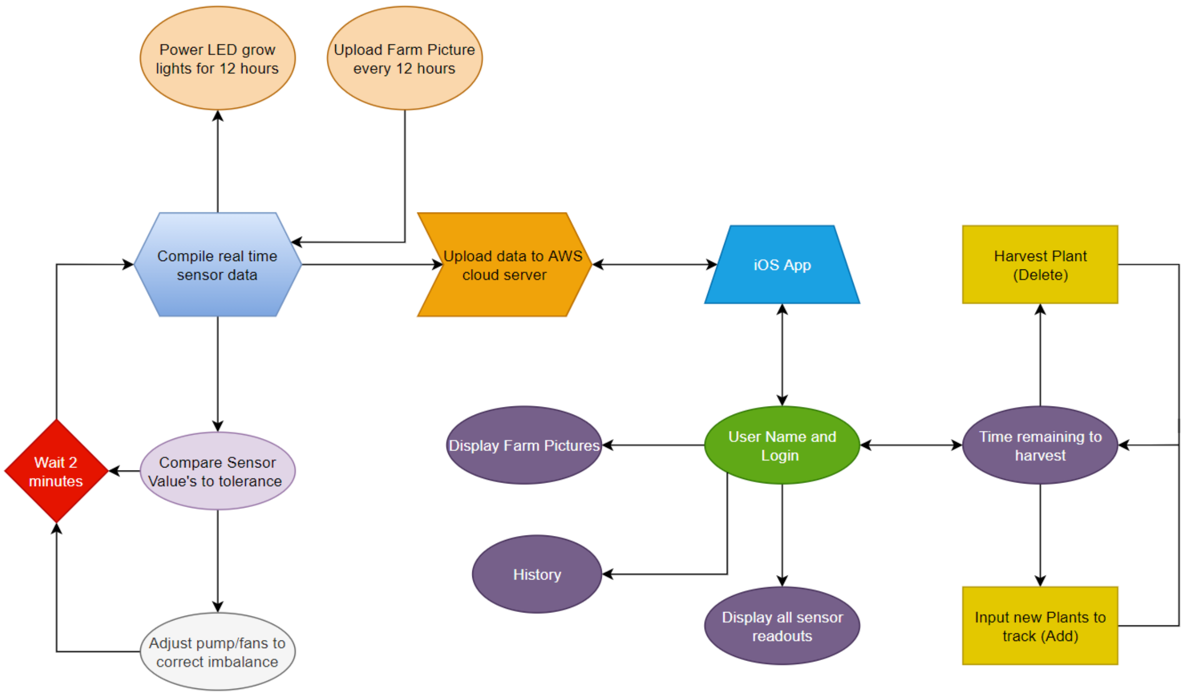
Figure 4: Hardware Diagram



2.9 Software Diagram

The software for this project will be broken into three parts as shown in **Figure 5**. The code for the microcontroller, seen on the left, will be written in the Arduino IDE using the C language. It will control the timing of event's, triggering of pumps and lights, and it will send data to a cloud server over Wi-Fi. Second, the cloud server, seen in orange below, will receive and store the uploaded sensor data. The server will also be able to send data to anyone requesting it. The third portion of software, seen on the right, will be an iOS app written in the Swift language using the XCode IDE on a Mac computer. This app is intended to be a read only interface letting the user know the current status of the hydroponics system to include all sensor readouts and uploaded pictures of the plants. The diagram below will illustrate the three parts working together.

Figure 5: Software Diagram



3.0 Project Research

The most strategic way to effectively plan, design, and create the Wi-Fi Hydro Garden requires research into every facet of the idea to be done. This segment will be primarily aimed at providing enough knowledge and information to make informed decisions regarding the physical implementation of the design. First, the field of hydroponics will be deconstructed into the differing methods available. Out of these different hydroponic methods, one will be identified that fits the main goals of the Wi-Fi Hydro Garden. This method will then be chosen to be implemented and from then on, all the components that allow that specific hydroponics system to work will be researched. Each specific component required will have all competitors looked at, being filtered through the products compatibility with our requirement specifications.

3.1 Hydroponic Systems

Fundamentally, this design concept revolves around the horticulture that is hydroponics. Hydroponics at its core involves growing plants without soil, by using a nutrient solution in an aqueous solvent. The plants can grow with their roots exposed to the nutrient water or have physical support with an inert substrate such as clay or gravel. The benefits of this are numerous. By using an aqueous solution infused with nutrients, a hydroponics system can ensure that there is a direct delivery of nutrients to the plants at all times. This reduces the expansion of plant roots and allows for an increased spatial efficiency in terms of number of plants per area. Due to the controlled nature of nutrient and water dispersion, hydroponics systems additionally use less water than traditional soil-based growing methods. This is mainly because hydroponics allows for continuous recirculation of water, reducing losses immensely. Hydroponic systems also reduce pest issues and completely remove the problem of weeds overgrowing the plants being grown, again owing from the controlled nature of the system. Within the hydroponics field, there exists a variety of growing methods that utilize different physical setups to achieve the same end goal. In regard to the design, the most desirable hydroponics system should feature great compatibility with automation features alongside simplistic construction.

3.1.1 The Wick System

Wick systems are generally the most basic implementation of hydroponics and offers an incredibly low barrier to entry. The system comprises of four main components—the grow tray, reservoir, wick, and aeration system. The grow tray is simply the container that holds the seedlings. In contrast to other hydroponic setups, the grow tray in a wick system does not use net pots to hold the growing medium. Rather, the growing medium fills up the majority of the tray, with the seeds being transplanted directly into the growing medium. With each plant embedded into the growing medium, the only way for nutrients to enter the enter the roots comes from the wicks. Each wick uses capillary action to transport the nutrient solution from the reservoir to the grow tray. The reservoir itself is simply a container of fertilized water that holds the aeration tools. Since the wick system requires the roots of the plants to be continuously moist, an active oxygen distribution method is necessary to ensure the health of the plants. This is mainly accomplished with an air pump and stone. While the wick system is one of the simplest hydroponic systems to set up, the fatal flaw is that such a passive system suffers when attempting to grow water hungry plants such as tomatoes. Due to the lack of control variables, this system was not considered.

3.1.2 Deep Water Culture

A deep-water culture system is similar to the wick system in its simplicity. In this variation, the roots of the plant are placed directly in the nutrient solution. This is typically constructed using a large reservoir tank to hold the nutrient solution and netting to hold the plants directly above the water. In order to supply a sufficient amount of oxygen, an air diffuser is required in the reservoir tank. The main benefit of this growing method is the increase of growth due to the plant roots receiving a constant amount of nutrients and oxygen. The DWC method, due to the stagnant nature of the reservoir tank, has difficulty maintaining a consistent water temperature. Additionally, in a small system, the pH, water level, and nutrient concentration may have extreme fluctuations which poses problems when calibrating the system. These risks and the lack of control variables made this system unusable for our design.

3.1.3 Ebb and Flow (Flood and Drain)

The Ebb and Flow process is an active system that comprises of a grow tray and a reservoir. The grow tray is generally filled with a grow medium that has the plants embedded inside. Over time, the grow tray of an ebb and flow hydroponic system is slowly flooded with a nutrient solution. At a designated time, the flooding ceases and the nutrient solution in the grow tray is drained into the reservoir. This operation is usually set up with a timer on the water pump. Notably, this system does not require an aerator. Once the nutrient solution is drained, the roots of the plants have time to oxygenate before being flooded again. This methodology is compatible with growing several kinds of plants, including root vegetables like carrots and radishes. However, this system cannot support large plants due to the space requirements of the grow medium and flooding act. One risk of the ebb and flow system is the pump being the focal point of the system. If the pump fails, the system cannot function.

3.1.4 Drip Irrigation

Another active hydroponic system is the drip method. This setup involves having a grow tray hooked up to a dripper that can deliver nutrient solution from the reservoir tank to the plants at a determined rate. The drippers are positioned such that the nutrient solution will drip onto the roots of the plants. Drip hydroponic systems can be circulating or non-circulating systems, allowing for certain behaviors that can be customized by the user. Compared to the aforementioned systems, utilizing drip irrigation offers extreme precision in regard to water and nutrient dispersion. In particular, the dripper can be integrated with technological features in order to allow the user to disperse water and nutrients and the best time. Another benefit of drip irrigation is scalability. This system can be successful in both small and large scale gardens.

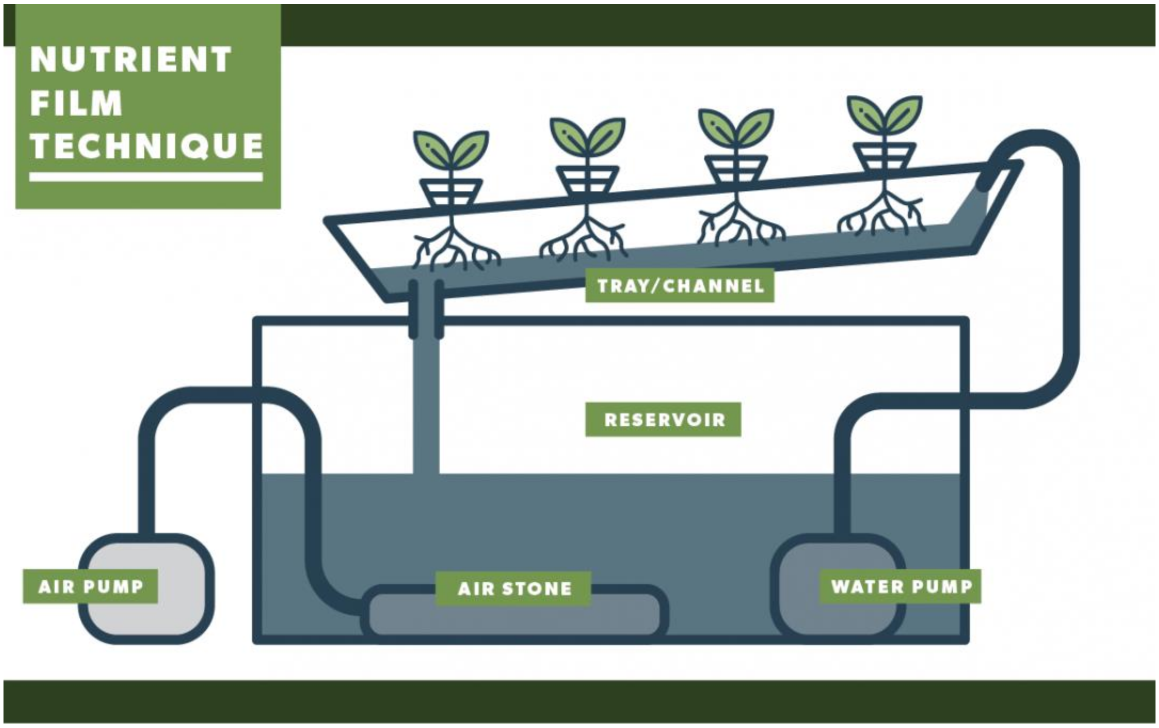
3.1.5 Aeroponics

An aeroponics system is an advanced form of hydroponics that requires the plants to be suspended within the air. Mist nozzles are positioned around all the roots of the plants. These nozzles spray nutrient solution onto the roots, with the excess falling into the reservoir tank. Since the roots are continuously exposed to oxygen, there is no need for an aerator. The mist nozzles offer technological integration for automation purposes and uses the least amount of water out of any hydroponic system. The downsides of this system are the complexity and space inefficiency. Larger plants require a deep reservoir, and this restricts the amount of plants per given enclosure. The nozzles also can suffer periodic blockages due to material buildup over time, which can effectively render the system useless until unblocked. After consideration, this form of hydroponics is competitive in comparison to other systems, but only offers benefits in terms of water savings, which is not a primary concern in our design.

3.1.6 Nutrient Film Technique (NFT)

The NFT system offers a relatively simple active design that scales incredibly well into a variety of different applications. Similar to other hydroponic systems, the NFT system features a reservoir tank holding the nutrient solution with an aerator oxygenating it. The grow tray is in the form of sloped channels that the nutrient solution is pumped through. Excess solution is fed through the downward slope into the reservoir. Since the grow tray is essentially a narrow tube, the scalability of an NFT system is exceptional.

Figure 6: Nutrient Film Technique Diagram



As **Figure 6** displays, the overall construction of an NFT system is not overly space reliant, being based off the size of the of the grow trays used. Similar to other active hydroponic systems, an NFT system offers enough functionality that can be monitored and automated. Most notability, the water flow design of an NFT system can be modeled as a control system for monitoring nutrient disbursement and pH monitoring.

3.1.7 Hydroponic System Chosen

After researching the variety of hydroponic systems that exist, it was unanimously agreed that the Nutrient Film Technique (NFT) system aligns with the specifications and goals of the Wi-Fi Hydro Garden. By being a relatively simple yet active hydroponic system, the NFT methodology provides many areas to monitor with sensors while being cheap to construct. Another playing factor into this decision was the lack of user maintenance. Continuous pumping and draining of nutrient solution provides an excellent control scenario that can be fully automated to the pure benefit of the consumer. After considerations of price, flexibility, and efficiency, an NFT system appeared be the best choice for the hydroponic methodology behind the Wi-Fi Hydro Garden.

3.2 Grow Medium Selection

Even though the nutrient film technique method is the method that was chosen for the hydroponics system, it was decided that a growing medium was needed for the plants that we desire to grow. This in return will help keep the roots from being exposed to light and help control the moisture and oxygen intake of the plant. This is going to help promote healthy growing for the plants. The medium that is going to be selected must be a medium that is going to allow for water to pass through easily since the system is going to require the circulation of water. The medium that is chosen must also be able to help promote the roots absorbing the nutrients needed from the water. The most important thing that the medium will need to do is provide support for the plants that are going to be put into the hydroponics system. Based upon research, it was founded that four of the most popular growing mediums for a hydroponics system are rockwool, expanded clay aggregate, coconut fiber, perlite, and river rock. These will be the mediums that are going to be considered for the hydroponics system. To compare theses mediums the following will be observed; Cation Exchange Capacity (CEC), Air Filled Porosity (AFP), and Water Holding Capacity (WHC). CEC refers to how many minerals are in the medium, AFP refers to the airflow of the medium, and WHC indicates how well the media holds water. Any interesting facts that can be beneficial or non-beneficial will be observed and analyzed as well.

3.2.1 Rockwool

The first Medium that is going to be considered is rockwool, which is a porous material made of spun basalt rock fibers. It is a popular medium that typically a lot of farmers use. It has a high WHC which is good because of the water is constantly circulating through the hydroponics system a lot of the water is going to be absorbed through the medium. It also has a low CEC which will allow for the extreme optimization of the nutrient delivery, but this leaves very little margin for error in terms of the pH of the water. Rockwool is also not biodegradable which can kind of turn off any user who is trying to be eco conscious. Rockwool also must be presoaked in water with a pH of 5 to 5.5 for 24 hours, otherwise it will not be habitable for the plants. This could possibly become tedious for a user. Also, it must be considered that if rockwool is used as a medium, plants could possibly be more prone to overwatering with the system that has been chosen because of the constant circulation of watering matched with its high WHC. This medium does not hold onto nutrients as heavily as another medium might as well, which will lead to having to rinse out the medium less often. It also needs to be considered that if the medium is holding too much moisture will not allow for oxygen to get to the roots which can cause the plant to die.

3.2.2 Clay Aggregate

The second medium is Lightweight Expanded Clay Aggregate, which is very lightweight, round pieces of expanded clay. This clay has a low CEC, a low WHC, and a high AFP. This is good for the system that is being used because it makes the system very difficult to overwater and will allow for the plant to get the amount of oxygen it needs to receive. The clay is also reusable which will allow for the user to not have to rebuy more of the medium as much. These clay pebbles may drain too quickly which might not be a problem for the system that is being used, but it is worth mentioning this since it could be a potential problem if the water is not flowing through the system enough. This medium is also known to work well with deep water culture systems that keep plant roots constantly exposed to water. The pH of clay is neutral as well so there wouldn't have to be an extra task for the user to do pertaining to the medium's pH level. This could very well be a suitable choice for the system that is going to be used.

3.2.3 Coconut Fiber

The third medium is coconut fiber, which is an organic biodegradable growing medium that is made from shredding the inner pith of coconut husks. Coconut fiber is somewhere in the middle when it comes to CEC and AFP, but it has a high WHC. This means that it can be prone to overwatering. It is also recommended to balance out its CEC because of the level that the CEC is at. It gets oxygen to the plant well and is similar to potting soil. This medium is said to work well with drip systems where water intake is highly controlled. This could potentially be a medium that could be used, but the only problem is its high WHC. The flow of the water in this system shouldn't be altered as much but if the medium is holding too much water it is feared that the system may not work. Also, the medium is very dependent upon the type of nutrients used within the system.

3.2.4 Perlite

The fourth medium choice is perlite, which is a volcanic rock. It is typically lightweight and has a very low CEC and high AFP, making it known for its ability to control nutrients. It's WHC is somewhere in the middle, so it absorbs water easily but not to the point that there is a high risk of overwatering. Perlite floats in water so as a result it is unsuitable for systems like the one being used in this project because it would not be able to provide the plant the support that is needed. After learning this information, it is highly unlikely that perlite will be used as a growing medium in this system.

3.2.5 River Rock

The final medium choice is river rock, which is relatively cheaper than the other choices. It has a low WHC, which can be beneficial for us but can also be a problem. The medium doesn't hold any moisture for the plant which can result in the plant drying out because of this if the plant isn't getting enough water. With this method it may not be considered at all unless it is combined with another medium to boost its effects due to the amount of air pockets being in the plant. River rock offers some support to the plant but due to it being very dense material. With river rock there is a risk of the plant dying if watering times are not adjusted properly which leaves little, to no margin for error in the system. A table listing all the growing mediums is displayed in **Table 2**.

Table 2: Grow Medium Comparison

Medium Type	Rockwool	Clay Aggregate	Coconut fiber	Perlite	River Rock
WHC	High	Low	High	Mid	Low
CEC	Low	Low	Mid	Low	High
AFP	Mid	High	Mid	High	Mid

With the knowledge that is known about the mediums so far shown in **table 2**, rockwool is chosen as the best choice for this hydroponics system because of it being highly beneficial for a nutrient film technique hydroponics system, which is exactly the system that is being utilized. This could possibly be altered after testing because there is potential for certain mediums to be mixed and this could result in a newer, more-qualified medium. It is important that the water be recycled as it is being used for the plant for this hydroponics system to be successful and it seems that the rockwool will help promote that success.

3.3 Sensors

This section will go through the various sensors that will comprise the required by the Wi-Fi Hydro Garden to meet requirement specifications. Each specific part will be considered among its brand competitors and the best one that can be identified will be selected as the chosen part for the design.

3.3.1 pH Sensor

This garden systems' success is going to heavily depend on the nutrients that each plant receives as the plants are receiving water and other nourishment. Nutrients can also build up within the system and solidify causing the user to have to clean the system as this would happen periodically which in this case would minimize the automation feature that is going to be very crucial within this hydroponics garden, but if the pH system of the water going into the hydroponic sensor is monitored via a pH sensor it will keep this discrepancy from occurring. The way this is going to be monitored is via the pH sensor, which is supposed to determine the acidity level of the water that is going into the hydroponic garden. This is measured based on a logarithmic scale from 1 to 14 with any value lower than 7 being an acid an any value higher than 7 would be a base. For most plants the optimum pH range is from 5.5 to 7.0 but some plants will grow in more acid soil or may require a more alkaline level. So, for this system the pH sensor will need to be able to sense if the pH range is anywhere from 5.5 to 7.0 consistently without the user having to constantly interact with the sensor. Since it is essential to keep the system automated, paper pH level tester will not be used even though they are cheaper to use. This would require the user to have to check the pH level constantly themselves which can get tedious if the system is supposed to be automated. Another way to do this is Via a pH electrode probe. The pH probe is a hydrogen ion sensitive glass bulb, with a millivolt output that varies with the changes in the relative hydrogen ion concentration inside and outside of the bulb. This probe is attached to a BNC cable and then is connected to a sensor module and the sensor will be used by having the probe placed into the reservoir and have it read the pH levels of the water constantly. With there are two parts that are being considered for this. The first part is the Gravity: Analog pH Sensor Meter Kit which is which is being sold on Arduino.cc for 29.50. The other part is the GAOHOU PH0-14 Value Detect sensor Module and PH electrode probe BNC for Arduino which is being sold for 35.99 on Amazon. The part that will be chosen will be the GAOHOU PH0-14 Value Detect sensor Module and PH electrode probe BNC which is sold on Amazon because of its wide availability, and speedy delivery.

3.3.2 Electrical Conductivity Sensor

An electrical conductivity sensor (EC sensor) measures the electrical conductivity through a varying number of electrodes that are submerged in the sample solution. Pure or distilled water has no electrical conductivity due to the absence of minerals. Once minerals are added, the dissolved salts in the aqueous solution allows it to conduct electricity. The higher the concentration of salts, the higher the electrical conductivity. Since the only input into our aqueous solution will be the nutrient dosing, having an accurate EC sensor is vital to ensure the nutrient level in the hydroponics system can accurately be monitored.

Electrode Designs

There are two popular design philosophies used in EC sensors on the market. One design relies on the use of a potentiometric method to measure electrical conductivity. This physically consists of four platinum rings on the electrode body. The top and bottom rings are located on the outside and apply an alternating voltage to the sample which then induces a current. The other two rings are placed in the center of the electrode body and are inside of the probe relative to the top and bottom outside rings. The center rings measure the potential drop in the current generated by the outside electrodes. This measurement is what produces the electrical conductivity reading. An example of this design is shown in **Figure 7**. Another design that is commonly available on the market is the amperometric approach. This method operates with two electrodes that are isolated from each other. The electrodes are constructed out of a non-reactive material and are fixed in a position such that both electrodes are in contact with the sample solution. Both electrodes pass a current through the sample at a specific frequency. **Figure 8** is a product that follows the two-electrode approach. In both design philosophies, if there is a high concentration of ions in the sample solution, there will exist a higher current being detected by the electrodes, and this can be used to measure electrical conductivity.

Figure 7: Grove Electrical Conductivity Sensor

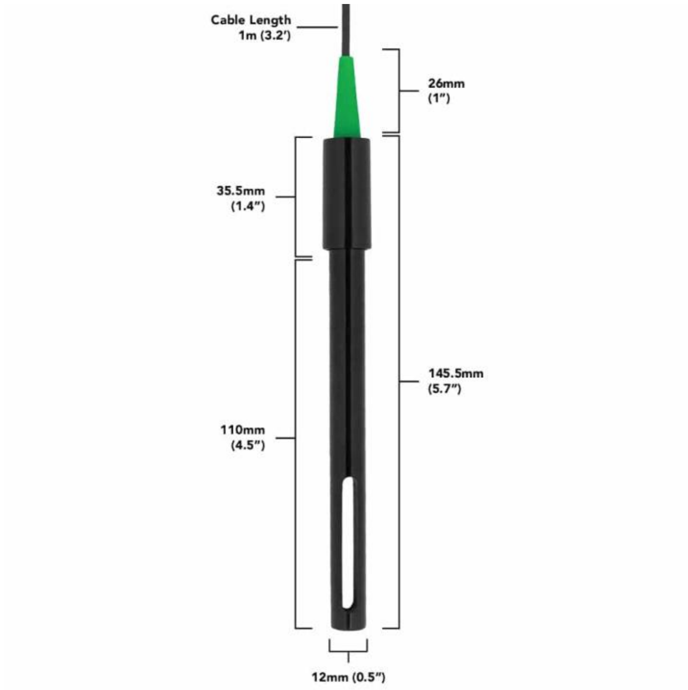
Grove EC Sensor

The cheapest option that had serious consideration was the Grove Electrical Conductivity Sensor. This specific EC sensor is specially designed for low-cost system, featuring a relatively high accuracy and compatibility for most applications. The provided connector and probe interface provide easy interfacing with Raspberry Pi and Arduino system. The kit comes with the EC probe and driver board, with support for 3.3V or 5V systems. The Grove kit offers compatibility with other Grove modules, improving prototyping development should other grove products be utilized.

DFRobot Gravity EC Meter

A direct competitor to the Grove EC sensor is the DFRobot Gravity Electrical Conductivity Meter. This sensor is advertised is as a tool used to measure the electrical conductivity of aqueous solutions and evaluate the water quality. It supports a 3V – 5V wide voltage input and is compatible with 3.3V and 5V main control boards. The output signal is filtered by the onboard hardware and has low jitter. Additionally, there is an open-source software library that offers temperature compensation for EC values. This EC sensor offers compatibility with the Arduino ecosystem.

Figure 8: Atlas Scientific Conductivity Probe



Atlas Scientific Conductivity Probe
Upon further research, the realization was made that the EC sensor would have to be fully submerged in water continuously. In an effort to find a sensor suited for that, we opted to consider the Atlas Scientific Electrical Conductivity Probe. This probe operates by utilizing two electrodes that are positioned opposite from each other. Since the probe itself consists of two graphite plates that are a fixed distance away from each other, the probe must be submerged such that the plates are fully covered. Since there is no black platinum layer at risk of being damaged, this probe is completely safe for extended periods of submerging. The Atlas Scientific EC probe is the most expensive option that we are considering.

Product Comparisons
As **Table 3** indicates, both the Grove EC Sensor Kit and the DFRobot Gravity EC Sensor have very similar specifications, with the Grove kit coming out as the cheaper option. As figure X indicates, the actual probe must be encapsulated when not in use, therefor requiring human interaction on some basis to function. Due to the black platinum coating on the aforementioned sensors, fully submerging them in water will cause degradation of sensor functions including a loss of accuracy. In addition, both of the cheaper sensors require recalibrations depending on how often they are used. In our design, the EC sensor will be used multiple times per hour. In order to ensure this sensor is reliable, we have decided that the Atlas Scientific Mini Conductivity Probe will be the sensor of choice. Figure X shows the difference in probe design, having no protective barrier for the sensor. Due to the

difference in construction, the Atlas probe can be fully submerged and according to Table 5, has better specifications in most categories.

Table 3: Electrical Conductivity Sensor Comparisons

Specification	Grove EC Sensor Kit	Gravity: Analog EC Sensor	Atlas Scientific EC
Operating Voltage	3.3V/5V	3.0V – 5.0V	unknown
EC Range	0 – 2000 us/cm	0 – 2000 us/cm	5 – 200,000 us/cm
Resolution	+/- 5% (STP)	+/- 5% (F.S.)	+/- 2%
Response Time	< 10 sec	unknown	90% in 1s
Probe Interface	BNC	BNC	SMA-to-BNC
Price	$35.90	$60	$159.99

3.3.3 Fluid Level Sensor

The hydroponics system heavily depends on the flow of water for it to be successful. Water is constantly going to flow into and out of the reservoir as needed for the plants. As this happens some of the water is going to be reused but this will not always be the case. As the water runs low the system becomes reliant upon the user to receive more liquid in the reservoir. Without the Fluid Level Sensor, the user has no way of receiving a notification from their phone implying that the reservoir needs to be refilled.

There are a couple different solutions for measuring the level of water within the reservoir. One of the solutions would be using a float level switch. The float level switch sensor works by just sitting on top of the water and once the water gets to a certain point the switch will switch to off. This sensor can only switch to on and off. As long and the sensor is floating on water or any fluid the sensor will stay on. These sensors are cheap and readily available via Amazon. This would not be a beneficial method because the system is trying to find the level of the tank so that the user can from there determine if they need to refill it. The fluid needs to be constantly flowing in the system and if the reservoir is empty this cannot be done. It is possible for the switch to be recalibrated to switch to off when the reservoir is at a certain point such as halfway, but this is not as ideal, and the system should be able to display current level of the reservoir. Another solution that could potentially be used is the water level sensor, which works by being placed vertically into the water to give continuous data on the level of the fluid that it is in. They are cheap as well and available on amazon for purchase but the problem with this is that they typically can only measure up to 10 cm which will not be suitable for this as the reservoir will be about 10 gallons of water. The water level sensor would need to be able to measure up to 3 ft. if we wanted to go with this sensor. Another option that could be considered is an ultrasonic distance sensor. With one of these sensors, you could measure the distance it is away from water constantly which would allow for the fluid level to update like the system needs it to. Ultrasonic sensors are ideal for measuring distances in the range of 10 cm to 250 cm, which is great because it would be able to measure up to 98 feet if used. If the sensor is placed on top of the reservoir and aimed towards the water that it is holding then it should be able to read the distance it is away from the sensor, and as the distance increases the water level should get lower. All ultrasonic sensors can determine distance to water as well via a sound pulse that reflects from the surface of the water and measures the time it takes for the echo to return. This could be a solution that would work but, the problem that there is not is which ultrasonic sensor should be chosen?

One sensor that is in consideration is the HC-SR04. It offers from 2 cm to 400 cm of range. Its operating supply voltage is 5 V and has a working current of 15 mA. It is a single small part that is typically very cheap and works better in a smaller area. The problem with this sensor is that it is not waterproof. This is a problem because the sensor is going to be used in the reservoir and during that time water could possibly end up being splashed on the sensor causing the sensor to not work at all. This shouldn't happen as the sensor would be placed far out of the way of any water that can splash anywhere. This sensor could be a senor that could be used for the fluid level of the system.

The other sensor that is being considered is a JSN-SR04T. It is an ultrasonic sensor that is waterproof and offers from 20 cm to 600 cm of range. It has a working current of 8 mA and is more expensive than the HC-SR04. This sensor could be potentially used but the initial distance range can become a potential problem.

Table 4: Ultrasonic Water Level Sensors

Ultrasonic Sensor	JSN-SR04T	HC-SR04
Voltage	3.3 – 5 V	5 V DC
Distance	20 – 600 cm	2 – 400 cm
Current	8 mA	15 mA

From this research displayed in **Table 4**, two different ultrasonic sensors were chosen and of the two, the HC-SR04 component was selected due to its availability and its distance range. The distance range of the JSN-SR04T only is accurate from 20 cm to 600 cm which makes it excellent to use for long distance range finding, but for the system, it will only need to sense in short distance. The HC-SR04 isn't waterproof but the reservoir shouldn't experience to much splashing that would cause the ultrasonic sensor to get damage. It should be noted that if this does happen then one of the switch water level sensors will be used in its place. It should also be noted that this method could potentially not work at all. If this method does not work in its entirety, then the water level switch method will be analyzed more closely, and a part will be selected for this.

Further Water Level Sensor Considerations

After group considerations and measuring out the constraints, it was founded that the sensor chosen was not going to be the best sensor for this project. The reason why is because it needs to be waterproof otherwise the sensor could end up malfunctioning along the way. So, as a group we looked at some options and found that it would be a smart idea to use a fuel tank sensor. The fuel tank sensor is a sensor that works by having a sensing system that is in the fuel tank and consists of a float usually made of foam and connected to an actuating metal rod. This rod is then attached to a resistor. When the float moves due to changing fuel levels, the wiper moves across the resistor, causing a change in voltage. This means that at the highest resistance the tank would be on empty and at the lowest resistance the tank would be full. This would result in a change of current. This in return, would result in us having to find out how to represent this change within the software. This is the best possible solution to properly show how much water is left in the tank There are a couple of considerations for fuel level sensors. It should be noted that the sensor must be 1" less than the depth of the tank if the tank is plastic and 0.5" less than the depth of the tank if it is metal.

The first consideration was the ITYAGUY Fuel Gas Sender, which is made of stainless steel and its length range is 150 – 500 mm. The sensor is a standard SAE 5-hole pattern, with mounting ease and hookup. This sensor is usually paired with a water level gauge but because we are making it to where it can display information on the phone this will not be needed. This sensor is also $28.99 making it a sensor that is also on the cheaper side. This sensor could be used for the design of the hydroponics system.

The second consideration is a AODITECK Marine Fuel Sending Unit, which has the size of 6" and is also stainless steel. It doesn't specify its length range on the website, but it does specify that the length of the sensor is 6". Its price is $40.99 which is way over the price of the other one. Based on the specifications It seems to be about the same as the ITYAGUY Fuel Gas sender, but with a more expensive price. Because of this, this sensor will most likely not be considered. A comparison of the two sensors are shown in **Table 5.**

Table 5: Water level Sensor Choices (Fuel Tank Sensor)

Fuel Tank Sensor	AODITECK	ITYAGUY
Material	Stainless Steel	Stainless Steel
Length Range	Not Specified	150 – 500 mm
Size	6" (0 – 190 ohms)	6" (0 – 190 ohms)
Price	$40.99	$28.99

Since everything seemed the same within these two sensors, the discrepancies that were examined in were within the reviews that were made on both within Amazon. After looking at reviews and seeing the prices the ITYAGUY was chosen. The reason why mainly came down to the amount of money being spent. It seems as if all the specifications of both were the same for the most part, so the group figured it would be better to spend the money that is being saved from this choice somewhere else.

3.3.4 Water Flow Sensor

A water flow sensor is a tool used to measure the rate of flow of water and aid in calculating the amount of water that has flowed through the pipe. Since the Wi-Fi Hydro Garden utilizes the Nutrient Film Technique, it will require a consistent amount of water flowing through each channel. Thus, it is important to have an accurate measurement of flow rate in our piping systems. Measuring water flow is a historic act and there exists several different methodologies regarding how to do so. Picking the correct method is crucial as it must confine to all the requirements and budgetary constraints while proving a reliable and accurate measurement.

Positive Displacement Flow Meters

A positive displacement (PD) meter is composed of chambers that host mechanical components that rotate in relation to the volume of fluid flowing through the chamber. As fluid passes through, a reciprocating component divides the fluid into a fixed volumetric unit. The number of units that rotates through the chamber within a specific time frame can then be used to distinguish the flow rate of the system. This design is a cost-effective option and requires no power to function. However, the lack of power also could create problems when attempting to read measurements from the sensor. The difference between a PD meter and a turbine meter is that PD meters can measure both liquids and gasses, as well as handle high viscosity fluids better. Unfortunately, none of these benefits aid in meeting the requirements of our design.

Electromagnetic Flow Meters

A more modern approach to measuring the flow of a liquid is through the use of an electromagnetic flow meter. This sensor features electrodes that connect to a coil which generates a magnetic field around the flow pipe. According to faraday's law, when a conductive fluid passes through a magnetic field, a voltage will be produced in proportion to the flow rate. Unlike other flow meters, a magnetic flow meter can measure fluids regardless of density, viscosity, or flow turbulence. Additionally, this flow meter requires no pipe obstructions or contact with the fluid involved, making it highly versatile. The largest pitfall of these types of sensors is that magnetic meters are only compatible with a conductive fluid. If a fluid is nonconductive, the magnetic field will not change, and the readings will be inaccurate. Likewise, if the fluid contains suspended solids, such as those found in plant fertilizers, the magnetic flow meter may also read inaccurate results.

Turbine Flow Meter

This form of flow meter features a multi-bladed rotor that is inline with the direction of the flowing fluid. As the flow rate increases, the turbine spins faster and the revolutions per time period increases. When equipped with electronic sensors, the number of revolutions can be transmitted and used as a measurement to determine the proportional volumetric flow rate required to get said number of revolutions per time period. In many cases, a hall effect sensor is used to monitor the number of revolutions the turbine makes. A hall effect sensor requires magnets placed on the turbine body itself. When a fluid causes the turbine to spin, the magnetized turbine ends generate a magnetic field in which the semiconductor sensor body can detect a measurable voltage. Hall effect turbine sensors can either have analogue or digital outputs, and generally output a square voltage wave.

After comparing the various flow meter designs, it was decided that a turbine flow meter that uses a hall effect sensor would be the best choice for the required implementation. Many of the other flow meters are designed with industrial use in mind and quantities of water that are out of scope of the project. The turbine flow meter can be scaled down to a very small size and be marketed for a very small cost. In addition, the use of the hall effect gives a consistent electrical signal that can be measured for automation purposes. Since turbine water flow sensors are widely available, the main considerations being made was the parts cost and ease of access.

DIGITEN Water Hall Effect Flow Sensor Meter

Out of the countless water flow sensors on the market, we settled for the DIGITEN Water Hall Effect Flow Sensor Meter. As the name aptly describes, this sensor detects the presence of a magnetic field as two magnets in a pinwheel rotate in a circle. As water spins the wheel to flow past it, the magnetics change in position relative to the sensor, and an electrical pulse is generated and can be used to determine the flow rate. DIGITEN offers these sensors in an array of packages, with one fitting the 1/4 ‘’ pipe diameter size required by the water pump that will be used. Additionally, the power requirements are low and there exists some compatibility for Android and Raspberry Pi systems. This sensor uses a plastic housing and is relatively cheap but fits our specification requirements.

3.3.5 Temperature and Humidity Sensor

Temperature is a vital measurement required in meeting the automation specifications set forth. Measuring the ambient temperature of the plant enclosure will be crucial in ensuring that the growth of the plants will be operating in ideal conditions. At the same time, wide availability of temperature sensors on the market means that the sensor should fit budgetary constraints while meeting the required specification of reporting the temperature at a regular time interval. The sensor must be able output the readings through a conventional standard, preferably through a serial communications protocol such as I2C. Temperature sensors generally operate through a thermocouple device, a resistance temperature detector (RTD), or an IC sensor.

Resistance Temperature Detector

An RTD consists of a variable resistor that changes its resistance in direct relation with a change in temperature in a precise and linear manner. Generally, this resistor is composed of metallic oxides that are pressed into a bead, disk, or cylindrical shape and then encapsulated with an impermeable material. The crucial material component that distinguishes an RTD from other designs is the use of pure metals for temperature detection. By choosing a stable metallic material, it is possible to get a consistent change of resistance per degree of temperature difference.

Thermistor

When a temperature detector uses a resistor comprised of semiconductor materials, it is known as a thermistor. Unlike RTD's, thermistors output readings in a nonlinear fashion. Within the thermistor designs, there are 2 main types. A Negative Temperature Coefficient (NTC) thermistor works when resistance decreases as temperature increases. This is the most common form of thermistor seen in products. Likewise, a Positive Temperature Coefficient (PTC) thermistor works when resistance increases as temperature increases. This form is mainly used for fuses or similar applications.

Despite being essentially different forms of variable resistors, RTD's and thermistors have distinct differences that change the application that they can be used for. Due to the material differences, a RTD can support a temperature range of -100 to 650 degrees Celsius, compared to a typical thermistor range of -15 to 60 degrees Celsius. However, the thermistor response time is very fast and accurate, often reading in less than 10 seconds. In contrast, a RTD can take an upwards of 45 seconds for a reading. Another area of conflict is in calibration of the sensor. Thermistors require a more intricate set up process compared to an RTD. Since the readings of a thermistor is not linear, there has to be a series of equations for a set of temperature ranges that can compensate and provide the correct data. A RTD linearly outputs a change in resistance in regard to temperature and can easily be measured when the sensor is supplied with a voltage.

Integrated Circuit Temperature Sensor

With the popularization of integrated circuits, another method of detecting temperature has become a market standard: Integrated Circuit Sensors. IC temperature sensor generally takes the form of a two terminal integrated circuit temperature transducer that can produce a current or voltage output in proportion to the absolute temperature. The sensor itself is small with low thermal mass and a quick read time. IC temperature sensors can be analog or digital. In the case of a digital IC temperature sensor, the output can be processed by an integrated Analog-to-Digital converter. IC sensors also do not require a linearization process as seen in thermistors.

After analysis on all the prevalent temperature sensor technologies listen in **Table 6**, an Integrated Circuit based temperature sensor seemed to be the best possible choice. A resistance temperature detector is less practical than a thermistor for our design, so that route was closed off. Yet, Thermistors themselves still require additional circuitry and a linearization process, both which the IC sensor skips. In addition, the thermistors price is not dramatically cheaper than an IC sensor, so overall the IC sensor saves time and effort while providing all the functionality required. An additional benefit is that IC sensors can be combined with humidity sensors and be marketed as a single module. This aides in installation and reduces the number of sensors that will be required.

Table 6: Comparison of Temperature Sensor technologies
***Temperature is displayed in Celsius**

Parameter	Thermistor	RTD	IC Sensor (LM335)
Temperature Range	~50° of center temperature	-260° to 850° C	-40°to 100°
Relative Cost	Very inexpensive	Most expensive	Moderately expensive
Average Readout Time	6 ~ 14 sec	1 ~ 7 sec	1 ~ 3 sec
Temperature Variation	+/- .0009°	+/- .05°	+/- .01°

Humidity Sensor

Before discussing the sensor methodologies, it is important to define the different ways to measure and describe humidity. Absolute humidity is defined as the amount of moisture that is in the air without reference to the air temperature. This is expressed as a measurement in grams of moisture per cubic meter of air. Relative humidity is the measurement most people are familiar with. This measurement expresses humidity as a percentage which reflects a ratio of the current value of absolute humidity over the maximum absolute humidity value possible for that temperature. In most cases, the end user does not care about the precise humidity value in terms of grams of moisture, but rather how humid it is compared to the maximum humidity value of the current temperature. Thus, relative temperature can be seen as the better measurement to use for our design purposes. There are three primary humidity sensor designs which are defined by a different approach used to provide an electrical signal that can be used to determine humidity.

Thermal Conductivity Humidity Sensor

One approach that uses technology from temperature sensors is the thermal conductivity design. Thermal conductivity humidity sensors measure absolute humidity through the use of two NTC thermistors that are suspended by thin wires within the sensor. One thermistor is placed inside a location that is exposed to air through ventilation holes. The second thermistor is placed in a chamber that is hermetically sealed, usually with dry nitrogen. An electrical bridge circuit connects the two thermistors and passes current, causing them to self-heat. Due to one thermistor being exposed to the humidity of the air, it will have a different electrical conductivity. By measuring the difference in resistance of the sealed and exposed thermistor, one can find a direct proportion of resistance change to absolute humidity. The main benefits of thermal conductivity sensors generally come from their use in industrial practices. They are suitable for high temperature or corrosive environments, and feature durability and a good resolution.

Resistive Humidity Sensor

Another form of humidity sensor comes in the form of resistive humidity sensors. This sensor design is more or less a variant of the electrical conductivity sensor. A resistive humidity sensor is composed of a hygroscopic conductive polymer that is mounted on a substrate. The polymer film is structured such that a set of comb-like electrodes, constructed out of a noble metal usually, are laid out in a specific pattern to increase contact area between the electrodes and conductive material. The resistivity of the conductive material will vary inversely with the amount of the moisture absorbed. As more water vapor is absorbed, the resistance of the non-metallic conductive material will decrease, and this can be used to establish relative humidity. This form of humidity sensor has a small form factor and can function in remote monitoring systems where distance between the sensor and signaling circuit is very large.

Capacitive Humidity Sensor

The last main design used to detect humidity is the capacitive humidity sensor. As the name implies, this approach uses a capacitor to detect relative humidity. A capacitor consists of two electrode layers between a dielectric material. In the case of a capacitive humidity sensor, the dielectric material used is one that can absorb moisture from the surrounding air such as a polymer film. Since theoretically, with the absence of air and moisture, the capacitance is determined by the geometry of the capacitor and the permittivity of the dielectric material. When water vapor is introduced as an element in room temperature air, the dielectric absorbs some of the vapor which causes the permittivity to change. Since the dielectric constant of water vapor is much higher than the dielectric in the capacitor, when the absorption occurs the capacitors dielectric constant increases, which in turn increases the capacitance of the sensor. From this interaction, a direct relationship between the relative humidity of the air and the capacitance of the sensor. The change in the dielectric constant is directly proportional to the value of the relative humidity. Thus, by measuring the change in capacitance, the relative humidity level can be established. The capacitor itself is the actual sensor but requires additional circuitry to function such as a probe, cable, and signaling unit. Capacitive humidity sensors provide stable readings and offer close-to-linear signal amplitudes over the humidity range. One potential problem is the distance between the sensor and signaling circuit must be relatively short.

For our design, there is no need for an absolute humidity reading, the two main considerations for humidity sensor methods were narrowed down to a resistive or capacitive humidity sensor. While both are offered as complete sensor units, most capacitive models come with an integrated temperature sensor as well, eliminating the need to purchase two separate sensors. With this being the case, the capacitive humidity sensor was the design decided upon for our project.

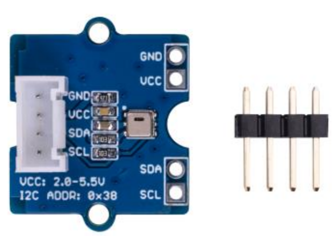
Temperature & Humidity Sensor Comparisons

Temperature and Humidity are two very important factors in ensuring the growth and prosperity of the plants inside the Wi-Fi Hydro Garden. By continuously monitoring the temperature values and humidity percentages in the enclosure, any irregularities will be able to be spotted quickly and resolved if possible. While it is possible to get separate sensors for each measurement, the most common configuration sold by manufacturers is generally a combination of both features. Due to the mass availability of temperature-humidity sensors, all products considered were of those type. Within the array of multifunctional sensors, there exists a variety of formfactors that serve specific needs.

Grove AHT20

The most common form of temperature and humidity sensor are those in integrated chip form. One product in this form factor that was being considered is the Grove AHT20 temperature and humidity sensor. As seen in **Figure 9**, this chip uses a MEMS semiconductor capacitive humidity sensor, and a standard on-chip temperature sensor. The output is delivered through the I2C protocol. This was considered as an option as it uses both a capacitive humidity sensor and an integrated circuit temperature sensor, fulfilling both of the design requirements. One of the main benefits of selecting this sensor is the price, with this combo package only being listed for a price of $6.40. The biggest difficulties faced with this product is the physical implementation of the sensor. Since the sensor is essentially exposed circuitry, there is concern regarding the placement of the sensor when there is possibility of water damage.

Figure 9: Grove AHT20 I2C Temperature & Humidity Sensor



SHT20 I2C Temperature & Humidity Sensor

Keeping the potential issues with the integrated chip variants of temperature and humidity sensors led to the consideration of the SHT20 I2C temperature and humidity sensor. The probe of the sensor is advertised as being waterproof as shown in **Figure 10**. In addition, the SHT20 contains an amplifier, A/D converter, OTP memory, and a digital processing unit. This allows for the output to be sent as a digital signal which provides an easier time interpreting data. The primary benefit of implementing this type of sensor is the ease of installation. The waterproof probe eliminates any fears of water damaging the sensor and allows for flexible placement inside the enclosure to ensure an ideal measurement can be made. The biggest issue is the increase in price. Listings from the DFRobot website has this sensor at $22.50, which is almost four times the price of the AHT20 sensor.

Figure 10: SHT20 I2C Temperature and Humidity Sensor

Our final choice after considering the specifications listed in **Table 7** was the SHT20 temperature and humidity sensor. Despite the Grove AHT20 having similar specifications that could fit our design requirements, the waterproof nature of the SHT20 is vital to ensure ease of installation and placement in the enclosure.

Table 7: Temperature & Humidity Sensor comparisons
***RH – Percentage of Relative Humidity**

Specification	AHT20	SHT20
Operating Voltage	2.0 – 5.5 V	3.3/5 V
Temperature Range	-40° - 85° C	-40° - 125° C
Humidity Range	0 – 100% RH	0 – 100% RH
Temperature Accuracy	+/- 0.3° C	+/- 0.3° C
Humidity Accuracy	+/- 2% RH	+/- 3% RH

3.3.6 Luminosity Sensor

The hydroponics system success is heavily dependent among the light that it is receiving. The reason why is because the light intensity influences the manufacture of plant food, stem length, leaf color and flowering. Plants are classified according to their light needs, such as high, medium, and low light requirements. The hydroponics system may be housing a plant that typically needs more lumens of light than other plants. The user should be able to change the brightness level of the lights that are in the system, but they should know that the brightness level is as well.

The luminosity sensor that was looked at first is the Adafruit VEML7700 Lux Sensor. This sensor is a simple lux sensor that can determine the brightness/darkness of ambient lighting. It is 3.3 V to 5V and can be used with any microcontroller. This sensor highlights its ability to automatically calculate the lux unlike a lot of other lux sensors. It is a cheap sensor and there is a high possibility that it can be used. It even contains holes for mounting.

The second sensor that was observed was the photo switch light sensor. This module has a built-in relay which can be used for switch on and off the lights. This module contains an operating voltage of 12 V and it is a wire as opposed to being directly connected to the module. This gives greater flexibility in the placement of the module. The module has four mounting holes as well.

The final sensor that was observed was the LM393 Photosensitive LDR. This sensor has a photosensitive resistor with a potentiometer to allow the adjustment of the brightness of light detected. This module has an operating voltage of 3.3 to 5 V. The module can also either be analog or digital. A comparison of sensors considered is displayed in **Table 8**.

Table 8: Light Sensor Specifications

Light Sensor	Adafruit VEML7700	LM393 Photosensitive LDR	Photoswitch light sensor
Operating Voltage	3.3 – 5 V	3.3 – 5 V	12 V
Cost	$4.95	$8.99	$9.99
Switching Relay	No	No	Yes

The sensor that was chosen was the Adafruit VEML7700 Lux Sensor. The reason why this was chosen was based on its ability to determine the exact lux. This is going to be extremely helpful to the user because the user can determine the needed lux for the plant that is being grown and can make adjustments from there. The sensor will be tested to determine if this is the best fit for the intended design.

If it is not than another sensor will be chosen. The placement of this sensor is going to be crucial to determine the brightness of the light. If the sensor cannot be put in the place that it is most needed, then the sensor will have to.

3.4 Plants

An important decision is what kind or kinds of plant(s) to grow. Overall, we would desire that our system can be used for any plant grown with seeds, and for any variety of plants at the same time. However, given time constraints, it is ideal to choose a plant that grows as fast as possible. Also, it would be ideal to only use one plant, or plants with similar nutrient and pH demands. There are different classes of plants that can be harvested in under a month, but the focus will be microgreens.

Microgreens use the same seeds that you would use to grow a plant to its full form but are harvested at a much earlier stage. They are harvested around an inch in length and consist mainly of seed leaves, or cotyledons, which are leaves that are already structurally within the seed and are the first to show. It is said that microgreens were first used in dishes in America in the 1980s and first consisted of arugula, basil, beets, kales, and cilantro. Today, some of the more popular microgreen plant family types include Brassicaceae, Asteraceae, Apiaceae, Amaryllidaceae, Amaranthaceae, Cannabaceae, Cucurbitaceae, and Lamiaceae. The Brassicaceae family includes cauliflower, broccoli, cabbage microgreens, red cabbage microgreens, watercress, radish microgreens, and arugula. The Asteraceae family includes lettuce, endive, chicory, and radicchio. The Apiaceae family includes dill, carrot, fennel, celery, and cilantro. The Amaryllidaceae family includes garlic, onion, and leek. The Amaranthaceae family includes amaranth, quinoa, swiss chard, beet, and spinach. The Cannabaceae family includes hemp. The Cucurbitaceae family includes melon, cucumber, and squash. The Lamiaceae family includes chia.

Microgreens are much more nutrient dense than mature greens with vitamins like vitamin C, E, and K, as well as beta carotene. Vitamin C helps your body eliminate free radicals, and there is up to 20 mg per 100 g of vitamin C in a microgreen seedling compared to 10 mg of vitamin C in a full-grown tomato. Vitamin E helps protect your body from free radicals formed when converting food into energy and is made up of alpha and gamma-tocopherol. A small serving of microgreens is enough to hit your daily requirement of vitamin E. Vitamin K is produced in great amounts when microgreen seedlings are exposed to sunlight in order to help the chlorophyll in the plant absorb nutrients. For humans, vitamin K helps in the blood clotting process and to maintain healthy teeth and bones. Beta carotene helps to reduce the risk of various disease. Microgreens do not only contain valuable vitamins, but minerals as well, including but not limited to potassium, iron, zinc, magnesium, and copper. Potassium helps the body to regulate fluid to muscle contractions and nerve signaling, potassium also helps to control blood pressure. Iron helps in regulating body temperature, boosting the immune system, and increasing energy and focus. Magnesium is involved in many bodily reactions and boosts bone and cardiovascular health. Magnesium can also be used to treat diabetes, migraines, premenstrual symptoms, and anxiety. Copper works with other minerals to create red blood cells, copper also helps to build the immune system and absorb iron, it may also prevent cardiovascular disease and osteoporosis.

When it comes to determining which microgreen is the healthiest, there are many contenders like pea shoots, sunflower shoots, radish sprouts, arugula, wheatgrass, chia, and kale. Pea shoots have high beta carotene levels which help produce vitamin A, vitamin C, folate, and fiber. Sunflower shoots are high in selenium, folate, and vitamin B, vitamin C, and vitamin E, they also contain various amino acids. Radish sprouts are a good source of amino acids, minerals like calcium, iron, magnesium, phosphorus, potassium, and zinc, and vitamins like vitamin A, vitamin B, vitamin C, vitamin E, and vitamin K. Arugula contains vitamin C, glucosinolates, and phenols, which helps to defend against environmental stress and toxins. Wheatgrass is rich in selenium, vitamins like vitamin A, vitamin B, vitamin C, vitamin E, and vitamin K, and minerals like zinc, potassium, iron, calcium, magnesium, and phosphorus. Chia is unique in that it is a good source of protein, unsaturated fats, and fiber. Kale has high amounts of vitamin C, which helps to protect cells and keep skin, bones, and blood vessels healthy. Though these different microgreens have varying benefits, determining which is the healthiest depends on what nutritional benefits are desired.

There are many ways to prepare and consume microgreens like baking, cooking, or eating them raw. You can use microgreens as a substitute for things like spinach when baking. Microgreens can be cooked on a stove, in a stir-fry, or even on a pizza. Raw microgreens are commonly mixed into smoothies in order to get vitamins and minerals. It also helps balance flavors from other ingredients in smoothies and juices. They can also be used in sandwiches as a substitute for basic lettuce. Lastly, and most commonly, raw microgreens can be used as a base for a salad or mixed in to add flavor and nutrition.

Growing microgreens is relatively easy. Assuming that they are being grown in the traditional way the planter must first see if there are special instructions on the seed packet. Next, the bottom of the container to hold the plants is to be covered with a couple of inches of soil. Following this the soil is to be flattened and the seeds scattered on top. After that, the seeds are to be covered with a thin layer of soil, then that surface is to be dampened. Next, the soil is to be misted daily in order to keep it moist until sprouts appear. During this process, the microgreens need at least four hours of sunlight a day in order to grow healthily. If the microgreens are grown indoors, the same process is followed, but the plant should be placed by a window, or a grow light should be used in order for the plants to get enough light. It is recommended that if the plant is placed by a window, then it is best if the window is facing south, but western or easter facing windows will also work. An alternative method to grow microgreens is to grow them without soil, a method known as hydroponic planting. Hydroponic planting grows microgreens in a totally water-based environment which leads to nutrients and oxygen being absorbed from water instead of soil.

When it comes to the specific details and ideals for growing microgreens, the one of the main factors is the choice of plant. Some examples are peas, basil, baby butter lettuce, arugula, and oregano. When growing peas hydroponically, a deep water culture system is particularly good. A deep water culture hydroponic system needs a container deep enough to hold at least 8 inches of water, nutrients, an air pump, a growing net, a growing medium, and air stones. The optimal growing medium for peas is perlite-vermiculite and expanded clay pebbles. The optimal pH range for peas is 6 to 7. The optimal nutrient mix is a mix of calcium nitrate, magnesium sulfate, and nitrogen phosphorus potassium. The ideal EC range is .8 to 1.8, the ideal temperature is around 55-65°F and peas require 8 to 10 hours of light per day. Peas germinate from 7 to 14 days and mature around 8 weeks.

When basil is grown hydroponically, a hydroponic method can be used. The optimal growing medium is rockwool, coco coir, or perlite. The optimal pH range for basil is 5.5 to 6. The optimal nutrient mix is a mix of calcium nitrate, magnesium sulfate, and nitrogen phosphorus potassium. The ideal EC range is 1 to 1.6, the ideal temperature is around 60-75°F, and basil requires 14 to 16 hours of light per day. Basil germinates from 3 to 10 days and matures around 50 to 80 days.

When baby butter lettuce microgreens is grown hydroponically, the tray method is most suitable. The tray method requires a seed planting tray, a bucket or reservoir for the water, a misting bottle, a fertilizer, and coconut coir or biostrate mat. The optimal growing medium for butter lettuce microgreens is coconut coir. The optimal pH range for butter lettuce microgreens is 6 to 6.5. The ideal EC range is around .8, the ideal temperature is around 65-75°F, and baby butter lettuce microgreens require 14 to 17 hours of light per day. Baby butter lettuce microgreens germinate from 1 to 3 days and mature around 8 to 12 days.
When arugula is grown hydroponically, any hydroponic method can be used. The optimal growing medium is coconut coir. The optimal pH range for arugula is 6 to 7.5. The optimal nutrient mix is a mix of calcium nitrate, magnesium sulfate, and nitrogen phosphorus potassium. The ideal EC range is .8 to 1.2, the ideal temperature is around 55-75°F, and arugula requires at least 12 hours of light per day. Arugula germinates from 7 to 10 days and matures around 35 to 40 days.

When oregano is grown hydroponically, any hydroponic method can be used. The optimal growing medium is rockwool or grow plugs. The optimal pH range for oregano is 6 to 7. The optimal nutrient mix is a mix for lettuce. The ideal EC range is 1.8 to 2.3, the ideal temperature is around 60-70°F, and oregano requires about 12 hours of light per day. Oregano germinates from 7 to 21 days and matures around 90 to 120 days, but it can be harvested before maturity.

Some of the previous data is represented in **Table 9**. When it comes to selecting a plant for this project, there is freedom in that there are multiple plants can work in any hydroponics system. Therefore, plant selection is mainly a matter of convenience regarding its ideal temperature, pH, and germination time. The plant chosen was arugula because it grows fast, grows at room temperature, and has a balanced pH range. Arugula takes about 7 to 10 days to germinate, it grows in a range of 55-75°F, and its optimal pH is between 6-7.5.

Table 9: Plant Growth Specifications

	Peas	Basil	Baby Lettuce Microgreens	Arugula	Oregano
Hydroponic Method	Deep Water Culture	Any	Tray	Any	Any
Growing Medium	Perlite-vermiculite & Expanded clay pebbles	Rockwool, Coconut Coir, or Perlite	Coconut Coir	Coconut Coir	Rockwool or Grow Plugs
pH Range	6 to 7	5.5 to 6	6 to 6.5	6 to 7.5	6 to 7
EC Range	.8 to 1.8	1 to 1.6	~.8	.8 to 1.2	1.8 to 2.3
Temperature Range (°F)	55 to 65	60 to 75	65 to 75	55 to 75	60 to 70
Hours of Light per Day	8 to 10	14 to 16	14 to 17	12+	~12
Days for Germination	7 to 14	3 to 10	1 to 3	7 to 10	7 to 21

3.5 Liquid Tanks

Section 3.2 will go over the potential options of various liquid storage solutions we need for this project. We will need to store at least 5 gallons of fresh water along with three different types of chemicals to regulate the pH balance and nutrient content of the fresh water.

3.5.1 Main Water

The main water tank of the system will store approximately 5 gallons of water to be pumped up into the grow chamber for the plants. Originally, I wanted to go with a 10-gallon tank but decided the cost and scale was unnecessarily large for our project. Readably available containers and stand sizes also drove us toward the decision of using a 5-gallon container.

Many options were available in the 5-gallon size. First and possibly the easiest and cheapest is the standard buckets available from Home Depot or Lowes. While this would work just fine, I wanted something a little more professional looking and intended for water storage. Searching for possible options online I found many fully enclosed water storage containers with a single screw on cap. They were all similar in quality and build so I picked the cheapest. We settled on a 5-gallon plastic container from Midwest Brewing and Winemaking Supplies. It had a large 2.75" cap so I could insert the main pump. It is food safe and made of BPA free plastic. It is currently on sale for $16.47 on amazon.com. This product is designed for water and liquid storage with graduated markings on the side for quick volume measurements. A comparison of the considerations is shown in **Table 10**.

Table 10: Main Water Storage Comparison

Manufacturer	Dimensions	Capacity	Material	Price
Midwest Brewing and Winemaking Supplies	15.8x10.6x10.5 inches	5 Gal	HDPE High Density Polyethylene	$16.47
Hudson Exchange	11x9.25x15 inches	5 Gal	HDPE High Density Polyethylene	$35.99
Home Depot	14.5x13x13 inches	5 Gal	.70 mil Plastic	$3.78

3.5.2 Chemical Tanks

Our hydroponics system features the ability to maintain the pH balance of the water and add nutrients as needed. To control the pH balance of a system you will either have to add an acid or a base to the main water supply to achieve the perfect balance. We will also choose a plant nutrient specific to the type of crop we will be growing. These three chemicals will need to be stored near the main water supply for frequent dosing. We expect to be using milli liters of solution at a time so our containers can be relatively small.

This did not need to be complicated, so I got on amazon and found a 6-pack of 16oz glass jars with a plastic lid. The idea is to drill a 5mm hole in the middle of the lid and feed in the silicone hose attached to the peristaltic pump. We only needed 3 but I was only finding 6 and 12 packs of jars. A comparison of the considerations is displayed in **Table 11**. As of the time of this paper the set was on sale for $11.99 on amazon.com. The bottles are just under 7" tall and 3" wide. We will print out labels for each bottle to distinguish between the chemicals. This product is marketed as multi-use to include juicing, smoothies, and water.

Table 11: Chemical Tank Storage Comparison

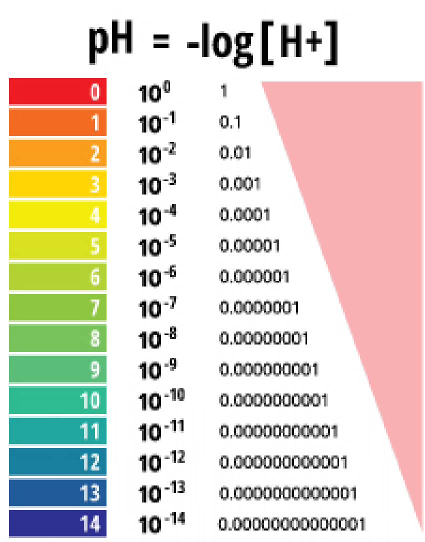
Manufacturer	Dimensions	Capacity	Material	Price
Cornucopia	6.75x2.75 inches	16 oz.	Glass/Plastic	$12.99
DilaBee	14.84x11.85x3.86 iches	36 oz.	Plastic	$15.99
Danallan	11.34x8.74x7.32 inches	8oz.	Plastic	$17.99

3.6 Plant Chemicals

3.6.1 pH Balance Solutions

The pH scale is a means to measure how acidic or basic a substance is. How acidic or basic a substance is dependent upon on how many positively or negatively charged ions it produces. A substance that is acidic produces more positively charged ions, specifically hydrogen ions (H+). A substance that is basic produces more negatively charged ions, specifically hydroxides (OH-). The pH scale ranges from 0 to 14 with a lower number being more acidic and a higher number being more basic. A substance like stomach acid is very acidic with a pH of 1, while bleach is very basic with a pH of 12, right in the middle of the scale is pure water, which is considered neutral with a pH of 7. While a scale from 0 to 14 may seem narrow, it is worth noting that the pH scale is not linear but logarithmic. This means that a change of one unit on the pH scale equates to a difference in the number of ions by a factor of 10. For example, a substance of pH 3 has 10 times the amount of positively charged hydrogen ions compared to a substance with a pH of 4. Therefore, the pH scale on linear scale is not narrow but very broad, with a range of 10^14 units difference between the most acidic and basic substances. **Figure 11** demonstrates these concepts.

Figure 11: pH scale



When it comes to plant growth and pH, the pH of soil does not inhibit or boost plant growth directly, but pH is a notable factor in determining what nutrients are available in the soil, and how efficient the plant can absorb them. For example, a plant may suffer from iron deficiency if the soil is too basic. Not because there is not iron in the soil, but the iron is not in a form that can be absorbed by a plant because of the lack of soil acidity. On the other hand, a soil that is too acidic may provide an abundance of manganese, but too much manganese can be toxic to plants and lead to poisoning. Another way that the pH of soil can indirectly affect plant health is the environment that it provides for other organisms. For example, too basic of a soil can harm microorganisms which help to convert nitrogen into absorbable forms.

For soil growers, when adjusting soil pH several factors must be kept in mind like current pH and soil texture. There are at home and laboratory soil test that can be used to determine what the current pH of a section of soil is, and once that is known, them how much the soil pH needs to be raised or lowered can be determined. The texture of the soil must also be accounted for because a soil with a consistency more like clay takes more material to change its pH, and a soil with a consistency more like sand takes relatively less material to change its pH. It is typical for sulfur to be used to lower soil pH and for limestone to be used to raise soil pH. Though powdered sulfur can be used as a fungicide, it is not necessary to use it in that form for acidifying soil, rather it can be used in pelletized form. Limestone is also available in powdered and pelletized form. Rather than using straight limestone, which is almost pure calcium carbonate, some use dolomitic limestone, which not only is better at neutralizing acidity compared to pure calcium carbonate, but dolomitic limestone also adds magnesium to the soil.

The pH level of the water in a hydroponics or aquaponics system must be at the proper level. Water that is too acidic or too basic can compromise plant health, which is why a pH balance solution, comprised of a solution to increase the pH and a solution to decrease the pH, is necessary. Another factor that must be accounted for is the water's buffering capacity. Buffering capacity is the ability that a substance has to resist changes in pH. A high buffering capacity means that the substance is more resistant to changes in pH, and a low buffering capacity means that the substance is less resistant to changes in pH. The use of hard water, which has a lot of carbonates, in a hydroponics system can increase the difficulty of balancing the pH because the carbonates increase the buffering capacity greatly at a high pH. If this issue arises then a reverse osmosis filter can be used to filter out the carbonates, or we can use water from a different source.

The distribution of the pH balance solution will be controlled by sensors and pumps, so the main factors in deciding a solution are cost, plant safety, and having a test kit to ensure that the pH sensors are working properly. With these factors in mind, it was decided to use the General Hydroponics brand pH Control Kit. An 8oz bottle of pH Up with an 8oz bottle of pH Down and a pH test indicator kit is $20.14

off of amazon. The solutions are designed for hydroponics systems and are safe for plants and use for soil, water culture, and various growing mediums. The pH Up liquid is made using potassium hydroxide and potassium carbonate, while the pH Down liquid is made using food grade phosphoric acid. The pH test indicator kit will be a means to test the pH of the water outside of the hydroponics system in order to verify that the pH sensor is working properly or need recalibration.

3.6.2 Nutrient Formula

Given that there is no soil, there still needs to be a source of nutrients for the plants to grow. The function of the plant nutrient formula is to provide these nutrients, which will be distributed in the water. Plant fertilizers are commonly labeled with an “N-P-K” number to denote the percentage of nitrogen-phosphorus-potassium in the whole fertilizer. For example, a 20-5-10 fertilizer has 20 percent nitrogen, 5 percent phosphorus, and 10 percent potassium. Some other nutrients which plants need in order to grow other than nitrogen, phosphorus, and potassium are calcium, magnesium, sulfur, chlorine, copper, manganese, iron, boron, molybdenum, and zinc.

Nitrogen is a primary plant nutrient. Nitrogen helps plants grow stronger, grow a darker green leaf color, and photosynthesize. Higher amounts of nitrogen are best suited grass and other plants which are almost entirely leaf like wheat, and oats. Phosphorus is also a primary plant nutrient. Phosphorus helps flowers bloom and fruits ripen faster and with higher quality. Higher levels of phosphorus relative to nitrogen are typical for growing trees and shrubs. Potassium is a primary plant nutrient which improves overall plant health and strength. Potassium also helps plants to resist disease, stress from drought, and extreme temperatures.

Calcium is a secondary nutrient. Calcium helps to build cell walls and promote the growth of young roots and shoots. Plant cell strength is important because weak cells lead to a collapse of a plant’s vascular system, which then prevents nutrient uptake. Therefore, a calcium deficiency will lead to leaf margins and tips withering because they do not get nutrients. Magnesium also is a secondary nutrient. Magnesium helps to form sugars, proteins, fats, and oils, and aids in the uptake of plant food and the forming of seeds. Magnesium also is a phosphorus carrier and is contained in chlorophyll, so it helps in making plants a dark green color, and in photosynthesis. Magnesium deficiency is evidenced by plant leaf veins staying green while the other parts turn yellow. Sulfur is a secondary nutrient in terms of the quantity necessary but is as essential as phosphorus. Sulfur is necessary in the manufacturing of chlorophyll which maintains a plant’s dark green color, sulfur also helps in enzyme and protein formation. Lastly, sulfur reduces the sodium content of, and conditions soil.

Chlorine is a trace element. Chloride’s primary function is to balance out the charge of potassium during gas exchanges to prevent plant damage. This function is critical for photosynthesis. Copper is also a trace element, very little is needed, but its absence is exceedingly destructive. Copper is a helper in chlorophyll formation and is used to activate enzymes which aid in cell wall health. Deficiency in copper may lead to leaf yellowing, and leaf nodes growing closer together over time. Manganese, though a trace element, is an essential mineral. Contrary to magnesium, which is a part of chlorophyll, manganese is not a part of chlorophyll, yet manganese deficiency has similar symptoms as magnesium deficiency with lead yellowing. Iron is a trace element that has vital role in various plant functions like chlorophyll production, metabolism, nitrogen fixing, and enzyme production. Like many other nutrient deficiencies, signs of iron deficiency include a yellowing of the leaves while the veins remain green, leaf loss, and poor growth.

Another trace element is boron. Boron is safe is small amounts but too much can lead to boron toxicity. In the right quantity boron is needed for plant hormone regulation, fruit set, seed development, cell wall development, protein synthesis, pollen tube growth, grain germination, and metabolism regulation. Molybdenum is a trace element whose main purpose is to help plants use nitrogen. Deficiency of molybdenum typically leads to nitrogen deficiency because the plants will not be able to take up nitrates from the soil, and the nitrates that are in the leaves cannot be used to make proteins. The final element for discussion is zinc which is a trace element. Zinc helps plants to produce chlorophyll, form seed, and develop enzymes and hormones. Zinc deficiency has a similar symptom as other nutrient deficiencies, leaf yellowing while the vein remains green. However, zinc deficiency is unique in that, the yellowing begins on the low leaves, while leaf yellowing for manganese, iron, and molybdenum begins on the upper leaves.
There are many brands of plant nutrients which come in different forms, such as powder or liquid, and are made of different materials, both synthetic and organic. Some plant nutrients are also suited for different growing mediums, for plants grown in soil, some recommended brands are the General Hydroponics brand, Flora series nutrient package, the Botanicare brand, Pure Blend Pro Soil nutrient package, and the Fox Farm brand, Soil nutrient package.

General Hydroponics Flora Series
The General Hydroponics brand Flora series is pH balanced and made to enhance plant flavor and aroma. The Flora series contains the FloraMicro, FloraGro, FloraBloom, FloraBlend, Liquid KoolBloom, FloraKleen, and Floralicious Plus nutrient packs. The FloraMicro is a micronutrient supplement and is derived from various minerals in order to provide nitrogen, phosphorus, potassium, and other micronutrients. The FloraGro contains nitrogen, phosphorus, potassium, and secondary nutrients for the purpose of stimulating thick structural growth for plants. FloraBloom is used to promote the growth of flowers, specifically to make the larger, denser, and filled with aroma, flavor, and essential oils. FloraBloom contains much phosphorus, potassium, magnesium, and sulfur. FloraBlend is made with a mixture of bioactive microorganisms to promote healthier soil and roots. FloraBlend also has seaweed, rock powder, and micronized Leonardite. Liquid KoolBloom is to be used at the start of the flower cycle in order to support heavy flowering and increase terpene production. This is done through the nutrient transporting acids and the stress-reducing vitamins that Liquid KoolBloom

contains. FloraKleen is a supplement which removes fertilizer residue from plants and soil in order to keep flowers clean with great taste. Floralicious Plus is used to improve root zone conditions, metabolic growth, terpene levels, bud density, and overall flower development.

Botanicare Pure Blend Pro Soil

The Botanicare brand Pure Blend Pro Soil nutrient package is all natural and contains the Pro Grow, Pro Bloom, Rhizo Blast, Liquid Karma, Cal-Mag Plus, Silica Blast, Sweet, and Hydroplex Bloom Enhancer recipes. The Pro Grow recipes is used to set up plants for a fruitful harvest and promote robust leafy growth. Pro Grow is made only natural sources of primary, secondary, and trace minerals. The Pro Bloom recipe is also all natural. Pro Bloom is used to encourage dense flower growth with the phosphorus it contains. The Rhizo Blast is a root stimulator, increasing root development in order for the plant to absorb more nutrients. The Liquid Karma recipe is as a catalyst to improve overall plant function. The Cal-Mag Plus recipe is made mostly of the secondary nutrients calcium and magnesium and the trace element iron. Cal-Mag Plus is used to prevent bud root and tip burn and improve nutrient uptake. The Silica Blast recipe is used to increase the strength of the plant and to facilitate photosynthesis. The Sweet recipe contains organic acids, amino acids, vitamins, and carbohydrates. Sweet is used to increase the energy of the plant and improve flavor. The Hydroplex Bloom Enhancer functions to encourage dense sticky buds using a variety of vitamins, minerals, and micronutrients.

Fox Farm Soil

The Fox Farm brand Soil nutrient package has many supplements and additives and contains the Grow Big, Big Bloom, Tiger Bloom, Bush Flowers Kiss, Bush Doctor Boomerang, Bush Doctor Kangaroots, Bush Doctor Microbe Brew, Bush Doctor Wholly Mackerel, Bush Doctor Kelp Me Kelp You, Bush Doctor Bembe, Open Sesame, Beastie Bloomz, Cha China, and Bush Doctor SledgeHammer formulas. The Grow Big formula is made for younger plants to lead to more compact and lush growth. Grow Big contains earthworm casting and both primary and trace nutrients. The Big Bloom formula contains bat guano, earthworm castings, rock phosphate, and other organic ingredients. Big Bloom functions to increase flower size, transfer energy, and encourage even budding. The Tiger Bloom formula is high in phosphorus and nitrogen. The phosphorus encourages thicker and denser buds when flowering and the nitrogen helps to increase plant vigor. The Bush Flowers Kiss formula works as a micronutrient supplement to prevent trace element deficiencies and promote overall plant health. The Bush Doctor Boomerang is used to heal root tissue, lower plant stress, provide organic nutrition, and encourage budding. Bush Doctor Boomerang is not an all-purpose fertilizer, but a microbial based additive. The Bush Doctor Kangaroots formula is liquid root drench that contains organic macronutrients, microbes, and micronutrients. Bush Doctor Kangaroots is used to improve the root system and the soil around it.

Bush Doctor Microbe Brew Formula
The Bush Doctor Microbe Brew formula is an additive made with different bacteria and fungi. Bush Doctor Microbe Brew is used to improve soil conditions which in turn benefits the plant. The Bush Doctor Wholly Mackerel formula is used to provide plants with many important nutritional sources. Bush Doctor Wholly Mackerel, as a marine based additive, contains 20 amino acids, 8 minerals, 13 vitamins, and organic macronutrients. The Bush Doctor Kelp Me Kelp You formula is used to improve plant water retention and nutrient uptake. Applied as a spray or at the roots, Bush Doctor Kelp Me Kelp You is a seaweed supplement and functions as a biostimulant. The Bush Doctor Bembe formula is made up of earthworm castings, bat guano, and other organic ingredients. Bush Doctor Bembe is used as a source of natural sugars and food in order to increase plant sweetness. The Open Sesame formula, made with much phosphorus, is a fertilizer used to stimulate flower growth. The Beastie Bloomz formula is an additive designed to be applied in the later weeks of flower. The Beastie Bloomz formula, containing organic nutrients, helps plants finish blooming and increase plant density and yield. The Cha Ching formula is an additive made to optimize flower flavor and texture. The Bush Doctor SledgeHammer formula is a rinse used for removing nutrient buildup. Even though these nutrient packages, whether from General Hydroponics, Botanicare, or Fox Farm, are beneficial for many plant growers both new and experienced, these will not be used in our project because these formulas were made for plants grown in soil.

Organic Nutrient Packages
For growers who desire to only use organic nutrients, some recommended brands are the Earth Juice brand, Original Big 5 nutrient package, Emerald Harvest brand, Pro 3 Part nutrient package, and the General Organics brand, BioThrive nutrient package. The Earth Juice brand, Original Big 5 nutrient line has the Grow, Bloom, Meta-K, MicroBlast, and Big Bloomin' Guano formulas. The Grow formula is an organic liquid fertilizer made to increase stem and leaf growth. Some other benefits are that it is non-burning and does not lead to salt residue. The Bloom Formula contains terpenes and essential oils and is geared to develop flowers. Designed for use at the site of the first buds, the Bloom formula is a notable nutrient source. The Meta-K formula is a natural liquid potassium supplement and benefits the plant with all the benefits of potassium. Meta-K, in correcting potassium deficiencies, helps increase yields, increase nutrient uptake, and increase drought resistance. The MicroBlast formula is made up of a variety of micronutrients in order to prevent deficiencies. The Big Bloomin' Guano formula, with it being a guano supplement, is made to increase flowers' size, aroma, and terpene production.

Emerald Harvest Pro 3-Part Nutrient Package
The Emerald Harvest brand, Pro 3 Part nutrient package has the Grow, Micro & Bloom, Emerald Goddess, King Kola, Honey Chome, Root Wizard, Cal-Mag, and Sturdy Stalk formulas. The Grow, Micro & Bloom formulas are three separate formulas but together make the base formulation for the nutrient line. The Grow, Micro & Bloom formulas are made to increase overall plant growth and health over

all stages of life. Grow, Micro & Bloom contains the primary nutrients nitrogen, phosphorus, and potassium, and other nutrient such as cobalt, copper, magnesium, molybdenum, manganese, iron, and zinc. The Emerald Goddess formula is a supplement made to increase harvest potential. The King Kola formula contains high amounts of phosphorus and potassium, and also contains nitrogen derived from hemp. King Kola is bloom booster made to increase the size of buds and decrease the time to produce buds. The Honey Chome formula is all natural and uses terpene to increase the natural smell and flavor of flowers. Honey Chome also helps to improve the condition of plant roots. The Root Wizard formula is an additive to improve root health in plants in order for plants to better absorb nutrients. Root Wizard functions by increasing bioactivity by the roots and breaking down organic matter into bioavailable nutrients. The Cal-Mag formula is a supplement made specifically to combat calcium and magnesium deficiency, which can lead to things like chlorosis. The Sturdy Stalk formula is a supplement made to strengthen roots, stems, and branches which lead to better plant health overall. The main ingredient of the Sturdy Stalk formula is potassium silicate.

General Organics BioThrice

The General Organics brand, BioThrice nutrient package has the Grow, Bloom, CaMg+, BioRoot, BioWeed, BioBud, BioMarine, and Diamond Black formulas. The Grow formula is made of vegan plant and mineral extracts in order to increase vegetative growth and microbial life. The Bloom formula is made to increase the size and improve the taste of flowers. The CaMg+ formula is an additive to provide calcium and magnesium. The calcium and magnesium of CaMg+ is derived from dolomite lime, oyster shell, and other natural plant extracts. The BioRoot formula contains a variety of organic humic acids, enzymes, and vitamins. BioRoot works to stimulate root growth in order to increase root density, root mass, and to improve root health. The BioWeed formula, with seaweed as its primary ingredient, is made to encourage root and foliage growth, increase plant and soil health, and decrease plant stress. The BioBud formula is made to be used during the flowering phase of the plant life cycle. BioBud improves overall flower development by enhancing bud production. The BioMarine formula contains high amounts of protein and polysaccharide. As a natural, organic fish fertilizer, BioMarine functions to increase the growth of plants and decrease the amount of time the plant takes to grow. The Diamond Black formula is a plant supplement that contains high amounts of plant humates. The purpose of the Diamond Black formula is to increase nutrient uptake, increase nutrient retention, encourage soil retention, and stimulate microbial activity. Even though organic nutrients are preferred for many growers and tend to lead to cleaner flower and richer tastes and smells, these will not be used in system. The reason is that organic nutrients are usually thicker and clumpier and have a much greater potential to clog our hydroponics system.

Hydroponic Nutrient Packages

In the same way that there are plant nutrients that are made for soil growers and organic growers, there are also plant nutrients that made for hydroponic growers. Some recommended plant nutrient brands for hydroponic systems are the Cultured

Solutions brand, Premium Hydroponic nutrient package, the Botanicare brand, Pure Blend Pro Hydro nutrient package, and the House and Garden brand, Hydroponic nutrient package. The Cultured Solutions brand, Premium Hydroponic nutrient package contains the Veg A & B, Bloom A & B, UC Roots, Coco Cal, Bud Booster Early, Bud Booster Mid, and Bud Booster Late formulas. The Veg A & B formulas are pH balanced and contain various macronutrients and micronutrients in order to boost plant growth. The Veg A & B formulas are designed to be used in different ratios through the plant's growth cycle. The Bloom A & B formulas are mineral based nutrients. Supplied with a feeding chart, the Bloom A & B formulas are made to optimize flower growth. The UC Roots formula is an additive that helps to prevent contaminants and deposits in the system. The UC Roots formula also improves nutrient uptake and oxygen availability which lead to conditions for better growth. The Coco Cal formula has concentrated calcium and magnesium. The concentrated calcium and magnesium promote plant growth and prevent calcium and magnesium deficiencies. The Bud Booster Early formula is used to develop buds. Bud Booster Early does this with nitrogen and magnesium as its main ingredients. The Bud Booster Mid formula contains potassium, magnesium, sulfur, and phosphorus. Designed to be used further into flower development than Bud Booster Early, Bud Booster Mid aids the flower in producing complex starches and sugars. The Bud Booster Late formula is designed for the end of the flowering cycle to help flowers ripen. Bud Booster Late is formulated in powder form with pure nutrients.

Botanicare Pure Blend Pro Hydro

The Botanicare brand, Pure Blend Pro Hydro nutrient package contains the Pure Blend Pro Grow, Pure Blend Pro Bloom Hydroponic, Rhizo Blast, Liquid Karma, Cal Mag Plus, Silica Blast, Sweet, and Hydroplex Bloom Enhancer formulas. The Pure Blend Pro Grow formula is made to optimize vegetative growth through a veg base formula. The Pure Blend Pro Grow formula contains exclusively natural sources of macronutrients, secondary nutrients, and micronutrients. The Pure Blend Pro Bloom Hydroponic formula is designed to optimize flowering and increase bud size and density. The Rhizo Blast formula is the same Rhizo Blast in the Pure Blend Pro Soil line. Rhizo Blast contains a blend of minerals, amino acids, vitamins, single cell algae, and seaweed in order to develop a plant's root system. The Liquid Karma blend is also a nutrient formula from the Pure Blend Pro Soil line. Liquid Karma helps to stimulate various plant functions and contains metabolically active and organic ingredients. The Cal Mag Plus formula is additive to prevent calcium and magnesium deficiency which also contains iron and other trace elements to improve overall plant health. The Silica Blast formula is designed to be used in the early stages of plant development in order to support heavy flowers later in life. The Sweet formula contains organic acids, carbohydrates, and trace minerals and vitamins for the purpose of improving plant flavor. The Hydroplex Bloom Enhancer formula is a nutrient supplement which works to help buds reach their full potential. Hydroplex Bloom Enhancer is made up of not only phosphorus and potassium, but also a variety of other vitamins, minerals, and amino acids.

House and Garden Hydroponic Nutrient Package

The House and Garden brand, Hydroponic nutrient package contains the Aqua Flakes A & B formulas, the Root Excelurator Silver formula, the Multi Zen formula, the Algen Extract formula, the Amino Treatment formula, the Nitrogen Boost formula, the Bud XL formula, the Top Shooter formula, the Top Booster formula, the pH Stabilizer formula, the Magic Green formula, and the Rhizo Force formula. The Aqua Flakes A & B formulas are the base formulas for the nutrient line and use fully soluble nutrients to improve overall plant growth and health. The Root Excelurator Silver formula is able to be used at all stages of a plant's life cycle. The Root Excelurator Silver formula encourages faster rootings and overall root growth and health. The Multi Zen formula is a supplement made to increase plant growth and speed of growth. The Algen Extract formula is designed to help a plant's roots develop. The Algen Extract formula is made using cold press technology and is made up of a Norwegian Kelp blend. The Amino Treatment formula with its various amino acids helps to strengthen a plant and prepare it for flowering. The Nitrogen Boost formula is a supplement for vegging plants. Nitrogen Boost contains a large amount of nitrogen in order to encourage leafy growth and branching. The Bud XL formula is designed to improve yield at the end of a plant's growth cycle. The Top Shooter formula contains potassium and phosphorus to enhance flower growth. Top Shooter is unique in that it is available in liquid and powder forms. The Top Booster formula also has potassium and phosphorus as its main ingredient and is used to maximize plant growth potential. The pH Stabilizer formula is designed for what its name states, to help maintain a balanced pH in the hydroponics system. The Magic Green formula is additive that does not go directly into the water of the hydroponics system but is to be used as a foliar spray. Magic Green is designed to increase plant vigor and optimize flowering. The Rhizo Force formula is designed for hydroponic mediums. Working as a slow-release, granular additive, Rhizo Force adds essential ingredients to recycled and work hydroponics mediums in order to improve conditions for growing.

Final Considerations for Nutrient package

The decision for the plant nutrient formula is primarily from the kind of plant we grow. Since we have already decided on arugula, it best to choose a formula for arugula. Arugula grows best with nitrogen focused nutrients, ideally a mixture of calcium nitrate, magnesium sulfate, and nitrogen-phosphorus-potassium. One option is to buy these ingredients individually then mix and dilute them with water, another option is to buy a powder fertilizer, and a third option is to buy a liquid fertilizer. The main factor in this decision is cost and convenience. For the purposes of this project, making a custom fertilizer from scratch would not be ideal short term. Regarding powder and liquid fertilizers, both would require dilution with water because they heavily concentrated, so a water-soluble powder fertilizer and a liquid fertilizer work out the same practically. Based off of previous research it was decided to go with General Hydroponics brand, MaxiGro formula, which is a nutrient formula that is dry and water-soluble. Currently, a 2.2lb bag costs $15.99 on Amazon.

3.7 PCB

The PCB for this project will be heavily influenced by the Arduino MEGA 2560. We will borrow all necessary components and pins from the open-source documents and add our own I/O as required. We plan to integrate power management, sensor I/O, as well as relay control all on one board. The sub-sections of 3.8 will cover the parts we considered and eventually decided to move forward with.

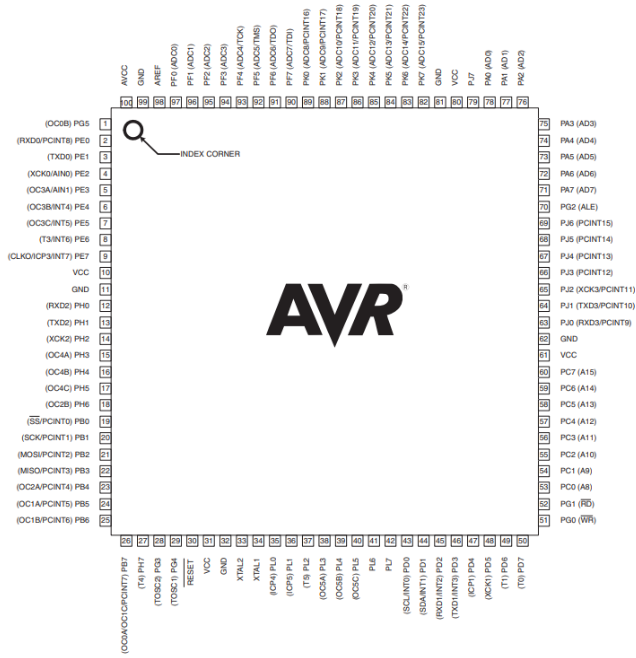
3.7.1 Microprocessor

The hydro garden project will require a lot of I/O to support our sensor array along with an 8-bit lcd display screen and various other relayed devices. The increased memory size was crucial to accommodate a relatively large amount of code to drive all of the devices and run different timers at once. In the early testing phase with half of the devices connected the code was already larger than 40KB. We knew right away that we were going to need the Atmega2560 Microprocessor from Microchip Technology but in the spirit of compare and contrast here are a few notable mentions. **Table 12** displays specifications regarding the microprocessors considered. Whereas **Figure 12** shows the Atmega2560 pin layout.

Table 12: Microcontroller comparisons

Microprocessor	**Atmega2560**	**Atmega328P**	**PIC24FJ256GB412**
Pin Count	100	32	121
Type	RISC	RISC	N/A
Interface	8-bit	8-bit	16-bit
CPU Speed	16MHz	16MHz	32MHz
Memory Size	256KB	32KB	256KB
Communication	4-UART, 5-SPI, 1-I2C	2- UART, 2-SPI, 1-I2C	6-UART, 4-SPI, 3-I2C
Timers	2x8-bit, 4x16-bit	2x8-bit, 1x16-bit	31x16-bit, 15x32-bit
Comparators	1	1	3
Operating Temp	-40 to 85 C	-40 to 85 C	-40 to 85 C
Operating Voltage	1.8-5.5V	1.8-5.5V	2-3.6V

Figure 12: Atmega2560 Microprocessor Pin Layout



The sensors and components of hardware that were chosen need a control unit in order for everything to work how it is needed for the system. There are many types of control units or microcontrollers that can achieve this job, but the goal is to find the control unit that not only fits the requirements needed, but also doing this while not being underutilized. Knowing that a control unit was needed, a deep dive into the different types of microcontrollers to find out which microcontrollers would not only properly fit our needs but also needs to be something that contains the comfortability needed to get through the design process of this smoothly.

Texas Instrument MSP430

The TI MSP430 was the first control unit that was researched. This is a control unit that the group has a lot of prior knowledge on due to the experience with programming and setting up this board. It also contains the option to be expanded with an LCD screen and Analog sticks. The specifications of the Microcontroller are, a CPU Frequency of 25MHz, Memory of 512 KB, and its form of communication is serial. This could be a board that is considered just because of the comfortability that the group has with the board. The problem with this board is that it could be overpowering for the design.

Raspberry Pi 4

The Raspberry Pi series is a well-known series of microcontrollers, so it is no surprise that the Raspberry Pi 4 is also being considered. The group doesn't have any prior knowledge to this board, but it is a board that contains a lot of power for sure. It has a CPU frequency of 1.5 GHz, and 2 GB of RAM. It also contains a 40 pin GPIO header, and It doesn't seem like it contains UART communication. After looking at the specs of this microcontroller, it was decided that this microcontroller may be too powerful to go with, but it may still be considered as a last resort.

Quark D2000
The Quark D200 board is a microcontroller board created by Intel and is well known for being a product of this reputable company. It is also one of the boards that is being considered for the project. It has a CPU frequency of 32 MHz and has an integrated flash memory of 32 KB and an 8 KB SRAM. This one also highlights its 8 KB cache that could possibly come in handy. One of the downsides of choosing this is it comes with certain software system studios that would only work for this board, and none of the group members have previous knowledge on this code composing studio. For this reason, it is highly unlikely that this microcontroller gets considered due to the time constraint on the project. It also contains a lot of features that will most likely not get used within the hydroponics system so this microcontroller may not get considered.

Arduino Mega 2560 R3
The Arduino Mega 2560 R3 is the next board that was researched. This microcontroller board is also a board that the group has a lot of prior knowledge on as well, but it is not as much as the TI MSP 430. This board also contains an Atmel Atmega328 microcontroller chip which will be very helpful when it comes to the final design of the hydroponics system. It can communicate with other devices as well via using Universal Synchronous and Asynchronous serial receiver and transmitter. This can be very helpful to the group as they are developing and creating prototypes. The specifications of the board are, a CPU Frequency of 16 MHz, 32KB of flash memory and 2 KB of RAM. This board could be used, and it doesn't use too much power so if chosen, the capabilities wouldn't feel wasted.

BeagleBone Black
The BeagleBone Black is known well for being one of the cheapest development boards available. It is also known for how easy it is to use and because of these two reasons, it is being considered. It has 512 MB of RAM with 4 GB of Flash storage. It also highlights its high number of I/O pins which makes it a good choice for the electronics project that we are working on. Its CPU frequency is 1 GHz, making it a very powerful, cheap microcontroller. This may not be considered because it may have too many pin inputs that are not going to be used for the system, and the high CPU frequency will eventually become a waste because it is not going to be used to its full capability.

After comparing the different specifications of the microcontrollers in **Table 15**, the group chose to go with the Arduino Mega 2560 This board doesn't contain a lot of I/O pins, but because of this project not requiring a lot of power from the board to create, and it not needing a lot of pins for us to create, this will be the microcontroller that we move forward. Its specifications and price match the needs of the hydroponics system and the clock speed is going to be fast enough for the group, although it has the lowest CPU frequency of the microcontrollers. The microcontroller being one that the group has a lot of prior knowledge on played a key part as well. Due to the time constraints given, there just is not a lot of time to play with and learn a completely new system, while calibrating the sensors and parts. The final thing that played a big part is the Atmel Atmega328, which is exactly what the Arduino Mega 2560 is based on. This will make it a far easier process as the group translates from a prototype design to the final design of the hydroponics system, because the group will have already been working with the microcontroller chip through the microcontroller board.

Table 13: Microcontroller Choices

Microcontroller Board	Texas Instrument MSP430	Raspberry Pi 4	Quark D2000	Arduino Mega 2560 R3	Beagle Bone Black
CPU Frequency	25 MHz	1.5 GHz	32 MHz	16 MHz	1 GHz
Memory	512 MB	2, 4, or 8 GB of RAM	32 KB flash memory and 8 KB SRAM	256 KB of flash memory, 8 KB SRAM	512 MB RAM
Communication	Serial	I2C, SPI, UART	UART	UART, SPI, TWI	UART, I2C
Price	$23.50	Starting at $35	$100	$40.30	$89.99
Other Features	Low power consumption	Integrated 802.11 ac/n wireless LAN	Ultra-low power Intel	54 digital I/O pins	4 GB on board flash storage

3.7.2 Wi-Fi and Bluetooth Module

For this automated WIFI hydro-garden one of the key features needed is for it to have Wi-Fi/Bluetooth capabilities because the garden is going to work closely with the app and the user needs to be able to access this at any place, at any time. For this to work the hydro-garden must be able to connect to Wi-Fi, and on top of this It must be able to send the information receive from the garden to the app via Wi-

Fi. It must also be able to transfer data to the cloud at a fast enough speed that would be acceptable to the user. To do this, the plan is to use a Wi-Fi and Bluetooth Module which can give most microcontrollers access to a Wi-Fi network, giving the users the ability to connect directly to their garden system.

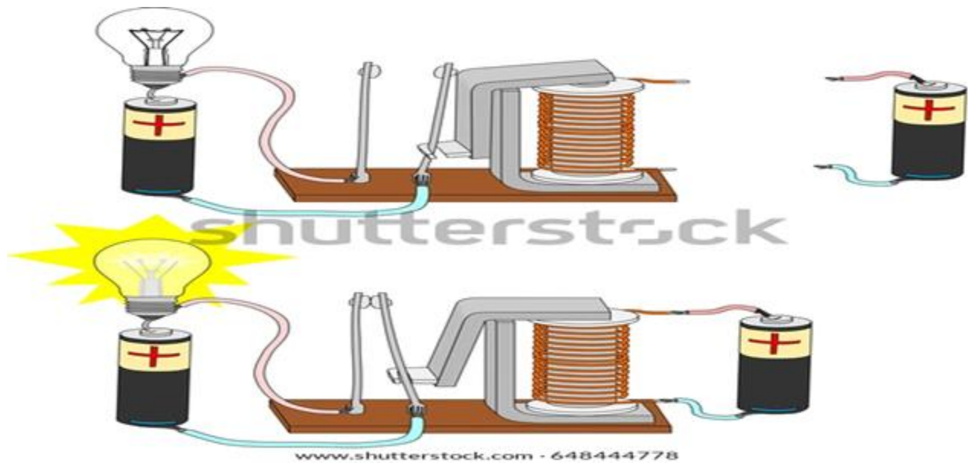
The Wi-Fi Module that we are considering must be able to connect to Wi-Fi signals using the ESP32, which is for task such as voice encoding, music streaming and MP3 decoding. This should be just fine for the Bluetooth module as we are not streaming or doing any voice encoding or MP3 decoding. The Wi-Fi modules that are currently being considered are ESP32 Wi-Fi-BT-BLE MCU Module / ESP-WROOM-32 that is being sold on adafruit.com for $8.95 and HiLetgo ESP-WROOM-32 ESP32 ESP-32S Development Board 2.4GHz Dual-Mode Wi-Fi + Bluetooth Dual Cores Microcontroller Processor Integrated with Antenna RF AMP Filter AP STA for Arduino IDE being sold on amazon.com for 10.99. The part that is being chosen is the HiLetgo ESP-WROOM-32 ESP32 ESP-32S Development Board 2.4GHz Dual-Mode Wi-Fi + Bluetooth Dual Cores Microcontroller Processor Integrated with Antenna RF AMP Filter AP STA for Arduino IDE because of its availability and ability to receive the part as soon as possible.

3.7.3 Relays

Relays are electrically operated switches. They are used when multiple circuits are controlled by one signal, or a circuit is controlled by a low-power signal. Relays prevent the combination of the controlling and controlled circuits. Relays typically have a primary and secondary side. The primary side contains the controlling circuit, and the secondary side contains the controlled circuit. There are three main types of relays, electromechanical, solid state, and reed.

Electromechanical relays are made with electrical, mechanical, and magnetic components. The primary side usually has a coil which is connected to a DC source and some kind of switch or sensor. The secondary side has an armature which is connected to a moveable contactor. When the primary side through the switch or sensor is connected, the current flow through the coil produces an electromagnetic field which attracts the armature. The movement of the armature connects or disconnects the moveable contactor which toggles the state of the secondary side. Two basic kinds of electromechanical relays are normally open and normally closed. In the normally open type, the secondary circuit is normally open, therefore the load, the device that consumes energy, is off. When current goes through the primary circuit then the electromagnetic field attracts the armature which closes the secondary circuit and turns on the load. The mechanisms of a relay are depicted in **Figure 13**.

Figure 13: Normally Open Electromechanical Relay



In the normally closed type, the secondary circuit is normally closed, therefore the load is on because current is flowing through the secondary circuit. When current goes through the primary circuit then electromagnetic field attracts the armature which opens the secondary circuit and turns off the load. Another classification of electromagnetic relays is between non-latching and latching. The previous examples were examples of non-latching relays. In a non-latching relay, the secondary is constructed in such a way that it maintains its initial state, whether normally open or normally closed, when no current is flowing, and maintains its opposite state when current is flowing in the primary circuit. In a latching relay, the secondary circuit is constructed in such a way that it maintains its open or closed condition even the primary circuit is turned back off. It will maintain its condition until another inverting input. A latching relay enables the device to have positional "memory."

Another classification of electromechanical relays is between single pole and double pole. Poles are the number of contacts toggled when current goes through the primary circuit. Poles are essentially the number of secondary circuits controlled by a single primary circuit. Therefore, in a single pole electromechanical relay one primary circuit controls one secondary circuit. In a double pole electromechanical relay one primary circuit controls two or more secondary circuits. Within the double pole classification there are single throw and double throw relays. The number of throws refers to the number of connection points. In a single throw relay, there are two loads but there is a single connector from the armature which toggles between the two loads when the primary circuit is toggled. In a double throw relay, there are potentially four loads because there two connectors from the armature which individually toggle between two loads.

Solid state relays have the same function as electromechanical relays but perform without moving parts and various electronic components. On the primary side of a solid state relay is usually a DC source and a Light Emitting Diode (LED) instead of a coil. On the secondary side of a solid state relay is a phototransistor instead of an armature and moveable connector. The switch, sensor, or whatever means used to allow current to flow through the primary side turns the LED on which shines light across a gap and into the phototransistor. The phototransistor on the secondary side does not allow current to flow through it unless exposed to light. When exposed to light, the semiconductor technology in the phototransistor enables current flow through the secondary circuit and turns on the load. A reed relay does not have an armature, rather a “reed” which is a switch with magnetic strips sealed in a glass tube which moves due to a magnetic field. The magnetic field causes the reed to move in such a way that the switch connects.

Some advantages of the electromechanical relay are that it is cost-effective, structurally reliable, not susceptible to external electromagnetic influence, able to carry high voltage and current load. The disadvantages of electromechanical relays are that they are usually slower than other relays, are not suitable for small projects, and suffer from mechanical wear. Some advantages of solid state relays are that it has a relatively fast switching speed, it operates almost silently, and no risk of sparking or physical shock. The disadvantages of solid state relays are that it is high in cost and needs a fan because it generates relatively more heat. The advantages of reed relays are that it switches fast, is affected very little by temperature, humidity, and other environmental factors, and has low power consumption. The disadvantages of reed relays include low load voltage and current, and that it is susceptible to inductive loads.

In selecting the relay module for the final product, we decided to use the 5 V ELEGOO 8 Channel relay module to integrate switching for the peristaltic pumps, fans, and lights.

3.8 Power Delivery

For the garden systems’ power supply, the goal is for the system to be able to be plugged in and used and a magnitude of different homes without much replacement to keep everything within the system as simple to use as possible. The system isn’t going to be moved a lot and is not meant to be a portable system. With this being said, to destroy the hassle of having to replace batteries often, it is a smart choice to go with power supply from a wall outlet. The power that is available within a wall-socket in the United States (which is the area that this system will be tested in) is a 120-volt, 60 cycle Alternating Current power (AC). Although, this is well over the voltage needed within the system, This is still highly advantageous over Direct Current power (DC) due to the versatility that is provided within AC power. AC power can be manipulated to get the exact needed power for the for the hydroponic system but in order to have power translate through the system and get the needed power for the system a AC-DC Adapter will be needed. An AC-DC Adapter contains transformers that are able to change the voltage rectifier with the wall outlet to convert to DC power. The adapter should allow the voltage to go down to a range of 9V to 12V which will likely have to be stepped down cause other electrical components contain a rail voltage of 3.3V or 5V depending on the what the electrical component is.

AC/DC adapters are going to be used to convert power from a wall outlet in a home, or any area that the hydroponic system is being used. There are a total of 4 AC/DC adapters chosen for analyzation and consideration of being used for the system. All three of them contain barrel connectors but the differences between them lie within the Amperes and voltage that they contain. In order for an AC/DC adapter to even be considered it must fall in between the range of 9V to 12V since the input voltage of electronics must match the rated input voltage. Out of the requirements that are needed for the system the three parts in **Table 13** below are the parts that were being considered.

Table 14: Power Supply Choices

Manufacturers	DC Voltage Output	Current	Connector Size	Cost	Cord Length
XINKAITE	12 V	2 A	5.5 x 2.1 mm	$8.99	3.3Ft/ 1M
Corporate Computer	9 V	1 A	5.5 x 2.1 mm	$6.99	3.3Ft/1M
ALED Light	12 V	2 A	5.5 x 2.1 mm	$8.89	3.9Ft/1.2M
LitStar	9 V	1.5 A	5.5 x 2.1 mm	$8.99	10Ft/3M

After more research it was decided that an AC/DC adapter with a higher current is needed everything to be powered properly within the system. This resulted in more AC/DC adapters being investigated for the project. None of the AC/DC adapters in the tables above are being considered anymore. We finally decided on an ALITOVE AC/DC adapter with 12 V voltage output, 5 A current output at a cost of $11.99

3.9 Display

Not only will the data collected from the various sensors be displayed on the app, but also on a display screen. This a matter of convenience, for example, if the user's wi-fi goes out, or if they leave their phone in a different room, they will still be able to check the status of their hydroponics system. The screen will display relevant data while also notifying the user if something is out of range. It is preferred that all of the values will be displayed at the same time.

There are different kinds of screens that can be used as a display. Some examples are OLEDs, QLEDs and LCDs. Organic light emitting diodes, or OLEDs, are light emitting diodes where the light is produced by organic molecules, which include things like sugar, gasoline, alcohol, wood, and plastics. A simple OLED is made up of six layers. The bottom layer is substrate, the next layer up is an anode or positive terminal. The next layer up is the conductive layer, followed by the emissive layer, where light is produced. The next layer up is the cathode or negative terminal, followed by the seal on top. In order to light an OLED, a potential difference, or voltage is applied across the anode and cathode. Current flow leads to the emissive layer being negatively charged, and the conductive layer being positively charged. When positive holes jump across from the conductive layer to the emissive layer and meet a negative electron, a burst of energy in the form of a photon, or a particle of light, is released. As long as current is flowing, the process continues and repeats, producing continuous light.

Quantum light emitting diodes, or QLEDs, are actually more similar to LCDs than OLEDs. As an example, the typical LED television uses an LED backlight with a colored LCD layer on top. The backlight shines out toward the viewers while the filter determines which colors are displayed for each pixel. For QLED televisions, the LCD layer is the same, but the backlight is changed to more pure colors by a film of quantum dots before the LCD layer. Quantum dots are lab made fluorescent particles which are only a few nanometers in diameter, and it is the size of the particle which determines the color, with larger dots leading to red and smaller dots leading to blue.

Liquid crystal displays, or LCDs, are displays which primarily operate using liquid crystals and are commonly found in smartphones and computer monitors. LCDs, like most if not all kinds of displays, use millions of pixels to make up the whole display. A pixel is simply a sub area of illumination on a display screen. These pixels are made up of subpixels, commonly categorized as red, blue, and green. It is a combination of subpixels which determine the color the pixel, and the combination of the pixels makes the image. LCDs are lit by a backlight while the pixels are rapidly and electronically switched on and off. During this process the liquid crystals are used to rotate polarized light, and filter are used to make them visible to the human eye. There are various types of liquid crystal displays, including but not limited to twisted nematic, in panel switching, vertical alignment panels, and advanced fringe field switching. In comparison to the other types of LCDs twisted nematic (TN) LCDs are inexpensive and have high response times, but they have low contrast ratios, viewing angles and color contrasts. In panel switching (IPS) displays, relative to twisted nematic displays, have much better contrast rations, viewing angles, and color contrast. Vertical alignment panels (VA) are seen as higher quality than twisted nematic, but lower quality than in panel switching displays. Advanced fringe field switching (AFFS) is viewed as the best type, being a top performed compared to in panel switching in color reproduction range.

A question that can be raised regarding displays is where they get the data from. The data can come from many different sources, but a matter of potentially greater importance is how that data is exchanged. Data is exchanged to a display by means of a display interface, and interface is a shared boundary across which two separate components of a computer system exchange information, it is a facilitator of communication between two or more objects. There are different kinds of interfaces including serial peripheral interface, inter-integrated circuit, red green blue, low-voltage differential signaling, and mobile industry processor interface. Developed by Motorola, serial peripheral interface (SPI) was made for short distances. It works with no protocol overhead, one master, or side that generates the clock, and one or more slaves, or other devices. Compared to other means, serial peripheral interface is easy to setup, is faster than inter-integrated circuit, and has bandwidth capabilities up to about 10mb/sec. However, serial peripheral interface may require many pins because for each slave device adds, an additional chip select I/O pin on the master is necessary. Overall, serial peripheral interface is a good option for smaller LCDs and low-resolution displays.

Invented by Philips Semiconductors, inter-integrated circuit (I2C) was made for short distances, being applied to displayed after keyboards and mice. Inter-integrated circuit works with a multiple master, multiple slave, single ended, serial computer bus system. Unlike serial peripheral interface, inter-integrated circuit can support up to 1008 slaves using only two wires, a serial clock, and serial data. Some other benefits are that I2C can handle a broad range of temperatures, it is easy to use and troubleshoot, it consumes a low amount of energy, and it has bandwidth capabilities up to 1 MB/sec.

Red green blue (RGB) interface is used to interface with large color displays. It works by sending 8 bits of data for each color every clock cycle. Given this large amount of data transmission, RGB can be used to display video frame rates above 60Hz. Some other benefits besides its high performance is that RGB is now low cost, has bandwidth capabilities up 1.2 GB/sec, and contrary to serial peripheral interface and inter-integrated circuit, RGB works with medium to large displays. However, RGB requires many pins, up to 29, with expensive connectors, and edges on wires can create electrical noise.

Developed in 1994, low-voltage differential signaling (LVDS) was made for large LCDs and peripherals, like high-definition graphics, which need high bandwidth. It includes an even pair of wires, a carrying clock and ground wires. LVDS works with two wires carrying the signal, and one wire carrying the inverse of its companion. Interference with nearby wireless systems is decreased by the electric field generated by one of the wires. At the receiving end, the circuit reads the difference between the wires in voltage, by this process noise is not generated. This process is done with 24-bit color information, which from the transmitter end is converted to serial, transmitted over the pairs of cables, then converted back to 24-bit parallel in the receiver. This interface is ideal for systems that also has wireless transmitters so that interference is avoided, LVDS also works for larger displays and has bandwidth capabilities up to 3.125 GB/s. Managed by the MIPI Alliance, mobile industry processor interface (MIPI) was made for mobile and wearable technology. It works with a clock pair and an even pair of data called lanes. Given that MIPI supports a complex protocol, MIPI can function at high speeds and low power modes and read data at lower rates. Though the complex protocol enables unique functions, it is a disadvantage, another disadvantage is that it was initially on cellphone displays and it needs a particular board layout to work at high speeds.

With these interfaces, they do not only bring data from a source to the display screen, but they can also transmit data from the display to a different receiver. A common means that a display transmits data is through a touch screen, particularly a thin film transistor (TFT) screen. Thin film transistor screens are a combination of a type of LCD display and touch technology overlay. This is what enables a TFT screen to both display and act as an interface. TFT screens, as seen in **Figure 14**, are in all kinds of technology, like computer monitors, high-definition televisions, and smartphones. TFT screens contain millions of pixels and it works by controlling red, green, and blue subpixels by means of transistors, and a backlight is used for illumination. The touch features are enabled through the touch screen overlay. There are two methods that these screens use to register touch interaction. One method is the resistive method which reads pressure by measuring variations in the potential difference caused by finger or stylus pressure on the screen. Another method is the capacitive method, which reads touch by measuring current interruption.

Figure 14: LCD with TFT

As stated earlier, the purpose of the screen is not to feed any data back, but just to display data. The screen of choice needs to be large enough, a picture that is clear enough, and comes at a low cost. Speed of data transmission is not much of a factor given the screen's function. One unique factor, given that we plan to use an Arduino microcontroller, is that the screen should be compatible with it. There are three options that will be considered, the SunFounder I2C TWI 1602 Serial LCD Module Display, the ELEGOO UNO R3 TFT Touch Screen, and the Adafruit 1947 Touch Shield TFT. The SunFounder I2C TWI 1602 Serial LCD Module Display is a 16x2 LCD, works at 5V, is compatible with Arduino and costs $8.99. The ELEGOO UNO R3 is a 2.8-inch TFT touch screen, works at 5V, is compatible with Arduino and costs $14.99. The Adafruit 1947 Touch Shield is a 2.8-inch TFT touch screen, works at 3.3V, is compatible with Arduino, and costs $44.95. A comparison of products considered is listed in **Table 17.**

Table 15: Display Comparison

	SunFounder 1602	ELEGOO UNO R3	Adafruit 1947
Size	16x2	2.8''	2.8''
Working Voltage	5 V	5 V	3.3 V
Arduino Compatible?	Yes	Yes	Yes
Cost	$8.99	$14.99	$44.95

When selecting a display, the SunFounder is too small to display all the data we desire to display at one time. Arduino compatibility is not a factor because all of the devices are Arduino compatible. The Adafruit 1947 having a lower working voltage of 3.3V compared to 5V for the ELEGOO UNO R3 can be advantageous, but not an advantage worth an extra $40. Therefore, we selected the ELEGOO UNO R3. However, in our final design we had chosen not to use a display screen and only display data via the mobile app, the display screen was only used for testing.

3.10 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 a container of approximately 5 gallons. For the size and scope of our project we will go with an aquarium or fountain pump that is variable in speed to fine tune the flow rate for our plants.

The first pump we looked at was from the company GROWNEER. It was a relatively powerful pump with a 30W motor and 550 GPH (gallons per hour) flow rate. This pump is intended for larger scale fountains, waterfalls, and hydroponic systems. The power was appealing but after further consideration we decided it was more pump than we needed and it would not fit inside the opening of the water container to fully submerge which would force us to find another storage container. This pump was $19.99 from amazon.com at the time of this research paper.

Instead, we selected a pump from PULACO. This was a much smaller pump with a 5W motor and 95 GPH flow rating used for small to medium fish tanks. This pump was much cheaper at $11.99 on amazon.com. This smaller pump would be more appropriate for our needs of watering only 12 plants. 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. The specifications are listed in **Table 18**.

Table 16: Main Water Pump Specifications

Manufacturer	**PULACO**
Dimensions	1.8”x1.8”x1.4”
Max Flow Rate (Max-Q)	95 GPH
Power	5W
Max Lift	3’

3.10.1 Peristaltic Pumps

Our grow system will have the ability to dose the main water tank with three different chemical solutions to control the pH balance of the water and to add nutrients for the plans. This will be done with three uniquely controlled peristaltic or dosing pumps. The storage containers for the chemicals will be 12-16oz so our pumps can be relatively small.

A quick search of peristaltic pumps will return either the very, very expensive all in one system with Wi-Fi integration and variable speed control some reaching over $600. That is definitely not a solution so we were left with various 12V stand-alone pumps from different companies, all seemingly the same except for color. We decided to go with one from the company Kamoer Fluid Tech mainly due to cost. At the time of research, it was only $9.50 for each pump on amazon.com. This was also a 12V DC pump with tube size of 3mm ID and 5mm OD. It has a variable flow rate of 5.2-90ml/min and only runs on 0.25A. Most likely only one pump will be running at any given time so this is perfect for our total system power management. The pump is marketed at labs, aquariums, and “bonsai irrigation”. The specifications are listed in **Table 18**.

Table 17: Peristaltic Pump Specifications

Model	**NKP-DC-S10B**
Pump Tube Type	Silica Gel Tube
Voltage	12V
Current	0.25A
Flow	5.2-90 ml/min
Pump Tube Size	3mm ID 5mm OD

3.10.2 Airstone

Similar to how animals need oxygen breath and function, plants need oxygen in order to function. The parts of a plant that do not photosynthesize like roots consume oxygen. In a hydroponics system in which the same water is used and recycled, like the Nutrient Film Technique (NFT) or Deep Water Culture (DWC), the plants can use up the oxygen in the water. If the plant does not have enough oxygen then the plant will drown and die. With that being said, our hydroponics system, which uses the Nutrient Film Technique needs a means to bring oxygen to the water. Three of those means are an airstone, a sponge filter, and a moving bed filter. An airstone, when connected to an air pump, creates small air bubbles in the water. A sponge filter uses air for mechanical and biological filtration. Waste is removed and water is cleared by the bubbles rising from the bottom to the top of the sponge. A moving bed filter is made for biological filtration, as air goes through the chamber, it causes a churning of oxygenated water which also helps bacteria grow. For the purposes of the hydroponic system, it was decided that an airstone would be used because biological filtration is not necessary. The only constraints in deciding on an airstone is to ensure that it can work with at least 10 gallons of water, the amount of water in the reservoir, and is cost effective. 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. The product currently costs $9.99 on Amazon. The specifications for this product are listed in **Table 20**.

Table 18: Airstone Specifications

	HITOP Single Outlet Aquarium Air Pump
Pump Dimensions	3.5 x 2 x 1.6 in
Tube Length	~ 35.5 in
Power	2 W
Max Tank Size	15 Gallons
Air Output	1.5 L/min

3.11 Grow Structure

There were two different options for the frame of our grow tent. The first and easiest one is to just buy. The best-looking tent on Amazon was from a company called VIVOSUN. They sell a model that is 48”x48”x80”, this is the approximate size we are going for. This tent is made of a thin metal pole frame wrapped in an opaque canvas and lined with a Mylar reflective material for better light efficiency. It featured multiple zipper access ports to include air vitalization and view port. At the time of writing this paper, it was selling for $155.99 on amazon.com.

A similar tent from a company called HORTIPOTS was only $69.95 on amazon.com. It was exactly the same size as the tent from VIVOSUN with a similar build but wrapped in a breathable mesh fabric with a silver interior. The price was very appealing on this unit but it seemed less efficient than the VIVOSUN tent. Still though, it was lacking in terms of mobility and a place to separate our electronics and chemicals from the grow chamber. This led us to the second option, to build our own.

I wanted our tent to be strong so we decided to build out of 1/8” steel square tubing and angle iron to be welded together. We will keep the size to no more than 24”x36”x72”, that is all that is necessary for this project. We would use plywood as an opaque barrier and either white paint or a reflective material for greater light efficiency. For mobility we could use swivel caster wheels welded or bolted to the bottom of the frame. Please see section 5.4 Grow Enclosure Design for final details on the grow tent. Below is a table that details the general steel pieces needed to start the frame and structure of the grow area.

Figure 15: Raw Material for Grow Structure

Table 19: Grow Structure Material List

Product	Thickness	Quantity	Length	Unit Price	Total

Steel Square Tube	1/8 inch	3	144 inches	55.54	166.64
Hot Rolled Angle	1/8 inch	1	144 inches	34.28	34.28
Hot Rolled Angle	1/8 inch	1	120 inches	25.09	25.09
Caster Wheel	N/A	4	5 inches	7.5	29.99

3.12 Software

The software portion of the project will be broken into three different areas. The code for the microprocessor that controls the actions on the PCB, the cloud storage solution that will store retrievable data send from the PCB over Wi-Fi, and finally there will be an iOS app written for our iPhones that will have the ability to retrieve the cloud data and display for the user. The following subsections of 3.7 will go into further detail on how we intend to achieve this.

3.12.1 Microprocessor Code

For the Wi-Fi Hydro Garden, we have chosen to model our PCB design and components around the Arduino MEGA 2560 board. This will allow us to utilize the Arduino IDE as there are many code examples to get us going in the right direction. The Arduino IDE uses a custom language that is very closely related to the C and C++ language. The key to utilizing the full range of sensors we intend to use is finding the correct libraries that are compatible with what we are using and, in some cases, defining our own.

A good example of finding the right libraries is with the 2.8-inch LCD display we have chosen. This is an 8-bit, 240x320 pixel display that requires initial orientation and starting point upon boot. This is all done in the Elegoo_TFTLCD.h header file. It allows me to define a color by inputting a 16-bit hexadecimal color code and use simple tft.println or tft.print functions to easily get a display output without defining pixel position. Because we are using the display in a custom way and the 2.8-inch display was never meant for the Arduino 2560 we had to redefine the analog and digital input pins. This display also has the ability to be used as a touch screen for button input, we may or may not use this feature in the future. Below is an example of how to implement the header files, setting custom pin inputs, and defining a few colors.

Figure 16: 2.8-inch TFT LCD Display Code

```
#include <SoftwareSerial.h> // Serial Commands
#include <HCSR04.h>         // Ultrasonic Sensor
#include <Elegoo_GFX.h>     // Core graphics library
#include <Elegoo_TFTLCD.h>  // Hardware-specific library

// The control pins for the LCD can be assigned to any digital or
// analog pins...but we'll use the analog pins as this allows us to
// double up the pins with the touch screen (see the TFT paint example).
#define LCD_CS A3 // Chip Select goes to Analog 3
#define LCD_CD A2 // Command/Data goes to Analog 2
#define LCD_WR A1 // LCD Write goes to Analog 1
#define LCD_RD A0 // LCD Read goes to Analog 0
#define LCD_RESET A4 // Can alternately just connect to Arduino's reset pin

// Assign human-readable names to some common 16-bit color values:
#define BLACK   0x0000
#define BLUE    0x001F
#define RED     0xF800
#define GREEN   0x07E0
#define CYAN    0x07FF
#define MAGENTA 0xF81F
#define YELLOW  0xFFE0
#define WHITE   0xFFFF
Elegoo_TFTLCD tft(LCD_CS, LCD_CD, LCD_WR, LCD_RD, LCD_RESET);
```

Other code considerations include custom analog inputs like the water level gauge that was intended to be used in fuel tanks. It’s simply a variable resistor on a float with an input and output line. This device was intended to work in a 12V automotive environment with a coil needle display gauge. The Arduino operates at a 5V max and has no library for this kind of input. To use the fuel sensor gauge, we set up a voltage divider circuit to measure the change in voltage between the fixed resistor and the variable resistor. Our sensor operates in the range of $0 - 193\Omega$. To get the most accurate reading we need the most voltage delta from the variable resistor which means the fixed resistor needed to be as small as possible. While they do make low ohm resistors with a high watt ratting, they are much more expensive. Instead, we went with a 100Ω resistor that could handle the load. This allowed us to get a voltage delta of 2.09V in practice with line loss and system draw taken into consideration using a 5V input. The Arduino Mega 2560 has a 10-bit analog to digital convertor ADC built into the board which will give us a reading from 0-1023. Because the output voltage will be between 2.85V and 4.94V we will get a reading from approximately 600-1023 from the ADC. To get a percent readout I used the following formula:

$$ADC_{\triangle} = ADC_{max} - ADC_{min}$$

$$Water\ Level = \frac{ADC_{max} - ADC_{value}}{ADC_{\triangle}} * 100$$

For every microcontroller there is a software environment which is used to program the device and make it work properly. To make sure that the microcontroller being chosen was the best one possible for the group’s needs, two software environments were researched. The two environments that were researched have differences within the environment and how the information is uploaded to the microcontroller. The two that were being researched are the Arduino Software (IDE) and the Code Composer Studio. The reason why these were the only two considered is because a lot of the microcontrollers were ruled out due to its capabilities being way too high for the task that is at hand. After those considerations were ruled out these were the only environments that could be used.

Arduino Software (IDE)
Arduino Software (IDE) is the programming software environment used specifically for Arduino products. This software is compatible with Mac OS and Linux, and the software is coded in C++ language, which will allow many more capabilities than just C. Since the Arduino Mega 2560 was chosen this is the software environment that the group will most likely go with. The group will have to learn some of the C++ elements as time progresses.

Code Composer Studio (CCS)
Code Composer Studio (CCS) is a software environment that was introduced to the group previously due to prior classes taken that require students to use the environment. This was a software environment that was going to be considered, but after it was found that Code Composer Studio was not compatible with Arduino Mega 2560, and that its capabilities don't expand beyond the use of C, the group decided not to use this software environment. A brief listing of the specifications of both software can be seen in **Table 16.**

Table 20: Software Environment Choices

Software Enviornment	Arduino Software (IDE)	Code Composer Studio (CCS)
Coding Language	C, C++	C
OS Compatibility	Windows, Mac OS, Linux	Windows, Mac OS, Linux
Board Compatibility	Arduino	Texas Instruments

Moving forward since the Arduino Mega 2560 was chosen as the microcontroller board the Software Environment that will be chosen is the Arduino Software (IDE). This seems to be the obvious answer since this board isn't compatible with any other environment, but as a backup and a last resorted, the TI instruments, such as the MSP 430 and the Code Composer Studio environment will be used if everything doesn't work properly during the use of the Arduino Environment.

3.12.2 Cloud Storage
One of the more interesting features of this project is the ability to connect to a cloud server over Wi-Fi and upload sensor data as well as pictures of the plants. There are so many options available for cloud storage but I needed to make sure we could execute. Some of the requirements our cloud server would have is the ability to store unique data from many different sensors into unique storage fields

as well as larger picture files from the camera. We would need some type of internet address to connect and send the data to like an IP or HTTP address. We would need a unique API key so that only our device could access this cloud and write data to it.

Our PCB will have an integrated ESP-8266 Wi-Fi module connected to the Atmega2560 over a serial bus. When we need to send data to the cloud, we will need to inteface with the ESP-8266 module using attention commands known at AT commands. Below are some examples of AT commands in our code so far.

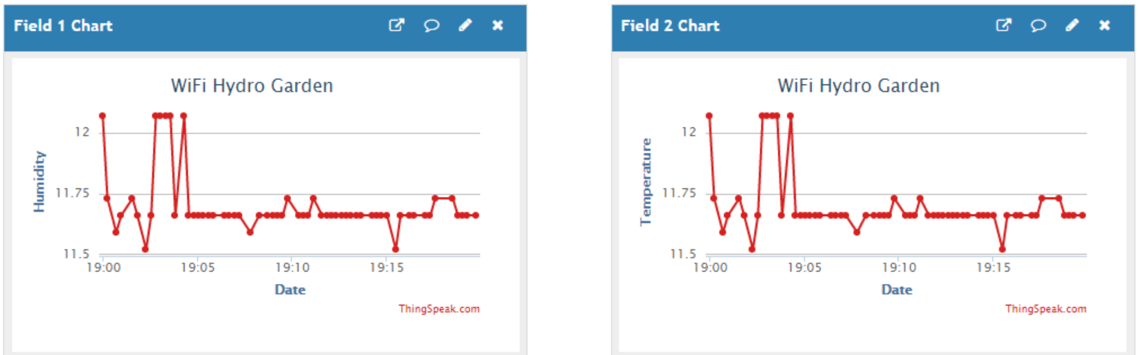
Figure 17: AT Commands for the ESP-8266

```
// TCP connection
String cmd = "AT+CIPSTART=\"TCP\",\"";
cmd += "184.106.153.149"; // api.thingspeak.com
cmd += "\",80";
ser.println(cmd);
if(ser.find("Error")){
  Serial.println("AT+CIPSTART error");
  return;
}
```

The most ideal way to store data would be to create a server on a separate Linux machine so that we could control all aspects of the memory allocation, storage, and retrieval. The learning curve on this one is much steeper though. This section alone could be the majority of Computer Science Senior Design course. There are opensource software packages in Linux like ZFS, which is a file system software, that could help me with this. Other options are a Windows based servers like Windows Server 2020. Most Linux based software including their sever software is open source and free which is much more appealing. Docker is a Linux Ubuntu based super server that creates many virtual instances of different operating systems, each of which could run its own server.

A quick and easy way to upload sensor data to the cloud can be done at thingspeak.com. Their services revolve around the IoT world. Your data can be analyzed with MATLAB or just viewed on a line graph like the test data below. The two charts are intended to show humidity and temperature of a DHT11 sensor hooked up to our test breadboard. The sensor did not work so I just uploaded data from a HCSR04 distance sensor to test it out. This is a very promising and useful service but I have yet to test the data retrieval for the iOS app and as of now there is no way to upload images. The free services will store data for up to 10 different sensors but it is scalable for enterprise levels of demand.

Figure 18: ThingSpeak Cloud Data



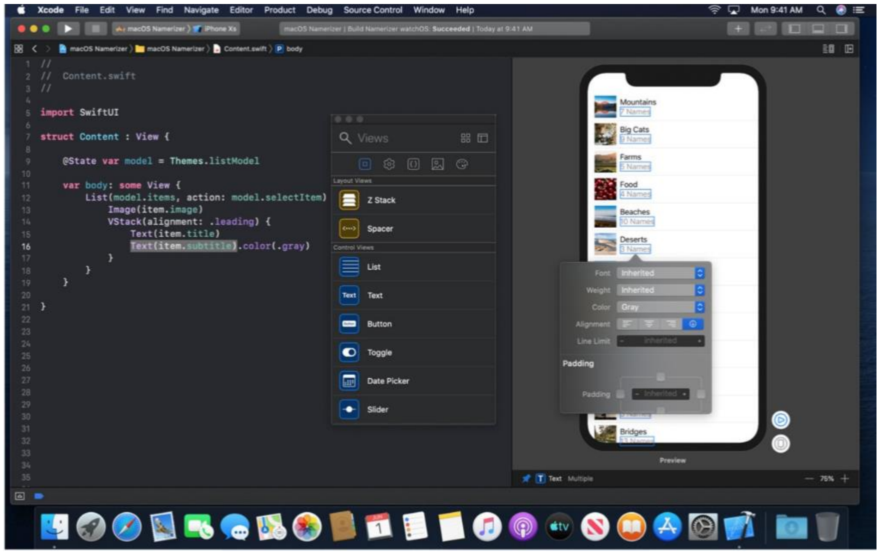
3.12.3 iOS App

We chose to make an iOS phone app to display sensor data because we all have iPhones. Due to the proprietorship nature of anything apple this had to be done on a Mac computer. All Apple applications are created in a program called XCode and are written in the Swift language. As late as 2019 you were required to pay a $100 Apple Developer fee in order to upload applications to your phone or devices. Thankfully the evil empire has loosened its grip and only requires the fee if you plan to publish to the app store where anyone can download and you can charge for your application. The membership only lasts 12 months because reasons. This will not be a problem for us because we will only need to load the app to one phone.

In able to learn how to create a phone app and link it to the cloud using API's I have enrolled in a Udemy course by Dr. Angela Yu. The course is titled iOS & Swift – The Complete iOS App Development Bootcamp. I purchased a similar course from a coworker of Dr. Yu for the android platform that covers android studio in depth and it worked out great. Dr. Yu has the voice of Laura Croft and nearly 60 hours of content. Provided we can find a good server solution I expect the phone app to go very smoothly.

XCode has the ability to simulate any apple device virtually so we can quickly troubleshoot and update the code to eliminate any bugs. We have yet to decide if we will give the iOS app the ability to make changes to the actual system like turn on and off the grow lights. We do plan to have virtual spots for each plant and depending on the date and type of plant added the app will estimate date of harvest and may even have growth cycle pictures for each spot. We are using Xcode version 12.5.1 on a 2020 Mac Mini running macOS Big Sur version 11.4. The iPhone I plan to eventually run the application on is a 2016 iPhone 7+.

Figure 19: XCode IDE with virtual iPhone



3.13 Climate Control Fans

The grow chamber that houses the plants will be enclosed for greater light efficiency. This could cause problems with temperature and humidity. The humidity of an environment that a plant grows in can drastically affect the plant's health, growth, and taste. Some symptoms of too high humidity include plant disease, fungus, growth stagnation, mold growth, mildew growth, white spots, and closed stomata. Plants consume water though their stems, and the water is extended through the leaves and veins in order to photosynthesize. The water escapes the plant in the form of water vapor and is released into the environment. If it is too humid and the water is unable to escape the environment, then the plant will reabsorb the same water unnecessarily, or it will stop absorbing it, which will limit the amount of oxygen and nutrients that it can absorb.

It is worth noting that the desired humidity of hydroponics systems depends heavily on the plant that is being grown. A potential gauge to determine the desired humidity is to know what temperature the plant is kept at. Plants kept around 50 degrees Fahrenheit are to be kept around 83% humidity. Plants kept around 60 degrees Fahrenheit are to be kept around 89% humidity. Plants kept around 70 degrees Fahrenheit are to be kept around 91% humidity. Plants kept around 80 degrees Fahrenheit are to be kept around 95% humidity. With that being said it is recommended that arugula, the plant of choice, is to be kept between 80% and 90% humidity because the recommended temperature is between 45- and 65-degrees Fahrenheit. A notable fact about humidity and plants are that generally, plants require lower humidity over time. Another notable fact is that a 20 degree drop in temperature will double the amount of water that the plant is capable of retaining. Typically, a hydroponics system will not need to humidify the space but dehumidify the space because water vapor is consistently escaping the plant. The higher the setting of the fans, the more air escapes which has a greater dehumidifying effect.

The temperature of a hydroponics section can potentially have a negative effect on the plants. Too high of a temperature can dry out and dehydrate the plant and too low of a temperature can frost the plant and damage its roots. The fans will be used for this also with the fans set to a higher setting to help cool the environment, and the fans can be set to a lower setting to help warm up the environment. As stated earlier, air ventilation is also an important factor in a hydroponics system. Air ventilation is important because stagnant air can lead to pathogens attaching to the plants, insect infiltration, and plant disease. The fans help prevent this by causing air to move throughout the environment.

To help regulate this we will install ventilation vans that are controlled by relays on the PCB. The idea is that whenever the grow chamber reaches a certain temperature or humidity threshold the fans would kick on and regulate the chamber until it returns to a normal growing environment. The DIY grow market is very large and there are all sorts of expensive fans designed to regulate CO2 and air temperature. One option is to purchase a whole ventilation set, like the VIVOSUN 4 Inch 190 CFM Inline Fan with Speed Controller, 4 Inch Carbon Filter and 8 Feet of Ducting with a Temperature and a Humidity Monitor. Another option is to use any fan placed in holes in the grow tent. The VIVOSUN ventilation kit, which includes a 4-inch 190 CFM inline fane with a speed controller, a 4-inch carbon filter, and 8 feet of ducting with a temperature and a humidity monitor, is an efficient ventilator, and a temperature, humidity, and smell controller. The fan works at 120V with 0.8A current is quiet with a noise level less than 31 dB. The system comes with a carbon filter, which helps to control dust and filter undesirable smells. The ducting is three layered with a PET core between two layers of aluminum and is reinforced with steel wire while able to handle temperatures from -22 to 266 degrees Fahrenheit. The system's temperature sensor has a range of 14 to 122 degrees Fahrenheit and accurate to about a tenth of a degree Fahrenheit. The system's humidity sensor can measure humidity from 10% to 99% with an accuracy around plus or minus 5%. This would give almost full direct control of the temperature and humidity in the hydroponic system to the user but this would be independent from the rest of the system.

However, due to the nature of this project, and our budget, we have decided to use standard 120mm computer fans. These fans are quiet, efficient, and run on 12V like the peristaltic pumps so power management will be easy. Below is a table comparing the different solutions we considered.

Table 21: Climate Control Fan Comparison

	Venturi HP	Venturi HF	Corsair ML120
Type	High Pressure	High Flow	Combo Fan
Size	120mm	120mm	120mm
Intended Use	Radiator Fan	Case Fan	Case Fan
Rotational Speed	1800 RPM	1200 RPM	2000 RPM
Noise Level	31.7 dB	26.5 dB	16-37 dB

Power Draw	1 W	2.2 W	3.6 W
Voltage	12V	12V	12V
Air Flow	61.4 CFM	118.2 CFM	12-75 CFM
Air Pressure	2.3 mm H20	0.95 mm H20	0.2-4.2 mm H20
Price	$24.99	$24.99	$28.99

We chose the Venturi HF fan due to its impressive CFM rating. The other fans were meant for radiator or all-purpose computer cooling. Our grow chamber will be, essentially, just a big box that will need to have its air circulated so pressure will do very little in this application. The actual grow chamber will be approximately 35”x36”x24” in size.

$$Grow\ Chamber\ Cubic\ Feet = \frac{35 * 36 * 24}{144} = 210\ CF$$

The Venturi HF 120mm fan has to ability to move 118.2 cubic feet in one minute so with a one fan setup we could completely replace the air in the grow chamber in 1 minute and 46 seconds. Because temperature and humidity are the most important thing for the plants, I believe a two-fan push/pull configuration will 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 could completely replace the air in the chamber in approximately 54 seconds!

3.14 Camera

In order to effectively provide a remote viewing experience of the growing operation, having a quality camera is essential. The camera will primarily be used to take periodic photos of the plants inside the growing chamber and provide the user with the ability to see a live photo of their hydroponics system at any time. The camera may also be used for the features required from the camera involves having a good resolution and Field of View. In our research, we concluded that there are two camera sensors that fit our requirements alongside budgetary constraints.

The first consideration was the Arducam OV5647, which is an image sensor built to primarily be an accessory for the popular Raspberry Pi development board. This sensor has an effective pixel count of 5.04 million, offering various image quality options from the get-go, including a range of resolutions from QSXGA to QVGA. This chip contains a variable 8/10 bit RGB RAW output for images. Since this product is generally intended to work with the Raspberry Pi, it is ease-of-use compatibility features for most of the existing Raspberry Pi models. Similarly, the Arducam is supported in the latest version of Raspbian, the Raspberry Pi Operating System.

Another viable option is the Sony IMX219. This is a diagonal 4.60 mm CMOS active pixel type image sensor with a square pixel array and an effective pixel count of 8.08 million. For communication purposes, the sensor supports 2-wire serial communication and a CSI2 serial data output (either 4 lane or 2 lane). This chip contains a variable 8/10 bit RGB RAW output for images. In addition, the chip features a 10-bit A/D converter and a data rate of 755 Mbps/lane for 4 lane data output, or 912 Mbps/lane for 2 lane data output. Having a high rate of data output is key since the camera in our design will constantly be taking photos, and potential videos. The Sony IMX219 is compatible with many machine learning algorithms such as the NVIDIA Jetson Nano/Xavier NX development kits.

Table 22: Camera Specifications Comparison

Specification	Sony IMX219	Arducam OV5647
Megapixels	8 Megapixels	5 Megapixels
Resolution	3280 x 2465 pixels	2592 x 1944 pixels
Board Size	25 mm x 24 mm	25 x 24.5 mm
Maximum Image Transfer Rate	30 FPS @ QSXGA	15 FPS @ QSXGA

With both sensors being in the same price bracket, comparing the differences in specifications from **Table 23** provided a simple analysis on which sensor to use. In short, we decided that using the Sony IMX219 image sensor will be the best camera module for our design. In the raw specifications, the IMX219 offers a similar board size to its competitor but has higher resolution capability and can record videos at a higher framerate at the respective quality. The Arducam OV5647's native Raspberry Pi compatibility does not provide enough of an advantage to replace the higher specifications of the IMX219.

3.15 Lights

Like water and nutrients, one of the essential things that a plant must have in order to grow is light. This is because one of the plants essential processes, photosynthesis, requires it. Photosynthesis, coming from two words which mean "light", and "place together", is the process in which a plant uses light energy and through chemical reactions converts it to glucose or sugar which is used to build the plant's cell wall, and adjust pH for growth. Light reacts mainly with cells in the plant called chloroplast which contain chlorophyll, from which plants get their green color. The main kind chlorophyll used is chlorophyll a, which has pigments with the potential to absorb red, blue, and violet light. On the entire light spectrum, which is from 400 – 700 nm, blue light is 400 – 500 nm, and red light is 600 – 700 nm, and though these are the primary wavelengths on the spectrum that are absorbed, plants can benefit from the full light spectrum.

In order to go into more detail, in photo synthesis when light energy interacts with a chloroplast then the chlorophyll in the chloroplast uses that energy to combing carbon dioxide and water. This combination leads to the forming of glucose and oxygen. Specifically, six molecules of carbon dioxide combine with six molecules of water to form one molecule of sugar and six molecules of oxygen. Photosynthesis can be split into two processes, the light dependent reaction, and the light independent reaction. The light dependent reaction is when light energy is absorbed and used with ATP. The light independent reaction is when that ATP is used to make sugar. Like humidity and temperature, light intensity is an important factor in maximizing the efficiency of photosynthesis. It is said that the optimal light intensity for plants in an indoor hydroponic system is around 10,000 lux.

When growing plants indoors, some growers use artificial light for their plants, but there are different kinds such as High Intensity Discharge (HID), Compact Fluorescent, Light Emitting Diode, and Sulfur Plasma. High Intensity Discharge lights typically consist of a ballast, lightning hood or reflector, and bulbs. The ballast converts electricity from an outlet into a voltage that the light so electricity can stream constantly and consistently through the bulbs. The lightning hood or reflector spreads the heat light around the environment for more even distribution. The bulbs usually come in two forms, Metal Halide or High Pressure Sodium. Metal Halide bulbs are mostly used for a plant's growth phase. Metal Halide bulbs imitate the hot summer sun by emitting light wavelengths toward the blue and white end of the light spectrum. High Pressure Sodium bulbs are mostly used for a plant's flowering stage. High Pressure Sodium bulbs imitate the autumn sun by emitting light wavelengths toward the orange and red end of the light spectrum. Metal Halide and High Pressure Sodium bulbs used together work for many indoor growers, they are inexpensive and highly effective, however, they generate a lot of heat and use more energy.

Compact Fluorescent lights contain a ballast integrated into the lighting and are made of small fluorescent tubes. Compact Fluorescent lights emit blue light and low amount of heat which is ideal for seedlings and plants at early stages of life. However, even though Compact Fluorescent lights are cool, inexpensive, and low power, they are not effective once the plant matures. Light Emitting Diode (LED) lighting usually plugs right into the wall and can be used to emit a variety of spectrums of light as well as full spectrum. Light Emitting Diode lighting is very energy efficient, and emits a low amount of heat, however, it is an expensive option. Sulfur Plasma lighting systems have the unique feature of being able to adjust the output to simulate wattage from 100 to 1300 Watts. Given that Sulfur Plasma lighting can be adjusted in this way, it can be used with various kinds of plants in different size environments. Sulfur Plasma bulbs are highly energy efficient and are said to come much closer to imitating natural light because it delivers a full and continuous spectrum. However, since this technology is very new, its effectiveness is unknown, and it is the most expensive option.

Table 23: Light systems

(HID) Metal Halide	(HID) High Pressure Sodium	Compact Fluorescent	Light Emitting Diode	Sulfur Plasma

- Blue/white light - Highly effective for plant's growth phase - Inexpensive - High heat emission - Requires ballast	- Red light - Highly effective for plant's flowering stage - Inexpensive - High heat emission - Requires ballast	- Blue light - Effective for seedlings - Inexpensive - Low heat emission - low power emission - Ineffective for mature plants	- Full Spectrum - Effective for all plant stages - Low heat emission - Relatively expensive	- Full Spectrum - High energy efficiency - Adjustable simulated wattage - Effectiveness unknown - Most expensive

Given these pros and cons, it was decided to go with the Light Emitting Diode grow light for the hydroponics system. Even though it more expensive, it is easy to set up by plugging into the wall and adjust if necessary. Also, it can be used at all plant growth stages and emits low heat, even if run all day. In deciding between different LED grow lights, since the grow tent is relatively small, the effectiveness should be about the same, but the cost is the main factor. It was decided to go with the Koopower brand LED Grow Light. Not only is it currently listed at $29.99, but also comes with a mechanism to hang the light and a timer.

4.0 Standards and Constraints

This section will discuss the engineering standards and constraints that were taken into consideration for the design idea. By meeting certain engineering standards, the Wi-Fi Hydro Garden design will guarantee a set minimum performance alongside compatibility with standardized equipment. Keeping within standard requirements helps ensure that the quality of the project will be sufficient enough to be potentially marketable as a product. In addition to the standards that will be required to meet, constraints that were taken into consideration when designing the project will be elaborated on to provide a thorough analysis of the project idea as a whole.

4.1 Wireless Communication Standards

An advertised feature of the Wi-Fi Hydro Garden is a mobile app that will be connected to cloud storage. In order for the measured data to be recorded and sent to a cloud storage service, the design will feature a Wi-Fi module. The primary standards used for Wi-Fi are written and maintained by the Institute of Electrical and Electronic Engineers (IEEE).

IEE 802.11 Standard

The IEE 802 standards contains a variety of standards regarding local area and metropolitan area networking. Wi-Fi specifically is under the IEEE 802.11 standards. The first IEE 802.11 standard was defined in 1999 as standard 802.11a. It defined standards regarding a wireless network bearer operating in a 5 GHz ISM band using orthogonal frequency division multiplexing with a data rate of up to 54 Mbps. The second iteration, 802.11b, allowed standard use of a 2.4 GHz ISM band with a lower data rate of 11 Mbps. 802.11e defined the approach to be taken in regard to prioritization of data and other quality of service elements. Eventually 802.11b was superseded by 802.11g, which created a standard for faster 2.4 GHz bands using OFDM technology. All modules in compliance with the 802.11g standard also featured backwards compatibility for the older standards. The modern IEE standards that the Wi-Fi Hydro Garden may seek to comply with are the IEE 802.11ac and 802.11n standards. 802.11n was the first standard to specify Multiple Input Multiple Output networks (MIMO), and allow usage for two frequencies. This is popularly known as a dual band network in many home systems. 802.11ac is what most current production home wireless routers are compliant with. This standard uses MIMO technology to have different antennas on both sending and receiving devices to reduce error and boost speed. This allows for the fastest speeds that have yet to be reached in most home networks, with data rates of up to 3.46 Gbps.

The Wi-Fi Hydro Garden is designed to be an indoor application and should there for be compatible with a variety of home networks, as every different indoor location will more or less have a different network enveloping it. In order to provide this compatibility, the Wi-Fi protocols will be in compliance with the IEE 802.11ac and the 802.11n standards, to provide the most compatibility in modern home networks.

4.2 Serial Peripheral Interface (SPI)

The serial peripheral interface is one of the most widely used interfaces between a microcontroller and peripheral circuitry like sensors, analog-to-digital converters, shift registers, etc. SPI is a synchronous, full duplex master-slave based interface. The data from the master or the slave can be synchronized through the rising or falling edge of the clock cycle. Both the master and slave can transmit data at any point in time. The serial peripheral interface can come in either 3-wire or 4-wire configurations. The modern approach for SPI typically utilizes the 4-wire SPI design.

4-wire SPI devices have four signals: Clock (SPI CLK, SCLK), Chip select (CS), Master Out Slave in (MOSI), Master in Slave Out (MISO). The device that generates the clock signal is referred to as the master device. In most configurations, this is generally the microcontroller. Data transmitted between the master and slave device is synchronized to the clock generated by the master. An SPI system can only support one master device but can have multiple slaves connected to the master device. The chip select (CS) wire is used by the master device to signal an individual slave. This is generally done with an active low signal, which is pulled high to disconnect the slave device from the SPI bus. When multiple slaves are used, an individual chip select signal is required from the master. The MOSI and MISO wires are the data lines that connect the master and slave devices respectively. Each wire allows for data to be transmitted from one device to another.

When beginning SPI communication, the master device sends a clock signal and enables the appropriate chip select signal to select the appropriate slave. During active communication, the data is simultaneously sent and received from the master and slave devices. The serial clock edge synchronizes the shifting and sampling of the transmitted data. The serial peripheral interface allows for flexibility with respect to the clock edge. The user can select a rising or falling clock edge to sample or shift data. In addition, the SPI protocol allows the master device to select clock polarity and clock phase. This creates 4 SPI modes that depend on the clock polarity (CPOL) bit and the clock phase (CPHA) bit. These settings determine precisely when the data is sampled and shifted out in respect to the rising or falling edge of the clock.

The main benefits SPI provides as a communication protocal lies in the improved communication and speed between devices. Having sperate MOSI and MISO data lines means that SPI is capable of full-duplex communication. Other communication protocols such as I2C have half-duplex communication systems, where the data send and received must alternate in transmissions. SPI is also considerably faster than I2C. In I2C's ultra-fast mode, the data transfer rates can go up to 5 Mbps. However, SPI data transmission speeds can be implemented at any speed with no hard limit.

4.3 Inter-Integrated Circuit (I^2C)

The I2C protocol is another popular communication system between master and slave devices that uses two bus wires: a serial data wire (SDA) and a serial clock wire (SCL). The slave device cannot transmit data unless specifically addressed by the master device. Each device on the I2C bus has a unique device address to differentiate signals from other devices on the same bus. I2C addresses are usually 7-bit numbers, so a bus can hold up to 127 devices total. The eight bit is used to determine if the signal being sent by the controller to the peripheral or vice versa. I2C utilizes a multi-master bus design that allows multiple masters on the same bus line, allowing for more than one chip to control the bus line at a time. When presented with messages from multiple masters, I2C uses collision detection and arbitration to avoid corrupted information bits. The setup of the SDA and SCL line status determines the order of master line control.

Writing to an I2C bus requires using a start marker by dropping the voltage of the SDA line to 0 V while the SCL remains at a high voltage. Changing the SDA line voltage when the SCL voltage remains high indicates a start or stop marker in an I2C bus. When the SDA voltage does not change and remains constant while SCL is at a high voltage, data will be initiated to be sent through the bus. the first batch of data sent through the line is the address bits followed by a read or write bit. Between each 8-bit data transmission, there is a single pulse 'ack' acknowledgement pause on the SDA line, timed to the ninth SCL pulse. When data is transmitted from the slave to the master device, there is a similar acknowledgement pause – a 'nak' signal or 'no acknowledgment' – that lets the slave device understand to end transmission.

The use of inter-integrated circuits fill a similar need to that of serial peripheral interfaces (SPI). By providing a communication system between master and slave devices, both protocols allow for easier sensor data readouts. A distinct difference between I2C and SPI protocols is that I2C allows for multiple masters and multiple slaves in the same system, whereas SPI can only have one functional master. The Wi-Fi Hydro Garden will only utilize one master microcontroller, meaning that the multiple master functionality of the I2C protocol is not advantageous when comparing it to SPI in this context. However, many sensors purchased specifically list I2C functionality. With this consideration in mind, I2C will be used to ease compatibility requirements.

4.4 Federal Hydroponic System Regulations

Due to the emerging nature of hydroponic based horticulture, the regulatory system has provided sparse standards regarding the system itself. The existing flexibility of hydroponic systems can create difficulty when setting a federal standard in the context of agricultural concerns. One area that is federally regulated with relation to hydroponics is the concept of “organic” food.

The National Organic Program (NOP)

The NOP is a federal program that is assigned with creating and regulating standards for organic produce and other agriculture products. Within the NOP, there exists the National Organics Standards Board (NOSB). The NOSB is a committee consisted of members appointed by the Secretary of Agriculture for the purpose of assisting in the development of standards regarding substances used in organic production. The NOSB over the past few decades have provided many comments about the status of hydronics as a certified organic system, but much of it has yielded nothing in concrete regulations by the NOP. In 2018, following the fall 2017 NOSB meeting and discussion on hydroponics, the USDA released a statement for clarification on the agency’s position regarding the “organic” status of hydroponic systems. In this statement, the USDA claims that certification of hydroponic, aquaponic, and aeroponic systems is allowed under USDA organic regulations. Despite this statement, many lawsuits have arisen amid food and safety concerns. Overall, the unclear nature of the NOP and USDA’s stance on hydroponic organic certification provides ample reason to avoid seeking compliance with this standard. The Wi-Fi Hydro Garden will not use any the term organic in reference to any USDA regulations.

4.5 Coding Standards

The Wi-Fi Hydro Garden’s software components will be designed by multiple members of our design group. Due to this, following a standard when writing the development programs will allow for improved readability and make the debugging easier. Typical standards include the use of naming conventions, formatting, indentation, commenting, and test approach. The benefits of applying these standards to our software elements are numerous. With standardized names and indentation, all variables should be interpretable by all members in the group. Debugging should prove to be easier due to the simplified nature of the code body composition.

4.5.1 Programming Language: C Standard

The international C Standard details and establishes the interpretation of programs written in the C programming language. Since the microcontroller currently selected is compatible with C/C++, understanding the C Standard is very important for all members engaging in programming. The scope of the standard is large, covering the representation of C programs, the syntax and constraints of the C language, the semantic rules for interpreting C programs, the representation of input and output data processed by C programs, and the restrictions and limits imposed by a conforming implementation of C. The standard is broken up into four major subdivisions that cover the aforementioned information. The first section is the introduction and preliminary elements. This sets up a standardized set of definitions that will be used henceforth in the C standard. The following section details the characteristics of environments that translate and execute C programs. Afterword’s, the language syntax, constraints, and semantics are explained. The last section goes into detail about the use of libraries. Having a thorough understanding of the C Standard is vital when the majority of the coding will be done with C or a C variant.

4.5.2 Software Testing Standards

The main standards for software testing are implemented as the ISO/IEC/IEE 29119 series of software testing standards. These standards define an internationally agreed upon set of rules for software testing that can be used by any organization when performing any form of software testing. There are four distinct parts that the standards are broken up into to. The first part, Part 1, consists of defining concepts into a standardized form that will be used in the later parts. This is useful for ensuring all members in a collaboration can use technical terminology with a mutually agreed upon ruling of what it means.

ISO/IEC/IEE 29119 Part 2: Test processes

Part 2 puts forth a general test process model for software testing that is intended to be used for actual software testing. This part is comprised of test process compositions that provide definitions for each testing process at an organizational, managerial, and dynamic level. The processes laid out in part 2 can be used with several different software development lifecycle models.

Test Monitoring and Control

One concept defined in part 2 revolves around test monitoring and the control process. This process checks whether the progress of testing aligns with the goals and policies of the test plan and the testing organization itself. This process is generally assigned to management faculty of the project. The monitoring process is broken down into four sections. the first activity (TMC1) is called the “Set-Up”, which involves creating suitable measures and means to create new changes within the test. Afterwards, (TMC2) the monitoring stage has begun, where a member collects, records, and measures changes and compares the results against the test plan to determine relative progress. Then begins (TMC3), the “control” activity for implementing specific activities required to finish the test plan. Finally, (TMC4) the test progress is reported to whoever leads the test plan so that progress can be finalized and reports can be made.

Test Completion Process

The continuation of the monitoring and control process leads to the test completion process. This process is a verification test that is performed when the test activities are finished. It can be used as a verification test to check testing done on a system or as a project wide check. The verification test begins with (TC1) an archive of testing assets. Whatever parts and materials used for testing must be properly identified and stored in recoverable storage for later use. Afterwards, a clean up (TC2) of the test environment must be conducted. This involves restoring the test environment to a pre-defined state upon completion of testing activities. When conducting tests on the UCF campus, this procedure must be followed strictly. At the testing site, there should be identification of lessons learned (TC3) when testing. This will provide valuable feedback for future debugging. Afterwards a report of test completion (TC4) should be compiled and implemented into the relevant documentation.

Test Execution Process

The last major concept that was considered from part 2 was the test execution process. This process outlines the test procedures generated from the results of the design and implementation process. The following **Table 25** outlines each individual step and code of the execution process. The procedures of the execution process may be requiring multiple attempts since in most cases, all available test procedures cannot run at a single time. When an issue is identified and fixed during the testing procedure, the test execution process should be performed again.

Each individual test may not utilize every test execution step. Regardless, having a formally defined process to begin testing with is crucial. Following these test execution process standards will aid in streamlining the debugging process and help with testing the various subsystems the Wi-Fi Hydro Garden is composed of. Being in compliance with these standards also helps create an industry-level composition of the project.

Table 24: Test Execution Process steps

Code	Activity Name	Task
TD1	Identify Feature Sets	Analyze test basis to understand the test item requirements, combine test features into test set and prioritize by risk value, document the feature set, and communicate with members.
TD2	Derive Test Conditions	Determine the test condition for each test case; prioritize the best condition based on risk, record test condition in test design specification.
TD3	Derive Test Coverage Items	Derive test coverage items through applying test design techniques; prioritize test coverage items based on risk, record test coverage items in test design specification. Record the traceability.
TD4	Derive Test Cases	Determine pre-condition and input values for one or more test cases and expected result prioritize by risk value, record test cases items in test design specification. Record traceability.
TD5	Assemble Test Sets	Distribute test cases into one or more test sets based on constraints and execution, record test case in procedure specification, record the traceability.
TD6	Derive Test Procedures	Derive test procedures from ordered test set based on pre-condition, post-

		condition, and dependencies, identify excluded test data, prioritize test procedures based on risk, record test procedures in procedure specification, record the traceability, get approval of stakeholder.

ISO/IEC/IEEE 29119-4: Test Techniques

This part of the software testing standards highlights techniques that can be used with the test processes defined in part 2. Test design techniques are defined for specification-based testing, structure-based testing, and experience-based testing. Specification-based testing involves using the user needs, requirements, and models to design a test case. Structure-based testing uses the source code or software model of a project to determine the test case. The last testing form, experience-based testing, relies on the experience and knowledge of the tester to generate a test case.

4.5.3 Team Coding Standards

The main team-wide standard that was agreed upon by all members was the idea of modular coding. The Wi-Fi Hydro Garden on a hardware level operates on several subsystems that all report back to the main controller for processing. The software related component of this would be for each different primary function being separated from the main function. Each component, or “module”, can then be independently tested without reliance on other functions. Once each module is firmly established and rigorously debugged, more complex modules that rely on multi subsystems to work can be established. This will all be done while keeping the main function as sparse as technically possible. In addition, the use of error flag reporting among all modules will provide consistent feedback when establishing software routines. The last major concept established was the polling nature of each module. The main software subsystem for the microcontroller will be operated on a continuous timer. Any module that polls an event will be brought to the microcontroller’s attention and be processed. If multiple events are polled then they will be sorted via priority. From this methodology, all modules must be designed in accordance with the continuous loop idea. All these team-wide coding standards were implemented to provide a clear picture of how the code will be implemented.

4.6 Time Constraints

As per the ABET requirements, this senior design project must be completed in two semesters. For the Wi-Fi Hydro Garden group members, there is approximately six full months to complete the design. This timeframe presents an important design constraint when considering what can be done within an appropriate context. Parts must be selected that can be ordered in a reasonable time and the development and debugging period must be planned accordingly. Due to the relatively strict schedule, any large mistakes in managing work can present massive hurdles for the future of the assignment. Technologies can be incorporated into the project must be seen within the lens of practicality. With the varying nature of how advanced a hydroponics system can be, there are questions regarding what is actually required for the end user. Such examples include implementing a hermetically sealed enclosure and the use of carbon-dioxide gas cannisters. Such features would aid in the growing process undoubtedly, but the time required to implement them would far exceed the current time left to design the project in its entirety. By skipping out on extraneous parts and subsystems that some hydroponics systems offer, we hope to improve the development process.

5.0 Project Design – Phase 1

After thorough research of all subsystems required for the selected hydroponic design, enough information has been compiled such that a design can be realized. The current chosen design will be highlighted in this section in great detail. Each design choice realized will be in accordance with the project specifications, requirements, and standards. In addition, each design choice will attempt to meet all criteria while considering the economic cost of said choice. If possible, each subsystem listed will provide a schematic and block diagram to aid in conceptualization of the design in mind. Potential design problems will be listed if found, and the overall implementation process from a practical view will be provided. It is important to note that the following section was theorized before much of the integration and testing was performed. The finalized project design will be detailed in section 7, titled Project Design – Phase 2.

5.1 Water Level Sensor Design

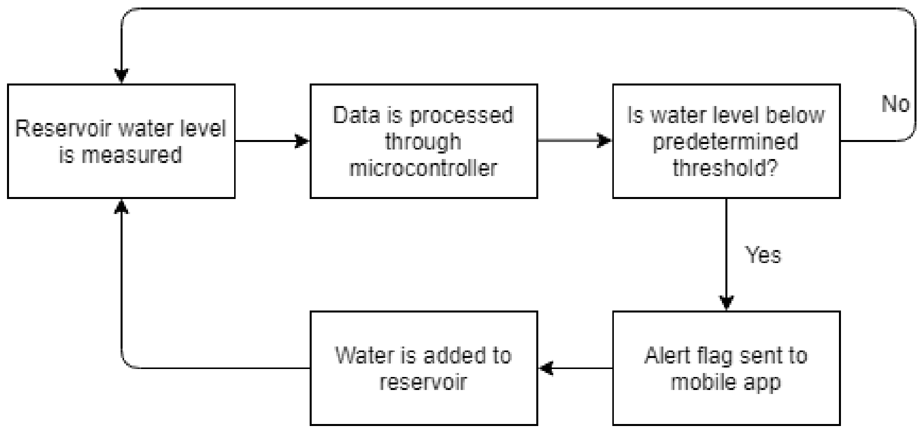
Within this design water is going to play a huge part. The reason why is because the life of the plant is going to heavily depend on this. At any point if the plant that is being used in the hydroponic system doesn’t receive the ample amount of water it needs, then it’s going to have a negative impact on the plant, which could either slow down the growing process of the plant, cause the plant to wilt, or worst-case scenario, the plant dies. This shouldn’t happen because the Nutrient Film Technique method is being used for the hydroponic system. This will allow for the water to flow through a slope and cause the plants to receive the amount of water that is needed. Then, the excess water flows back into the reservoir. With this system, most of the water and watering solution is being reused as it should, but as time goes by the reservoir will eventually need to be filled. In order to notice the water is at a level where it needs to be refilled, we will need to use some sort of sensor that will be able to somehow measure the water level within a reservoir, like gas within a gas tank of a car.

The reservoir will have a rectangular shape with a top. With this being said, the water level sensor that was chosen, which is technically called a magnetic float level transmitter, will be connected to the top of the reservoir. While the sensor head is connected to the top of the reservoir, a sensing probe and float will be interacting with the fluid the most. As the fluid level increases or decreases, the float will always float on top of the water. As the water level increases or decreases the magnets within the float will cause the sensing probe to change the resistance. This can happen because the sensing probe has a resistor chain that is built within it. The change in resistance will be used to measure the how much and how little amount of water is left in the tank. If the resistance is zero ohms, then that means that the reservoir has no water left and when the resistance is at its peak, this will represent the water level being at capacity. Also, the way that the water level will be displayed to the user is via percentage. So, if 25% of the water has been used the system will display 75% and so on. This system will be tested to see if it works properly and efficiently during the prototyping stage. If not, another method will be determined.

This system was designed so that it will be able to operate without the user having to periodically check on the system. The system also operates with the intentions that it is going to operate over extended periods of time with little to no user interaction. Knowing this information, the team wanted to create a way for the user to receive an alert when the water level reaches a certain percentage. This alert will inform the user that the reservoir needs to be refilled. There are also users that like to constantly micromanage certain tasks so to accommodate to those users, we used color codes that are set to change the color of the percentage being displayed when it is at certain percentages. The color codes are going to display red, yellow, and green based on the percentage, with red meaning that the water level is low, and green meaning that the water level is high. In the design of the water level sensor, the group had to determine what the threshold was going to be that causes the alert to be sent. The reason why this needed to be determined is because, if the user is going to have to fill up the reservoir when they get an alert, then they will need enough time to be able to do this. The user may have other tasks that they need to complete, and they may not prioritize filling it directly at that time when the alert is sent. Knowing this, it may not be smart to have the alert be sent when the reservoir is too low because it would risk the plant not receiving enough water if the user can't complete the task for the hydroponics system in time. If the threshold is too high the group may risk the user becoming annoyed or irritated by the alerts. The reason why this may happen is because users could potentially start to feel as if they are receiving too many alerts. This may even cause the user to ignore the alert at that moment and forget about it which may in return cause the plant to not receive enough water. Keeping the user's behavior in mind led the group to choose to send the alert at 50% so that the alert doesn't get sent too early or late.

The system will constantly repeat itself so that the reservoir's water level is measured constantly. This will also help to maintain the safety and preserve the life of the plant. It also is worth noting that if the water levels percentage does not change over periods of the water being pumped into and out of the reservoir, then the system is malfunctioning, and the user will also be alerted by this. The reason why this alert is being implemented is because if the water continues to pump in and out of the reservoir and the water level being displayed is not changing, then eventually the fluid in the reservoir will run out and may cause the plant to die. This alert will also be sent to the mobile app and the user will then have to act accordingly to get the system back on track or refill the reservoir and recalibrate the sensor. It is also worth noting that the system may be adjusted after the prototype is built and if those adjustments do happen it will be mentioned here.

Figure 20: Water Level Sensor Block Diagram



5.2 Nutrient System Design

This section will detail the automation procedures for the growing process. With the nutrient system being the most vital component of the design, the methodology behind the process must be robust. **Figure 21** displays a block diagram detailing the overall nutrient system process. First, the user must fill the reservoir with water. Distilled water is preferred due to the known pH and lack of added chemicals or contaminants, but the automation system should be able to account for local tap water as well. Once the reservoir is filled and the water level sensor provides a positive reading after a set time interval, the water pump will activate and begin pushing water up into the 3 channels up in the growing enclosure. These channels are diagonally situated, forcing the water to travel down into a collector pipe and back into the reservoir. During pump activation, the flow rate meter will begin to provide measurements to the microcontroller. Once the flow rate is satisfactory, the average water level of the reservoir should be stabilized and allow for dosing of the nutrient system.

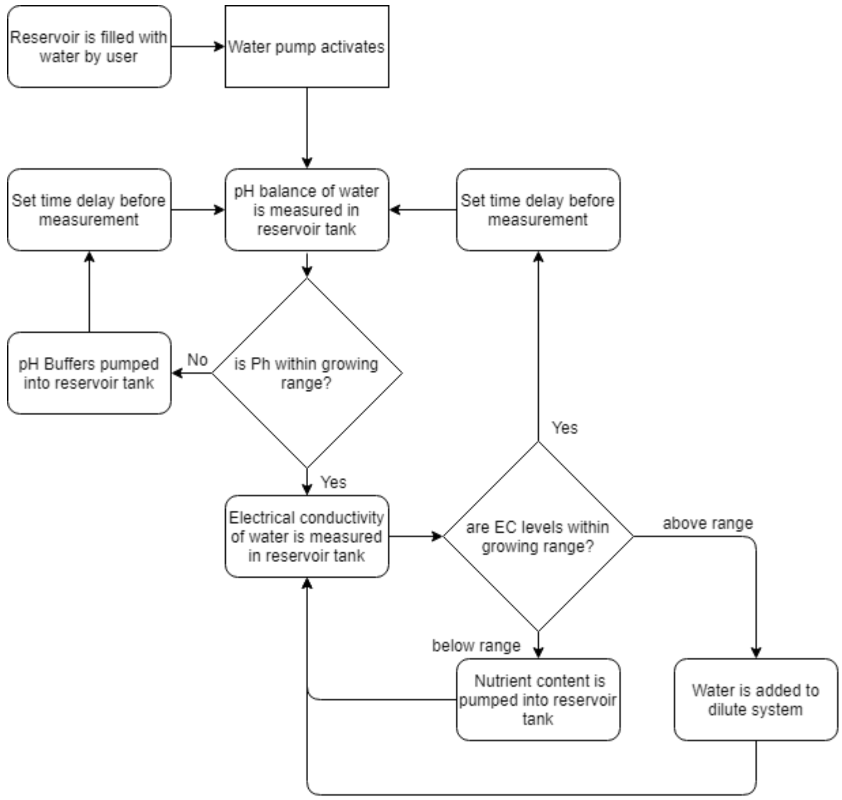
Before dosing can begin, the pH sensor measures the pH balance of the water in the reservoir tank. Distilled water is neutral at a pH of 7 but tap water and other sources may have a differing pH. When the pH is measured to be out of an acceptable growing range, then the microcontroller will signal the peristaltic pumps to dose a set amount of pH buffer defined in the preloaded software. If the pH balance is reported as too acidic, which is generally seen as a pH balance approaching 4.5, a pH buffer containing a base solution will be dispensed. If the pH balance is reported as too alkaline, which is generally seen as a pH balance of close to 8.0, a pH buffer containing an acid solution will be dispensed. In a typical hydroponics system, the nutrients added will cause the water in the system to become more acidic. However, the base pH of distilled water being 7 is too alkali for some plants. These conditions necessitate both forms of pH buffers.

The microcontroller will then wait a set time period before measuring the pH balance again. It is important to wait a set time period because the chemicals dosed into the water will take time to be pumped throughout the system. The reservoir readings will not be accurate for the entire system until enough water has been sufficiently cycled through. This process will repeat continuously until a constant pH value that is within the growing range is attained. If the pH is measured to be consistently within an acceptable growing range as dictated by software loaded onto the microcontroller, then the next step of nutrient measuring begins. An electrical conductivity sensor will measure the electrical conductivity of the reservoir water. If distilled water is used, there should be little to none electrical conductivity. If tap water is used, the EC values will report higher, but generally not high enough to be out of growing range. The first measurements recorded will be tared so that when additional nutrient content is added, the measurements will stay consistent. If the EC levels indicate that nutrients in the system are below the growing range, the microcontroller will signal a peristaltic pump to send out an appropriate amount of nutrient solution into the reservoir tank. If the nutrient solution is too high, a peristaltic pump will be signaled to add additional water to the reservoir tank to lower dilute the entire system.

Once the EC levels are determined to be within range, the microcontroller waits, and then repeats the process of checking pH and EC levels. Adding nutrient content will always change the pH of the solution, so a fine balance of pH buffers and nutrient solution is required to maintain homeostasis in the system. As the plants grow in the enclosure, the overall nutrient content in the system will decrease. It is also possible for growing medium contamination into the reservoir water and changes in chemical composition to occur. These factors over time will require continuous dosing of nutrient solution over time, which will in turn require continuous pH dosing. Certain situations may cause system imbalances that cannot be fixed with the automation system. The software set into the microcontroller will be programmed to identify measurements that indicate critical failures and provide an alert to the user through the mobile app.

Without automation, the Nutrient Film Technique simply involves pumping a premixed water and nutrient solution from a reservoir into various sloping channels. By continuously mixing and balancing the nutrient solution in the reservoir, the process is completely user removed and automated. All the user has to do is add water and let the system do the rest.

Figure 21: Nutrient Cycle Design



5.3 Luminosity Sensor and Grow Light Design

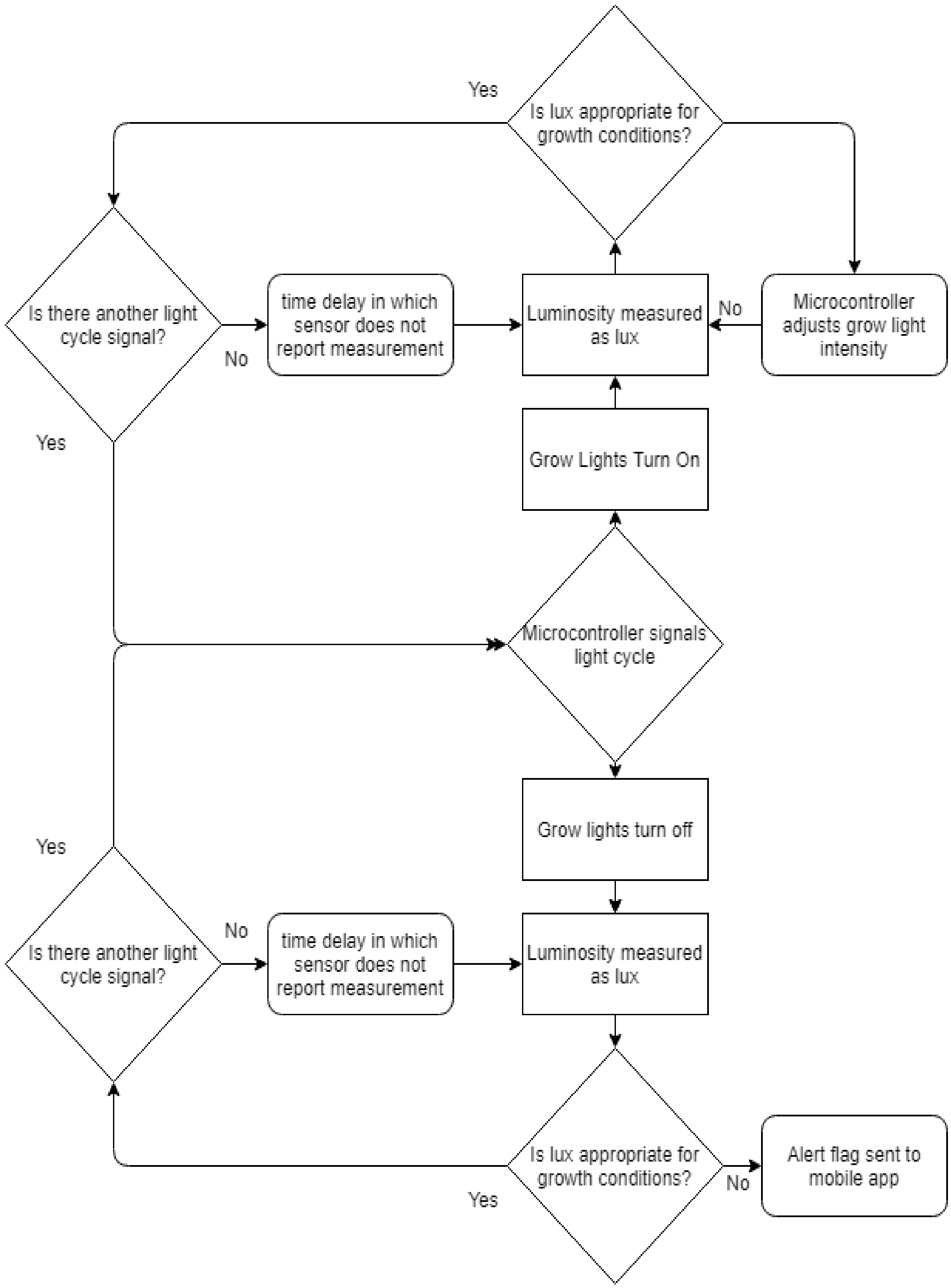
When a person thinks about what is important to plants, one of the many important factors of plant growth that comes to mind is light. The reason why is because light is what is going to produce the chlorophyll needed for a plant. Chlorophyll plays an important role in not only keeping the plant healthy but keeping the plant green as well. This is what provides the plant with vitamin antioxidants and therapeutic properties. Without light the plant can risk potentially dying. Hydroponic systems usually focus a lot less on human interaction because the system is typically trying to do everything for you in an automated state. Knowing this information, the design of the luminosity sensor and grow light will focus less on human interaction with the system.

The luminosity sensor is a sensor that is used to measure the light intensity of the surrounding area. It measures this in LUX so design will work around this. The luminosity sensor will also be placed in area close to where the plants are so that whatever light the sensor is receiving the plant is receiving also. This sensor alone is going to play a huge part in the design because the readings that the sensor give is going to be the determining factor of if the brightness of the grow lights will be increased or decreased. The grow lights will play a huge part in the design as well because the light is needed for the plant otherwise the plant will die. The grow lights will be placed above the plants in a row and column like manor so that they can almost imitate the sun’s rays when the sun is not able to provide any light.

These two parts are going to work together in the system to keep the plant as healthy as possible. The sensor will measure the light being provided in lux and from there will determine if it is appropriate for growth conditions. If yes, then the design will enter its first cycle and make no adjustments to the lights as they are not needed and then it will prepare to go into the next cycle. If no, then the microcontroller will adjust the light as needed and measure the luminosity again and prepare for the next cycle. The app will also send an alert to the user so that the user knows that the light's intensity was adjusted. At certain times the microcontroller will be able to turn on and off the light as well completely just for adjustment purposes. It is also worth mentioning that if after the cycles that are implemented the lux isn't at the right level then the user will be alerted. This would be the result of a malfunction and the user may have to adjust the lights via the app, but this should very rarely happen.

The reason why this design is going to be implemented is because the group wants to make sure the user will not have to interact as much with the system since the process is supposed to be as automated as possible. The group also believes that this is the best way to go to make sure the plant is receiving adequate lighting. It also should be noted that sometimes the light will not need to be on all the time and there will also be times where the light will be off in the design. It just depends on the plant that is being tested in the design. It also is worth mentioning that if during prototyping a better method is founded then that design will be implemented. It will be updated in this design as well. The design is also show in the figure below in more detail involving the time delays, the cycles, and what happens if there is no other cycle signal. The light will also not be turned on during nighttime to emulate the regular, more natural plant growing process.

Figure 22: Luminosity Sensor and Grow Light Design



5.4 Temperature and Humidity Sensor Design

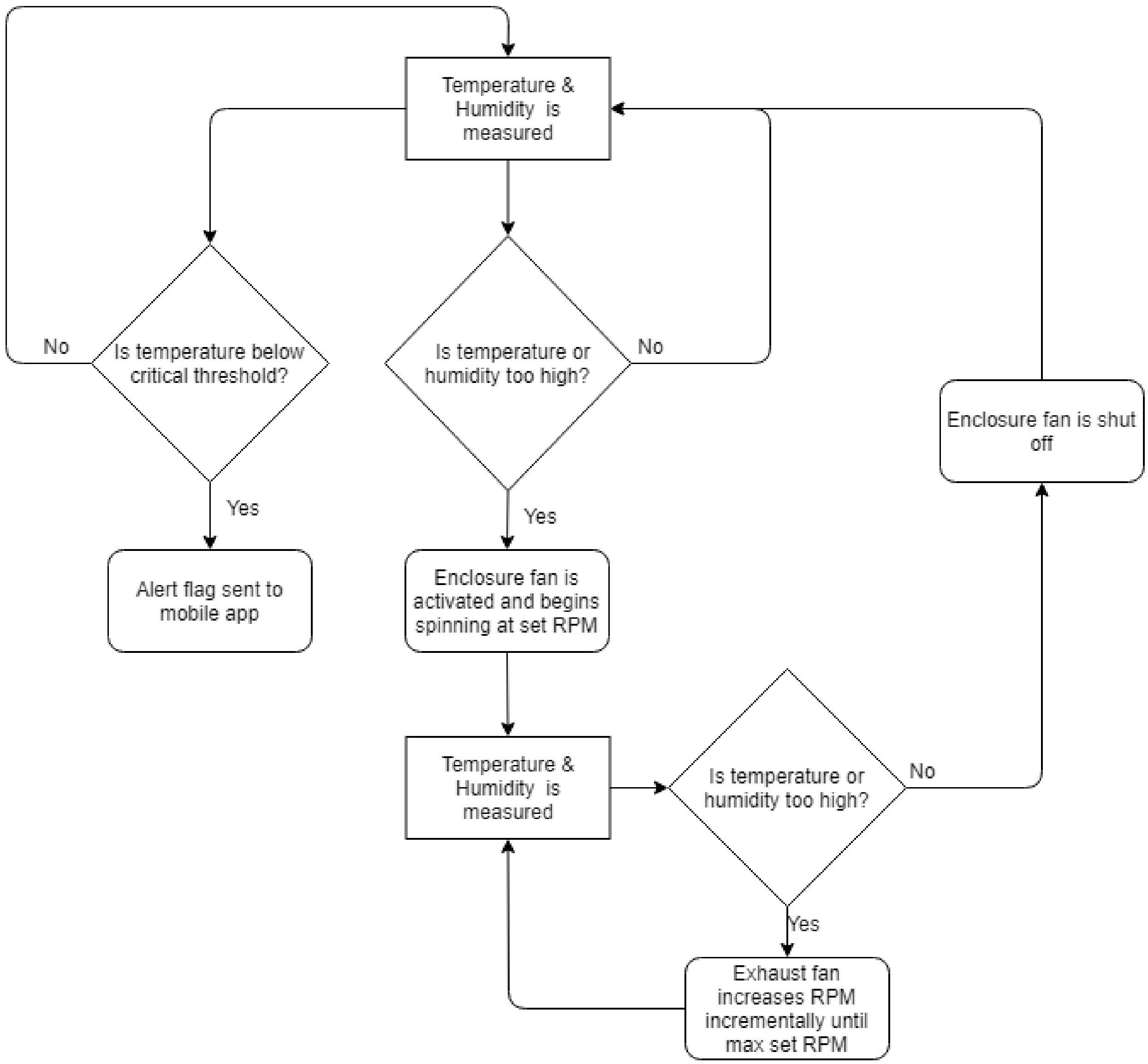
Temperature and Humidity plays an important role in making sure the plant is growing healthily in the Wi-Fi Hydro Garden. The design of the Temperature and Humidity Sensor is going to be key in emulating the environment that the plants are normal in and without this the plants are not going to be able to grow healthily. This is something that is not highlighted within most hydroponic systems because it seems like it is something so small, but if the design of the temperature and humidity sensor works perfectly, then this will promote healthy growth, and efficient growth within the Wi-Fi Hydro Garden.

The sensor that was bought for this design is a sensor that includes being able to read humidity and temperature. The sensor will be placed in the enclosed hydroponic system where the plants are in order to make sure that the right reading is being read. The sensor will work with the enclosure fan that was chosen. The enclosure fan is going to be what has control over the temperature changing.

The sensor will constantly check the temperature and see if it is above the certain temperature and humidity threshold. If it is then the exhaust enclosure fan will turn on and make the humidity and temperature lower. If it is not above the certain threshold then the fan will turn off until it gets to the point where the fan is needed again. With this design of the sensor and fan working together, this will keep it below the temperature threshold so that the plants that are trying to grow in the hydroponics system do not begin to wilt or die. It should be known that there is not a way to increase the temperature because in Florida (where the system is being tested) It is very rare that the temperature goes below the temperature range required for the plant to grow. Because of this, a way for the temperature to increase was not implemented into the design but after prototyping, and testing, if it is found that this is needed for the system then it will be implemented. For now, if this happens then the user will get alerted via the app, but the group highly doubts this will happen often.

The reason why this design is being implemented is because the group believes that this is the best possible way, with the current knowledge the group has, to control the climate without the user having to do a lot. This way the user is interacting with the climate of the Wi-Fi hydroponics system as little as possible. The only time the user will ever have to interact with the climate is if the temperature goes below the threshold which will rarely ever happen. It should be noted that the placement of the system in the enclosed atmosphere may be adjusted in order to receive the proper reading of the environment. If this happens it will be mentioned. The design could possibly change as well to implement the increase of temperature instead of only the decrease of the temperature. If this happens then as the sensor does its checks, if the temperature is below the accepted range of temperature, then something that emits a safe amount of heat that is not harming to the plant will be activated. This something must be able to increase the heat safely without the risk of a fire, or any other danger to the hydroponics system. The group doesn’t expect the sensor to malfunction either because all it must do is take the temperature of the climate, but if the group notices a malfunction within the sensor happening a lot, then an alert will be sent to the user via the app. This will result in the user having to tend to the matter themselves, but this is not projected to happen at all right now. Below, is a block diagram of the system that maps out exactly how this should work.

Figure 23: Temperature and Humidity Sensor Design



5.5 Water Flow and Pump Design

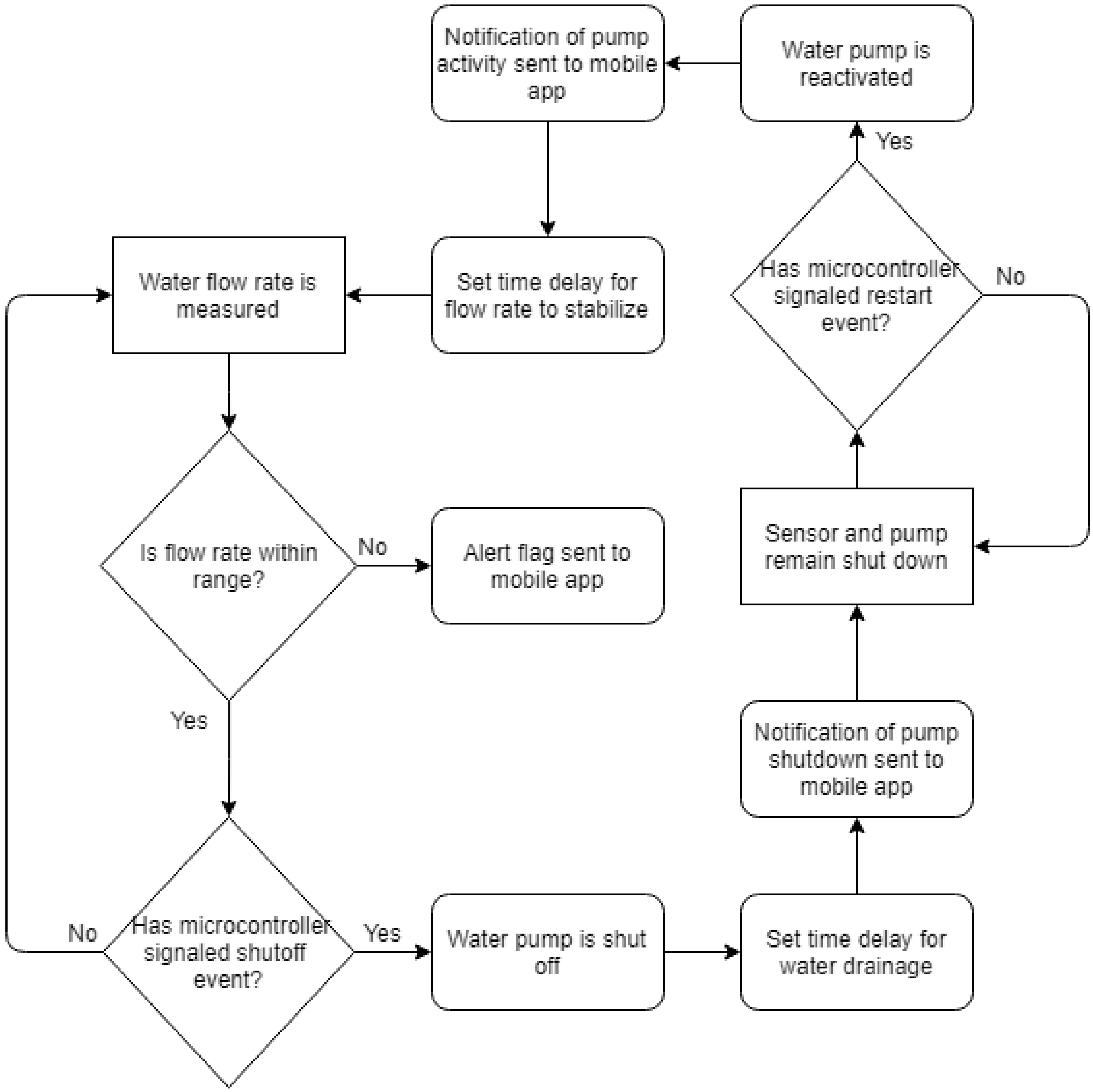
The water flow and pump design will include the working parts that help transport the water from the reservoir to the plants being used in the Wi-Fi hydroponics system. The components will work together to make sure that water is being pumped within the hydroponic system. The effectiveness of this design is going to be important because this is going to be how the water transfers and if the water doesn't transfer properly, plants can risk dying from not getting the amount of water it needs. This system is going to involve the use of the water flow sensor that was chosen by the group and the main water pump that was chosen by the group.

The water flow sensor that was chosen works by detecting the presence of a magnetic field as two magnets in a pinwheel rotate in a circle as water flows through the sensor. As the water spins the wheel to flow past it, the magnetics within the sensor change in position relative to the sensor and an electrical pulse generates. This electrical pulse is what generates and allows for the sensor to determine the flow rate. This sensor will be placed in the main pump which is a pump that has a 5 W motor and 95 GPH flow rating. This way the water flow rate can be properly measured. The main pump will run from the reservoir to the enclosed climate area of the hydroponics system.

The design will involve the sensor measuring the water flow rate. After it does this it will use that measured water flow rate to determine if the flow rate is within range. The reason why It needs to do this is because if the water flows too fast it can result in more water being used than needed. If the water rate is flowing to slow then the group risks not enough water reaching the plants at a time. If the flow rate is not within range an alert will be sent to the user via the mobile app. If it is within the range that is needed, it will progress to the next step which involves the system asking if the microcontroller has triggered a shutoff. If the microcontroller did not trigger a shut off, then the loop restarts and the water continues to flow. If the microcontroller does trigger a shut off event, then the water pump is shut off, and then the notification of the pump shutdown is sent to the user via the mobile app. After this the pump will continue to stay shutoff until the microcontroller signals a restart event. When this happens the water pump is reactivated, and the notification of pump activity is sent to the mobile app. After this happens there will be a slight time delay that allows time for the main pump to stabilize and for its flow rate to stabilize also. From this point on the design restarts and constantly goes through this process again to make sure that everything is working correctly. Malfunction alerts were not implemented into this design because if the sensor shows that there is no water flow during the time that water is supposed to be flowing through the system then there is a problem with the pump. This shouldn't happen often at all but if this does happen during testing then a malfunction alert will be implemented.

The implementation of this design came from the idea that the user shouldn't have to come and manually adjust everything themselves. Everything should be adjustable through the app so that the user doesn't have to always be by the hydroponics system. It should be noted that this system will be subject to change as well and may be altered during prototype testing.

Figure 24: Water Flow and Pump Design

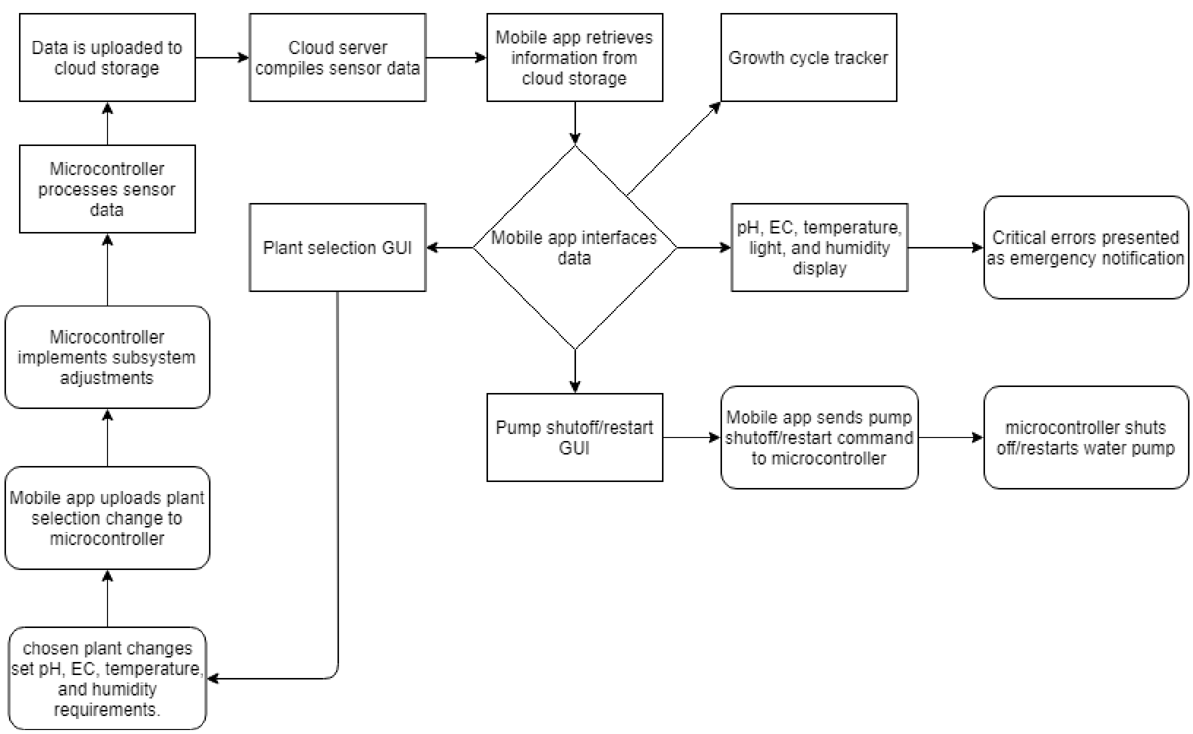


5.6 Mobile App Design

The mobile app design is going to be what grants the cohesive bond throughout the rest of the designs. The reason why this is said is because the mobile app houses a lot of information that is gathered from the other designs within the Wi-Fi Hydro system. The mobile app is going to be capable of interfacing data such as pH balance of nutrients, temperature, light intensity, humidity, and EC. The critical errors that show up from the other designs are also mentioned within the mobile app design. The mobile app also grants access to shut off and restart the pump that is talked more about in the water flow and pump design section. The way it does this is by sending pump shutoff/restart commands to the microcontroller that is being used. From this the microcontroller will shutoff and restart the water pump. The mobile app will also feature a growth cycle tracker that is needed for the user to be able to determine if the plant growth is healthy or not. The most important part that this design holds is the ability to select the plant that the user is trying to grow and then from there it sets the threshold for the pH, EC, temperature, and humidity requirements from the designs that were previously spoken about. After this happens the microcontroller implements the subsystem adjustments and processes the sensor data to upload it to cloud storage. After this is done the cloud server for the app completes the sensor data and then the mobile app retrieves the information so that the mobile app can interface the data.

The reason why all this is being implemented into the app is because the app serves as a managing platform for the user. Without this platform being created for the user, all the information for the different plants must be found by the user on their own. The group wanted to create an easier way for the user to dive straight into being able to use the hydroponics system without a lot of setups. This allows the user to start the growing process of the plants as soon as possible. Another reason why this design is being implemented is so that the user can easily use the hydroponic system from anywhere in the world. The user will not have to be next to the hydroponic system as it is being operated as long the user is confident in the ability to control it from anywhere in the world. It is also worth noting that more functions and capabilities may be added to the app if time allows for this.

Figure 25: Mobile App Design



5.7 PCB Design

Now that the prototyping of the system on the Aduino Mega 2560 Development board is done the group can now move on to designing the PCB. Because the group chose to use the Arduino Mega 2560 as the development board, the microcontroller that is going to be used is the ATmega2560. When designing the PCB the group is now able to focus on more permanent connections and a greater current carrying capacity as opposed to when the breadboard was being used. Before we can dive into this though we must first choose a development environment for the PCB to be used.

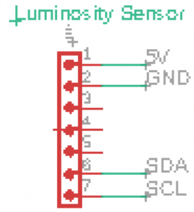
Before the PCB can even be printed the group must first design the PCB that is needed for the project. This happens by first designing a schematic of the device and then using this to create the board layout. There are a couple different software programs that can be used to achieve this and out of the ones that are available to the public there are only two that are being considered. The first one is EAGLE, which is a software that the group is more familiar with and have used it in previous courses. It isn't as simple to use and would take a lot of time to get familiar with using. It also contains an auto route feature that allows the group to route the wires and saves them a lot of time. This may be the one that gets used due to the time constraint given and how there isn't enough time to learn another piece of software. The second one that is being considered is the KI CAD which is a software program that a lot of people were using based upon the research that was found. It seems easy to learn and could potentially be used as well.

After careful consideration the group decided it would be smarter to use Eagle mainly because of everyone's familiarity with it. Now that the software that the PCB will be designed on has been chosen it is time to start designing the PCB. It is also worth noting that the PCB will contain two layers. It will have an upper layer and a lower layer, and the size of the PCB should be as small as possible so that it isn't taking up as much space. It will also affect the cost if the PCB is bigger, so we want to make the area as small as possible. The group hopes to have more components that are surface mounted to reduce the cost in fabrication due to the drilling for through hole components.

The schematic below outlines the pin layout for the ATmega2560. This involves some of the currently planned sensors needing to be added into the system. It is worth noting that some of these connections could possibly change as more information is found out about certain sensors and parts. This controller contains 16 input analog pins and has 54 digital pins.

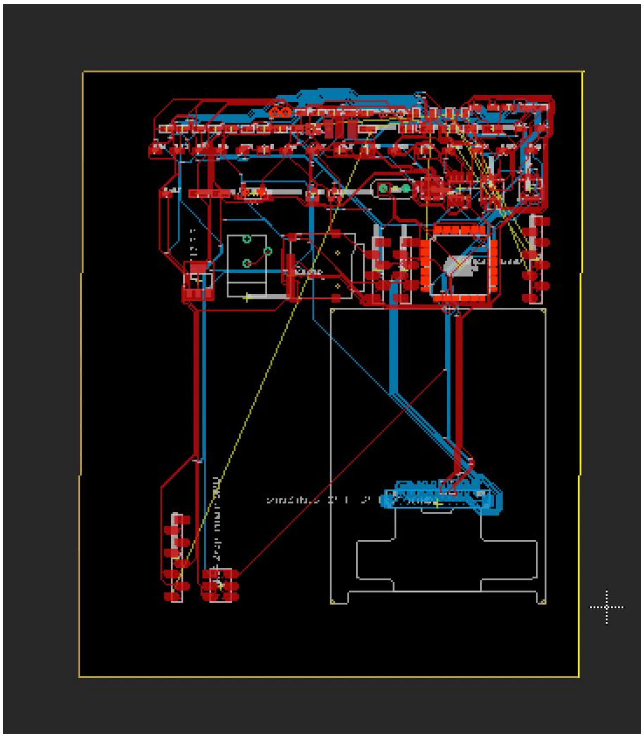
Due to some of the parts not being able to be implemented directly into the schematic some of the parts will be justified using pin headers that connect directly to the analog output and other respective components. An example of how sensors are represented in the schematic is shown below. It is also worth noting that some of the sensors were not able to be implemented just yet due to parts having to be swapped out after prototyping was complete. Also, the schematic for the Bluetooth module, wifi module, and mini touch screen were implemented into the design.

Figure 26: Header Pin Example



After the schematic was finished the PCB board can be made and when this happens, and you go onto board view the wires are not initially routed. Eagle has an autoroute function that still has to be viewed carefully afterwards otherwise the finished product will not look as good or be as efficient. It is a good start on how to get some guidance on the board especially because of the amount of things that are going on in the PCB. After the auto trace was done it was looked at further to see if there was a way to possibly get shorter traces. The figure below shows the result of this.

Figure 27: PCB Before Being Fully Routed



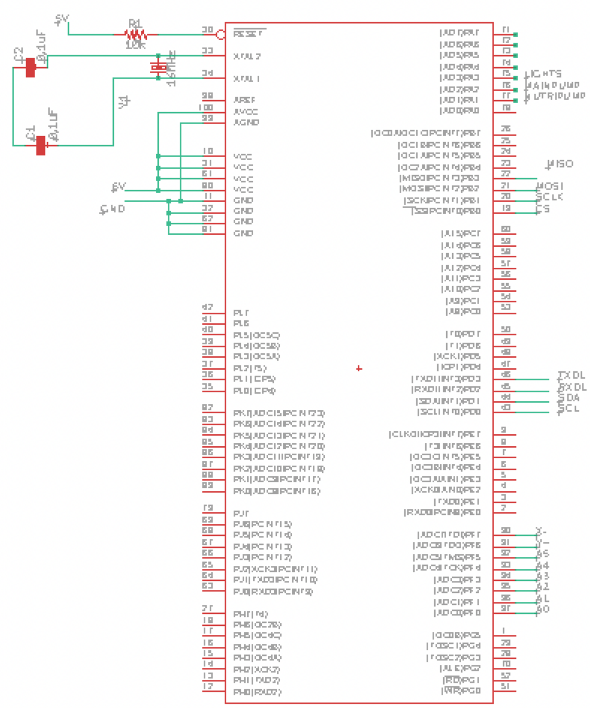
After these two layers were applied to make sure that everything was connected. Creating a ground plane is done by using the polygon tool in eagle. The polygon tool should cover everything in entirety to complete the board. This also assures that every pin can connect. After everything is done with the design and testing on the board should be done to make sure that this is the best possible design.

After the final layout of the PCB is finished, the group must pick a company that can build and ship it off to us. It is probably a smart idea to pick a company in the United States just so that we can receive everything with a cheaper cost. Also, this will cause delivery time to be lower, which is perfect because of the time constraint being given. Additional research and the final decision of the company that prints the PCB will be determined at the time that the final implementation of the PCB is ready.

5.7.1 Board Schematic

The Wi-Fi Hydro Garden system design boils down to a variety of sensors that report back to a main microcontroller. This system can be implemented using a single circuit board that houses the microcontroller and each and every embedded system required to receive sensor data. The board should include the Wi-Fi/Bluetooth module, pin headers for sensors that cannot be integrated, and any other embedded systems required. The schematic of the main microcontroller is shown in figure X. The Atmega2560 features several pins, enough to connect all the sensors required for the design specifications.

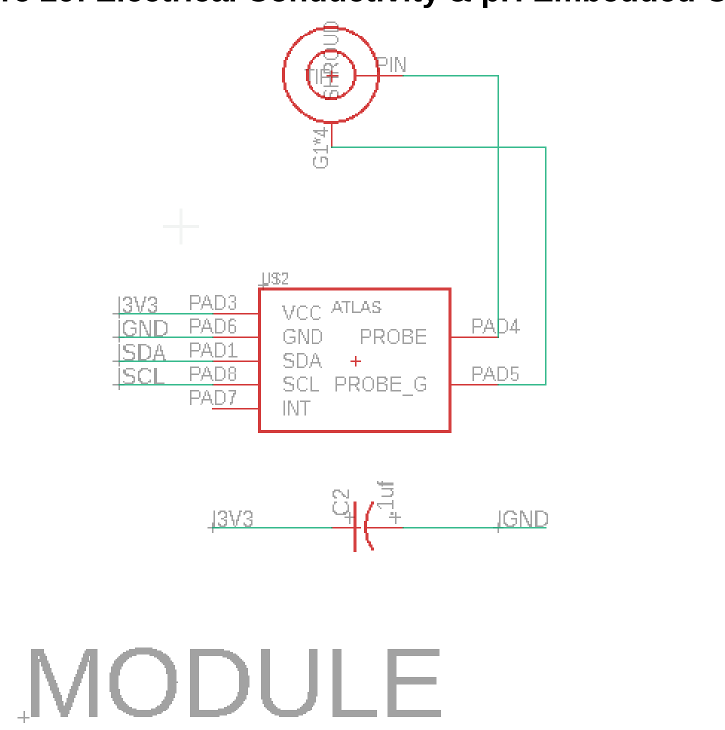
Figure 28: Atmega2560 Connection Schematic



Electrical Conductivity & pH Sensor Processor

The electrical conductivity sensor used to measure the EC and pH levels in the reservoir tank cannot directly connect to the Atmega2560. It requires additional circuitry designed in order for a proper connection to be established. Figure X displays the ATLAS10P embedded circuit connected to a female SMA connector. The output of the ATLAS10P must be connected to an isolator circuit and then the readings can be made by the ATMEGA2560. A VCC, GND, SDA, SCL, and INT pins are required for the ATLAS10P to function correctly. The Atmega2560 provides all these connections. The EC and pH sensor both will require SMA connectors and a ATLAS10P. Therefor, the PCB will have to be designed with consideration for two coaxial SMA cables as part of the system.

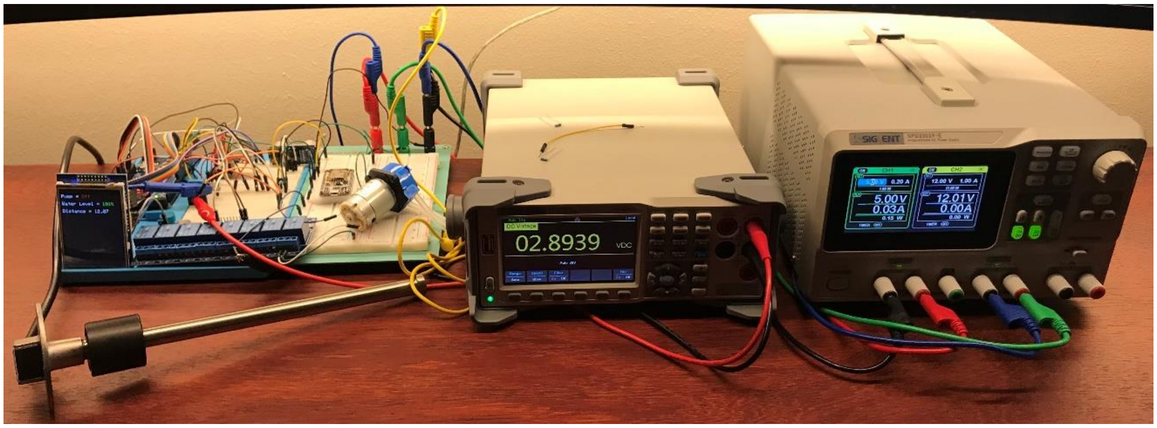
Figure 29: Electrical Conductivity & pH Embedded Circuit



6.0 Integration and Testing – Phase 1

Testing for this project was done mainly on the Arduino Mega 2560 attached to a few different breadboards to accommodate all the different sensors. Because the Arduino is only capable of supplying 500mA at a max of 5V we implemented the use of an 8-way relay module attached to an external power supply to power our devices. Voltage, current, and resistance values were measured with the Siglent SDM 3055 Digital Multimeter. Supplemental power for the 5V and 12V devices were supplied with the Siglent SPD3303X-E Programmable DC Power Supply. The Arduino was programed through the Arduino IDE using a 64-bit Windows 10 machine.

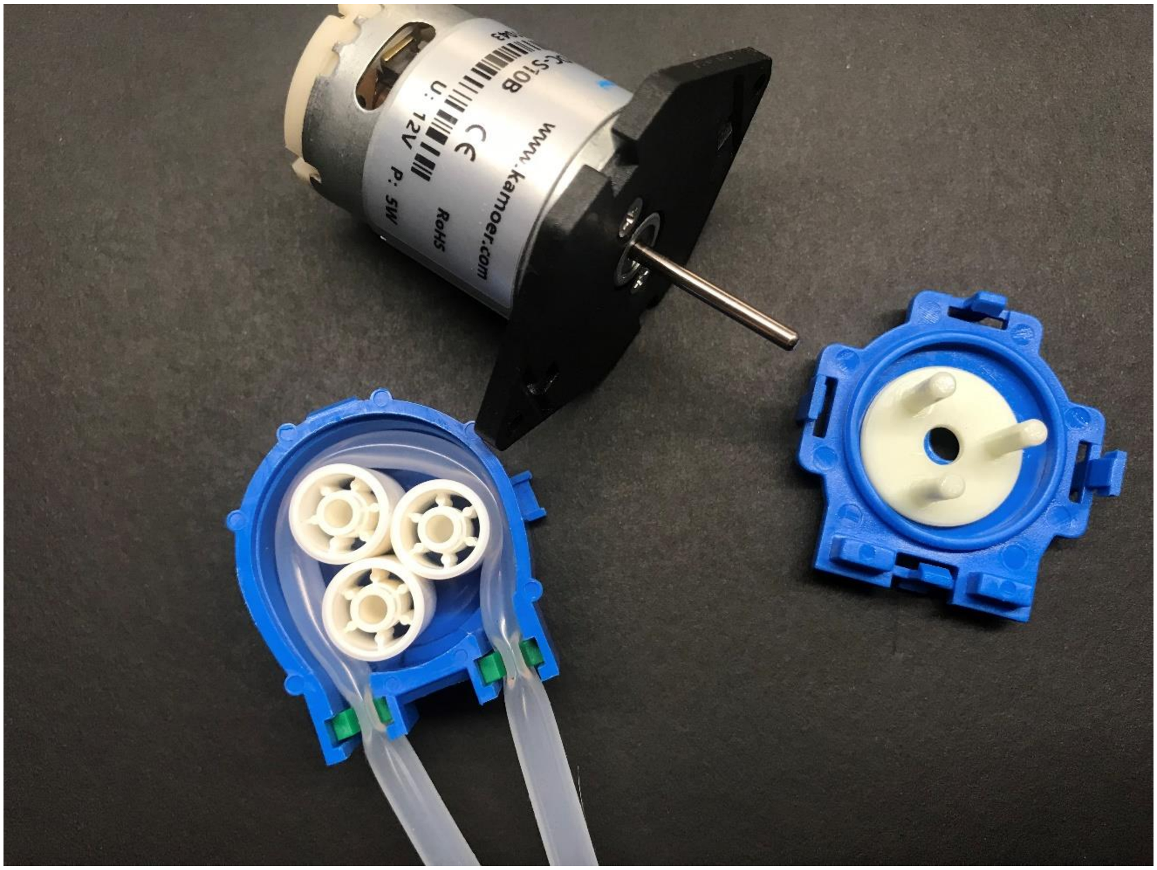
Figure 30: Test Configuration Image



6.1 Peristaltic Pumps

The purpose of the peristaltic pumps is to deliver micro doses of pH balancing solution as well as nutrients to the main water supply to later be pumped up to the plants. There will be a total of three pumps in the final build. The pumps do not need to be primed. You can see in the picture below that the pump works by pushing fluid through the tube with three wheels engaged by a DC motor. The final conditions to engage the pumps will be based on the pH and EC levels of the main tank. For testing the pump was triggered by a simple sonar sensor that would trigger a relay for any object less than 10mm away and supply the required 12V needed to power the pump. The manufacturer states the pump will draw up to 5W of power. Under testing conditions, and with no liquid, the pump was only able to draw an average of 130mA of power or 1.6W. The pump would switch on every time with no issue and provide suction on the intake tube and air pressure on the output side. The final product will control the amount of fluid moved by restricting the amount of time each pump will run. Preliminary research would suggest very little chemicals are needed to change the chemistry of the water dramatically.

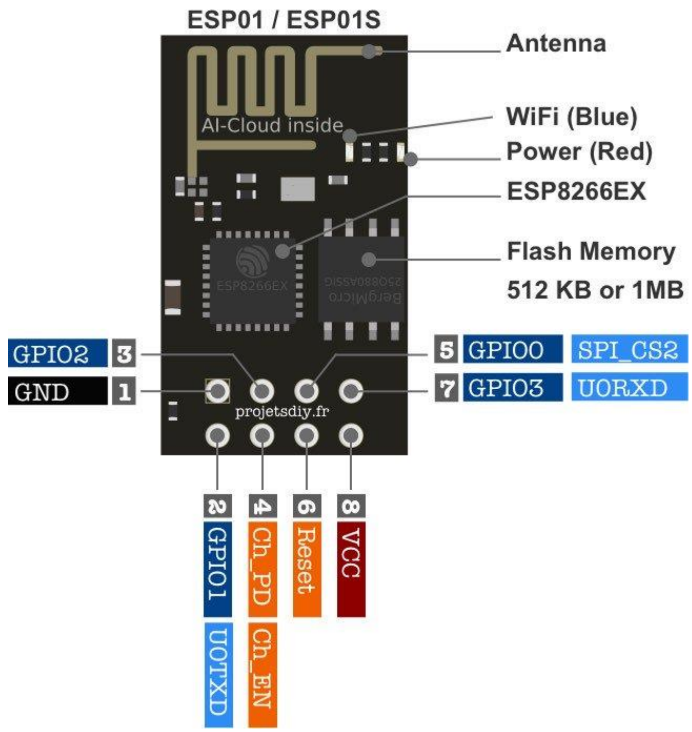
Figure 31: Peristaltic Pump



6.2 Wi-Fi Module

To test our Wi-Fi module, we attached the ESP8266 ESP-01 to a breakout board in order to interface with a breadboard. The ESP8266 ESP-01 comes preprogrammed with firmware version 1.3.0.0 (Jul 14 2016). This firmware mainly controls the AT, or attention commands list which is the primary way of sending and receiving data to and from the module. The module is capable of running its own internal code as a stand-alone module but we need it to interface with our Arduino Mega 2560 board to integrate multiple sensors and commands. You start by defining your SSID and password and sending it to the module through the AT command AT+CWJAP to connect to your local network. So that we were not running blind we set up a guided loop that checked the connectivity status and if not connect would start the connection process over until connected to the requested SSID.

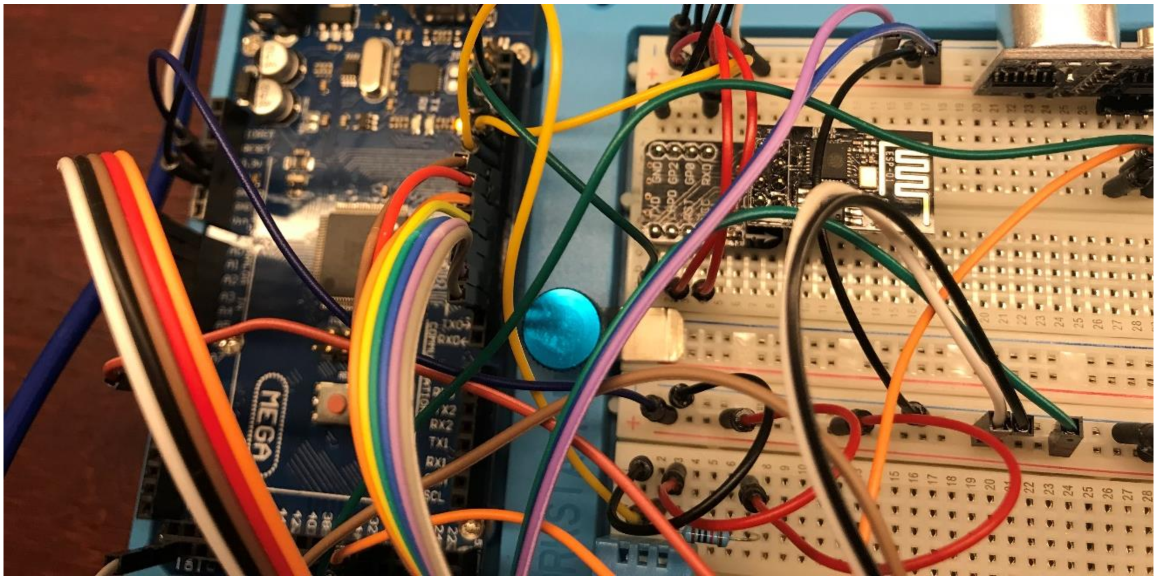
Figure 32: ESP8266 ESP-01 Pinout



After we have connected to the local wireless network and the microcontroller has entered into the main loop of the code, we will need to continuously send data to a specified server. We start by defining the protocol and then the address and port. This is done with the AT+CIPSTART command. For testing we used the thingspeak.com server, you can use HTTP address or IP address, we used the ladder. The thingspeak.com server was able to receive up to 10 different unique variables for the free version. This needed to be ordered in a specific way for the server to add the data to the correct storage allocation. Our program uploads all sensor data every main loop cycle, for us that is about five seconds.

We have not finalized the amount of sensor data that will be sent to the cloud server. Once we have chosen a format, we can adjust the AT+CIPSEND command which includes all sensor data in a specific order so that the cloud can read and store correctly.

Figure 33: ESP8266 Wi-Fi Breadboard Layout



6.3 Temperature / Humidity Sensor

For our project we have decided to use the SHT20 I2C Temperate & Humidity Sensor which is also waterproof seen below. We did not actually get our hands on the sensor by the end of Senior Design 1 to test but we believe this sensor to be the best fit. We talked about integrating two sensors into the build, one in the main water supply and one in the grow chamber. We eventually decided one would be enough and went with the grow chamber. Monitoring the water temperature would be cool but pointless in the end as we would have no way of controlling the water temperature anyway.

The sensor in the grow chamber will be able to, of course, monitor the temperature & humidity of the air the actual plants will be living in. If the values are found to be outside the set limits that are defined in the Arduino microcontroller code, then it will trigger two fans. One fan will be on the bottom of the grow chamber to suck in cool air and the other fan will be mounted to the top of the grow chamber to exhaust hot or moist air. The code will have the fans run for a set amount of time and if the temperature or humidity have not reached a safe level the fans will just continue to run. This sensor will be very import to maintain a safe grow environment. With an enclosed grow structure like ours the temperature could easily run away from us when the lights are powered on.

Figure 34: SHT20 Temperature & Humidity Sensor

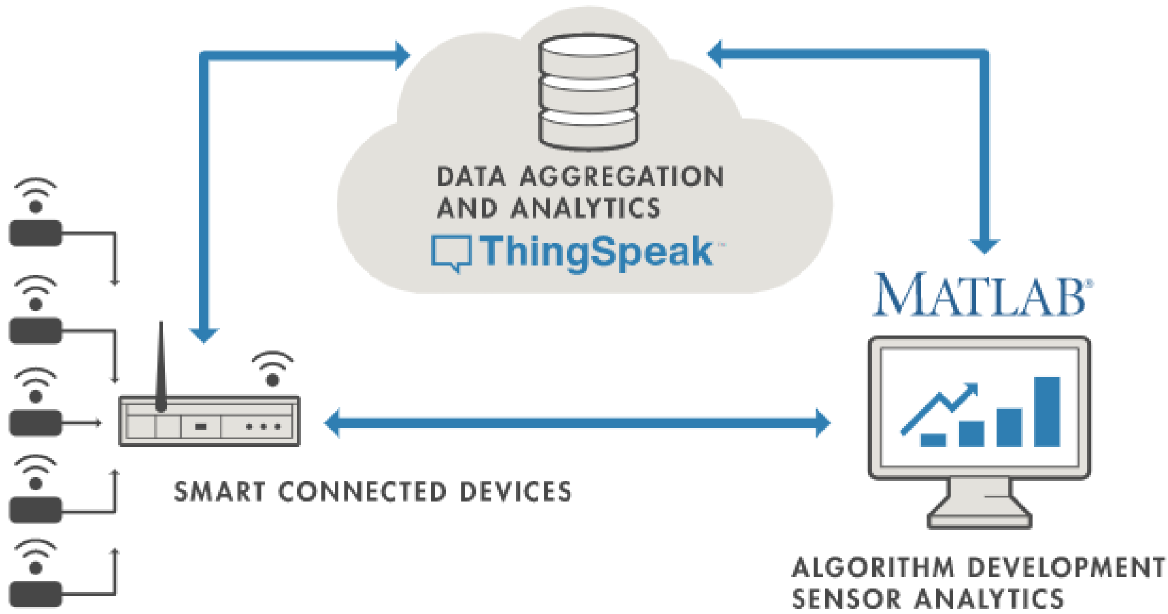
6.4 Cloud Storage

The cloud storage used in testing was the thingspeak.com online server. They offer free all the way up to enterprise levels of service for data analysis. The free service offered up to 10 different data inputs which is more than enough for our current stage of development. During testing we used two different data points labeled temperature and humidity. We originally intended to use the DHT-11 temperature and humidity sensor to send the two different data types but quickly found out that the only sensor we had was broken and we were getting no IO readings.

For the purposes of testing, we used the HCSR04 ultrasonic sensor to measure distance in millimeters. We are not going to use this sensor in any way in the final product but we need something to send data to the cloud and something to trigger the peristaltic pump on and off. We ended up just sending the distance value twice to fill the two data slots. As predicted, there were two identical charts on the thingspeak.com server which proves the proof of concept enough to move forward. You can find an illustration of the data graph on section 3.7.2 of this paper. This site offers advanced data analysis tools like MATLAB and machine learning to further enhance the usefulness of your data.

Because we have a unique data storage requirement, I don't think we will end up using the Thingspeak.com server. As of now it does not have the ability to store pictures and the data retrieval by the iOS app has not yet been tested. I think the solution lies in a custom database running on a dedicated Linux server with specific and custom data fields in order to store our sensor data and image files for easy retrieval by the iOS app. Other options like an SQL server running on a Windows machine will also be explored.

Figure 35: Thingspeak.com Cloud Diagram



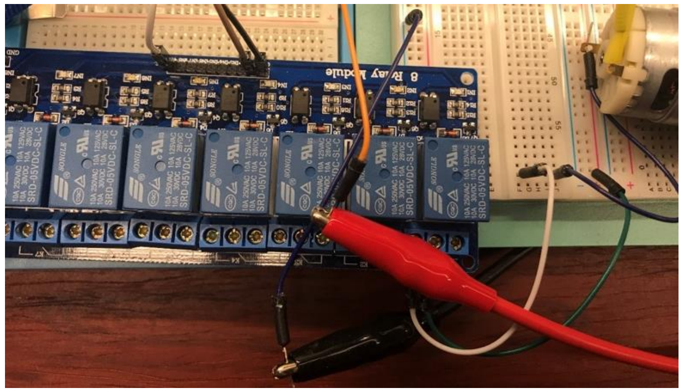
6.5 iOS App

Unfortunately, as of the end of Senior Design 1 we had not started the creating of the iOS app. We still do not have all the details worked out with the cloud storage interface. Once we find the perfect fit for our data storage, we will know how to interface with the cloud using specific API keys and methods of data retrieval. Until then we will continue to learn the XCode IDE through the training course offered by the Udemy online course.

6.6 Relays

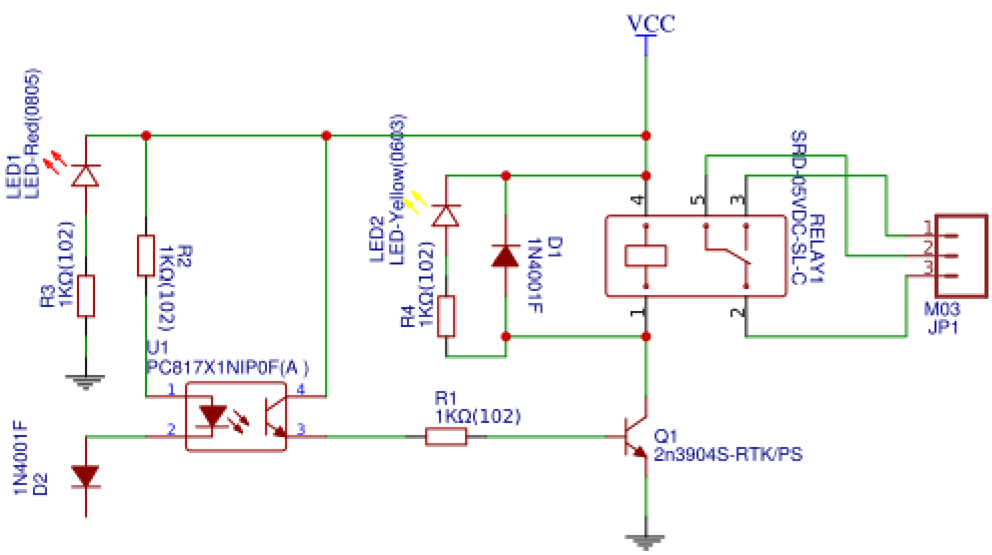
The relay's used for this project are the SONGLE SRD-05VDC-SL-C relay modules. The particular module board used in testing was the ELEGOO 8 Relay Module Board. As you can see in the picture below the top pin header controls the board. It receives 5V VCC from the Arduino board and a ground. All relays are controlled with a single line which supplies a high/low status to the board. In our experience the relay needed to be set to HIGH for an open circuit and LOW for a closed circuit which would turn the peristaltic pump on.

Figure 36: Testing Relay Modules



As you can see in the relay schematic figure below there are five pins to the actual relay module. Pin's 2, 3, and 5 are for powering the device. For our purposes we only used 3 and 5, pin 2 is for a constant power situation which is not applicable for us. Pin 1 and 4 are for actually switching the magnetic relay. Pin 1 is constantly supplied with 5V VCC power and pin 1 is the specific relay on/off command from the Arduino that throws the switch and lets the external power from pin 3 flow to the connected device through pin 5. In our testing we supplied 12V from our DC power supply to pin 3 to run our peristaltic pump. When the LOW command was sent to pin 1 of this relay the switch was triggered allowing current to flow through pin 3 which allowed the pump to run.

Figure 37: SRD-05VDC-SL-C Relay Schematic



7.0 Project Design – Phase 2

In this section, the finalized design for the Green Steel Garden will be detailed. Many of the decisions and theorized ideas were radically changed from the previous sections due to a variety of unforeseen problems that will be detailed in this section. Great effort was had in keeping the core functionality of the Green Steel Garden, however many of the extraneous features were either cut or minimized due to approaching deadlines.

7.1 Final Subsystem Designs

This part will detail the various finalized subsystems used to operate an automated Nutrient Film Technique system. These systems must work in tandem to ensure that growing conditions are in an optimal state.

7.1.1 Nutrient Monitoring 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 38 for a block diagram of the water and nutrient balancing and delivery 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

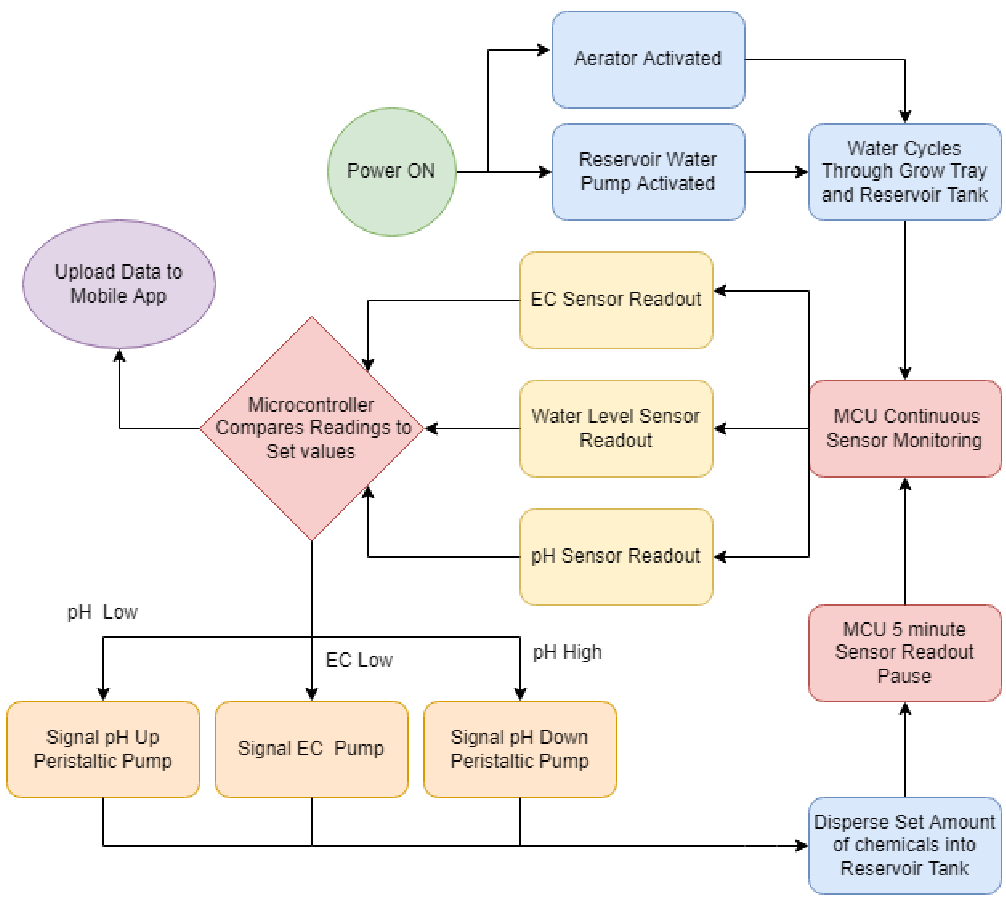


Figure 38: Nutrient Monitoring System

7.1.2 Lights, Temperature, and Humidity 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.

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. Refer to figure 39 for a complete diagram of the final lights, temperature and humidity system.

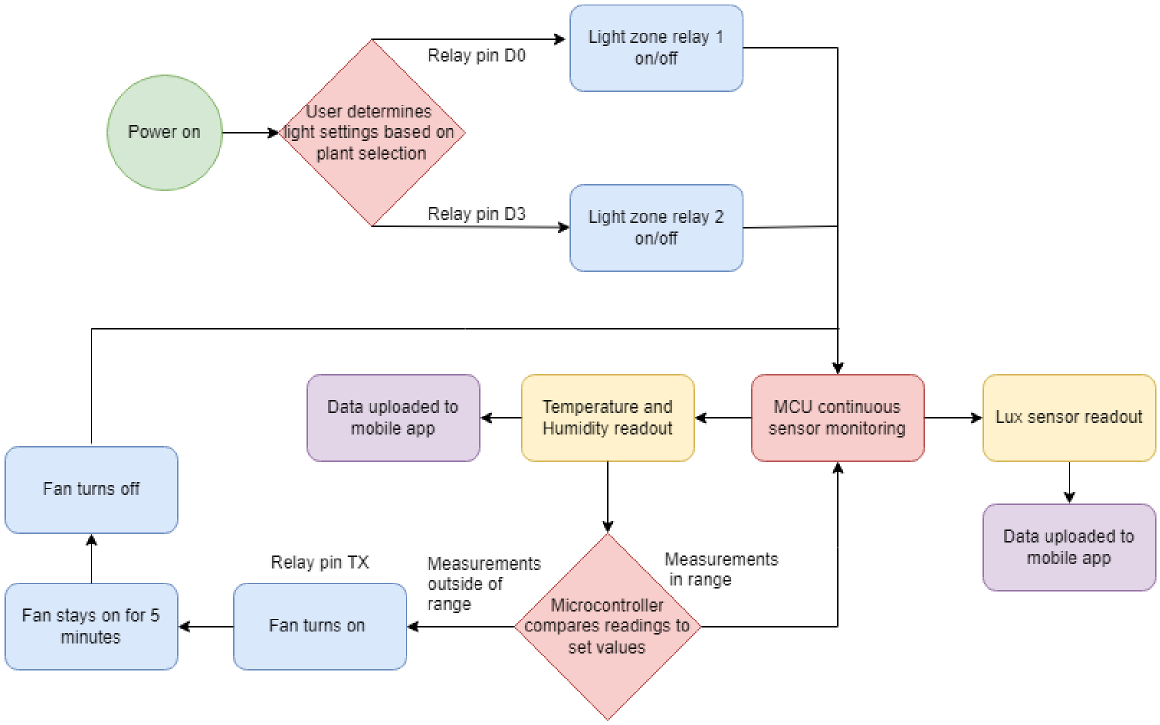


Figure 39: Lights, Temperature & Humidity System

7.1.3 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 25: 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.

1. Water Reservoir Pump
2. Aerator
3. 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. Refer to figure 40 for a complete diagram of the power delivery system.

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 26. Relay Controlled Components

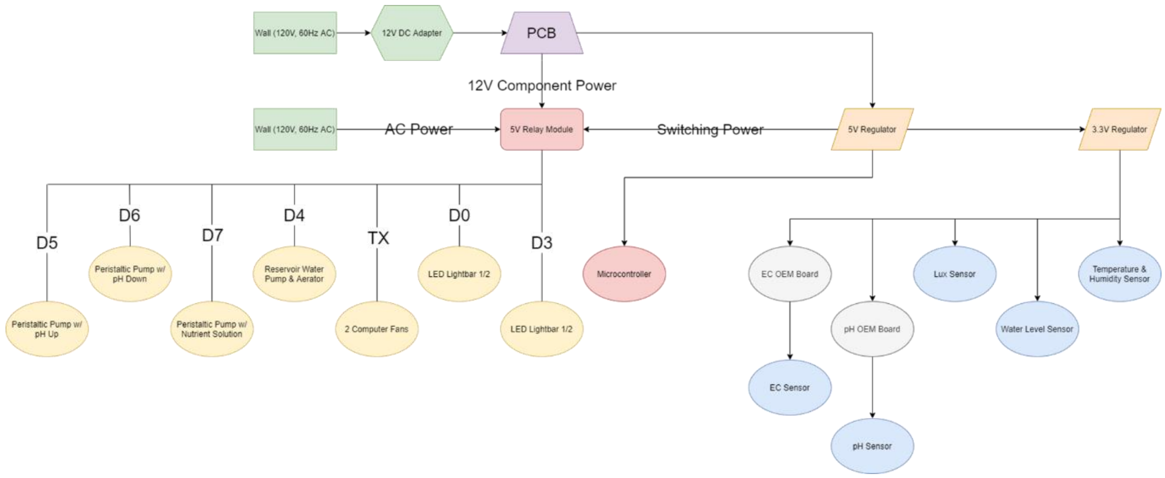


Figure 40: Power Delivery System

7.2 Unchanged System Components

Despite many changes being made to the final overall project design, we are fortunate enough to have many elements remain the same from the initial research conducted. This section will briefly detail the components that were selected from the beginning and remained as part of the system until the final design.

7.2.1 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.

7.2.2 Peristaltic 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.

7.2.3 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.

7.2.4 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.

7.2.5 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.

7.2.6 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.

7.2.7 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.

7.3 Changed System Components

This section will detail changes in our system design that happened after initial research was constructed. Many of these changes were related to time constraints and development difficulties.

7.3.1 Final Microcontroller Choice

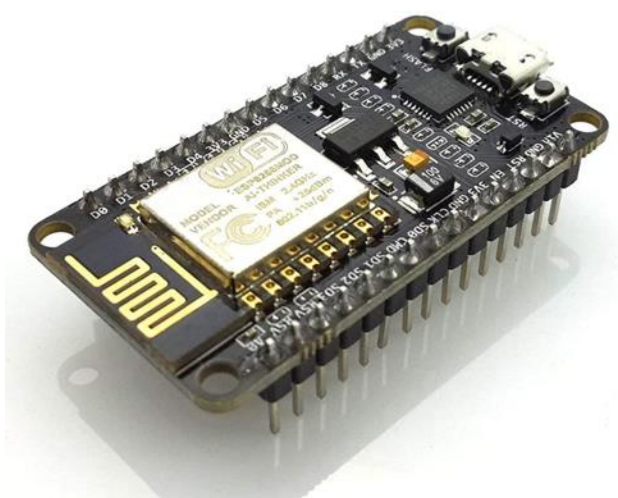


Figure 41: HiLetgo ESP8266 NodeMCU

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.

7.3.2 Final pH Sensor Design

The previously selected pH Sensor was the Mini Lab Grade pH Probe by Atlas Scientific. Despite the high up-front cost, it was selected due to the ability of the probe to be submerged continuously without degradation of the sensor readings. Unbeknownst to us at the time was that was fact that the pH sensor itself cannot be directly connected to the a microcontroller and have reliable measurements be read out. The Atlas Scientific pH Probe requires the use of a proprietary circuit sold by Atlas Scientific. Figure 42 displays the OEM circuit required to attain functionality of the pH sensor selected.

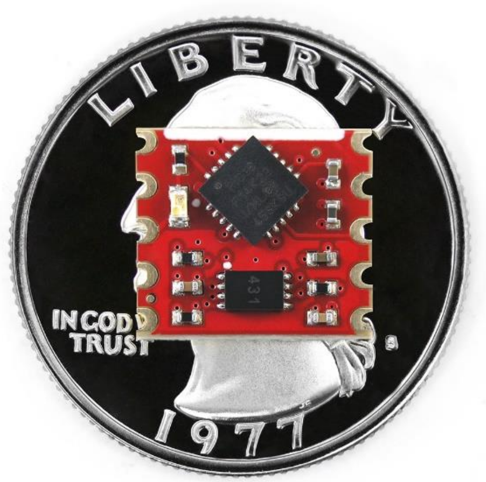


Figure 42: Atlas Scientific pH OEM Circuit

The pH OEM Circuit allows for sensor outputs to be done through UART or I2C. For our purposes, I2C proved to be the most comfortable choice. The circuit used contains 26 different read/write accessible registers. Many of these are used to calibrate values and control addresses used. The pH OEM circuit has a readout time of 420 ms per reading.

7.3.3 Final EC Sensor Design

The electrical conductivity sensor selected in the previous section was the Atlas Mini Conductivity Probe K 1.0. Similar to the pH sensor, the EC sensor provided by Atlas Scientific has a high up-front cost but was selected due to the ability of the probe to be submerged continuously without giving erroneous readings. Continuing with the similarities, the EC sensor also requires an OEM circuit provided by Atlas depicted in Figure 43.

Figure 43: Atlas Scientific EC OEM Circuit

The EC OEM circuit functions similarly to the pH OEM Circuit in the sense that it allows for sensor outputs to be done through UART or I2C. Since the pH sensor was already set up through I2C, the EC OEM circuit was initialized through the same process. Due to the differences in what the probes are measuring, the EC OEM circuit has different characteristics compared to the pH OEM Circuit. The most notable difference is that the current used by the EC OEM circuit is not a constantly being drawn. If the solution being measured has an electrical conductivity of 0 then the probe does not have any electricity flowing through it, and the OEM circuit will draw enough current to power the microcontroller on board. Comparatively, if the solution has very high conductivity, then the current draw of the OEM circuit will be higher. The range Atlas Scientific has listed on relevant documentation depict a current usage of 10.6 mA to 26 mA. With the finalized power system, this proved to be a nonissue.

There are 36 different 8-bit registers accessible through I2C. Despite not being mentioned on the probe component, when used with the proprietary OEM circuit, there are sensor readings for total dissolved solids and salinity within the solution. This proved to be a pleasant surprise as it increased the functionality of the Green Steel Gardens sensor readouts without incurring any additional development.

7.3.4 Final Webserver Choice

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. Refer to a figure 44 for a depiction of the InfluxDB Server layout.

Figure 44: InfluxDB Server used for Data Metrics

7.3.5 Final PCB Design

After several PCB design iterations, we arrived at the schematic depicted in figure 45. This schematic features all sensor connections localized onto the board with the addition of the of an integrated power delivery system. The result is a singular 12V DC power input onto the PCB that will fully power every single component utilized in the Green Steel Garden's autonomous system.

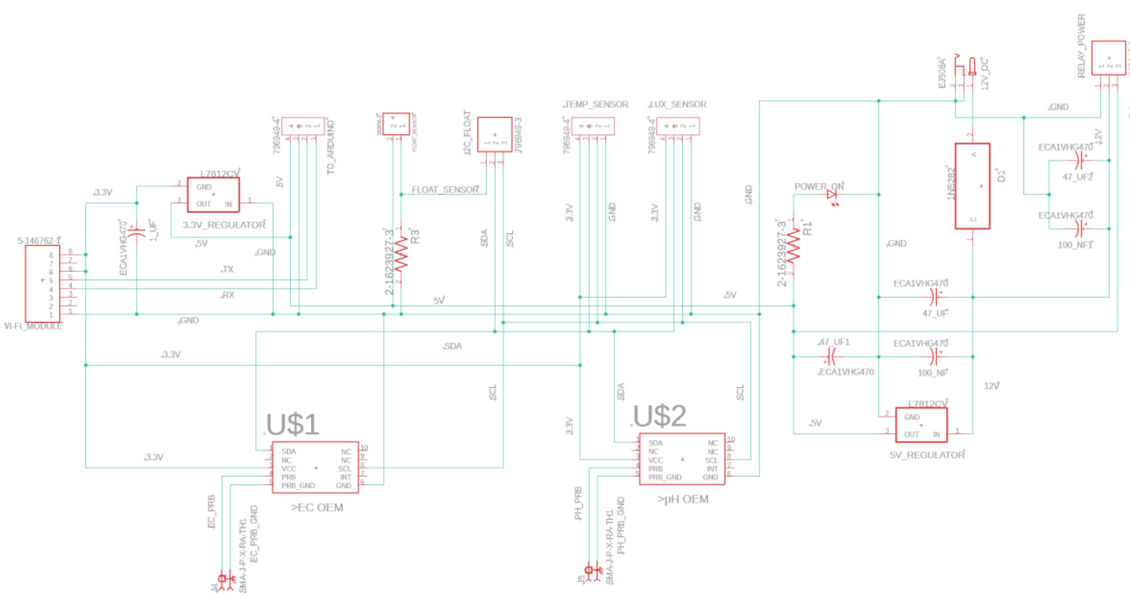


Figure 45: Final PCB Schematic

The PCB schematic does not include an integrated microcontroller on the board itself. In the earliest iteration of the PCB, this was included using the Arduino Atmega 2560. Despite the intentions of including this on the PCB, the cost and time it would take to have the PCB fabricated and delivered proved to be too far out of the scope of the project timeline. Faced with this reality, we opted to trim down the PCB to components that we could readily test and have shipped out without too much delay. Despite the absence of a microcontroller on board, the PCB still fulfills significant design requirements by having all primary sensor inputs

& outputs on board, as well as using an integrated power delivery system to power the Green Steel Garden.

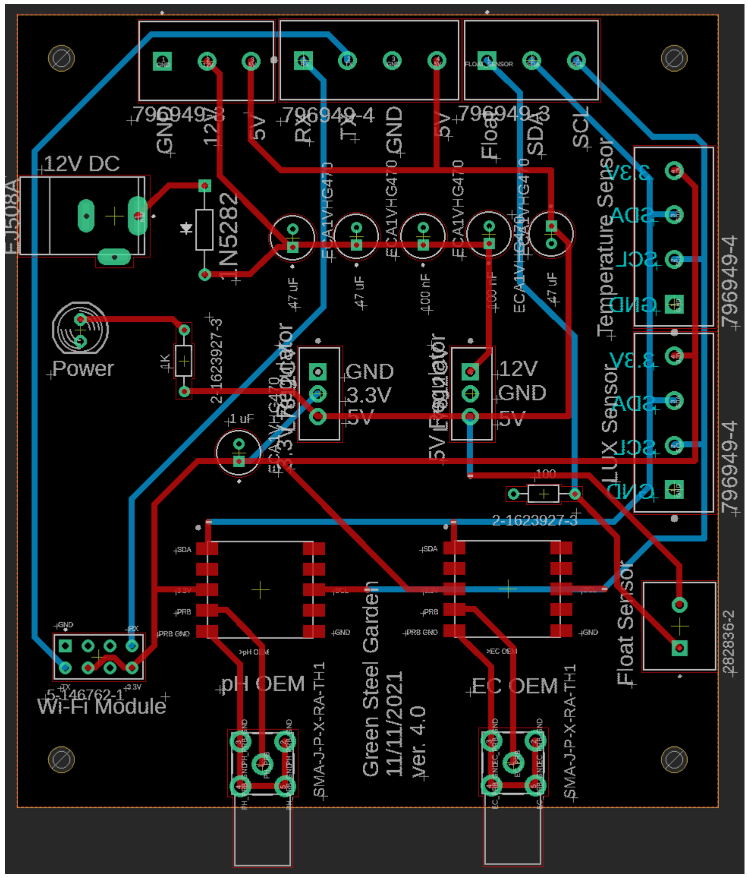


Figure 46: Final PCB Routed Design

Figure 46 depicts the routed PCB design after the schematic was finalized. As one can see, all wires are angled appropriately to reduce interference while maintaining the shortest possible distance between nodes. 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 47.

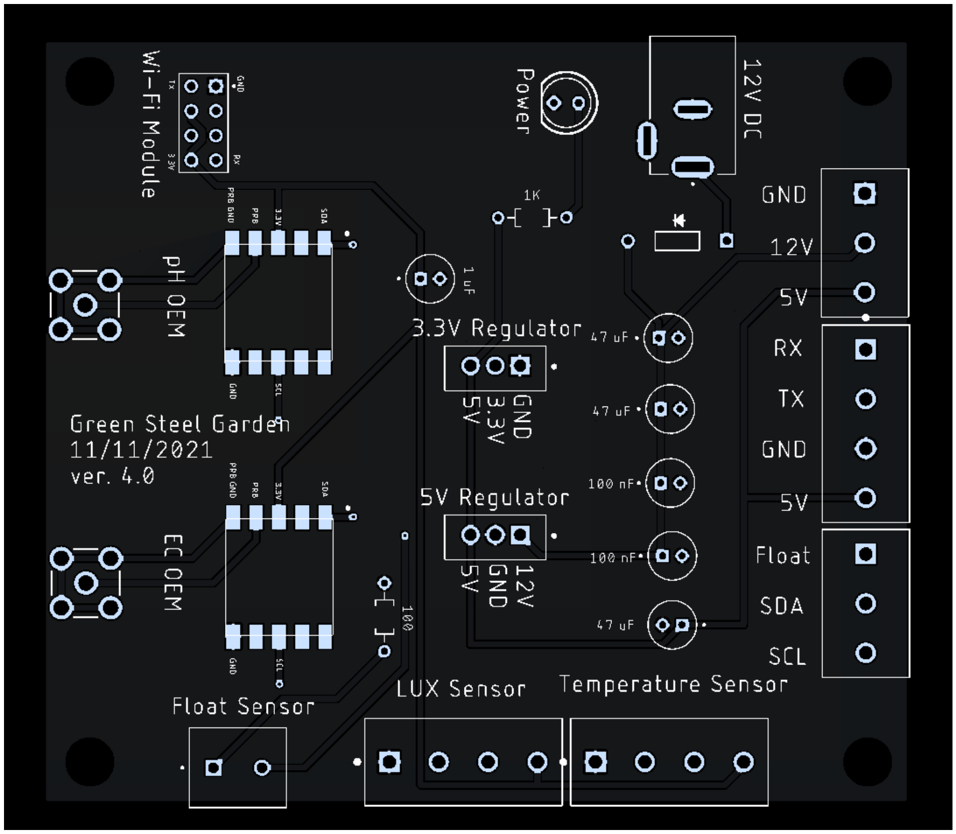


Figure 47: Final PCB Layout

7.3.6 Mobile App Design

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. Refer to figure 48 for mobile app layout.

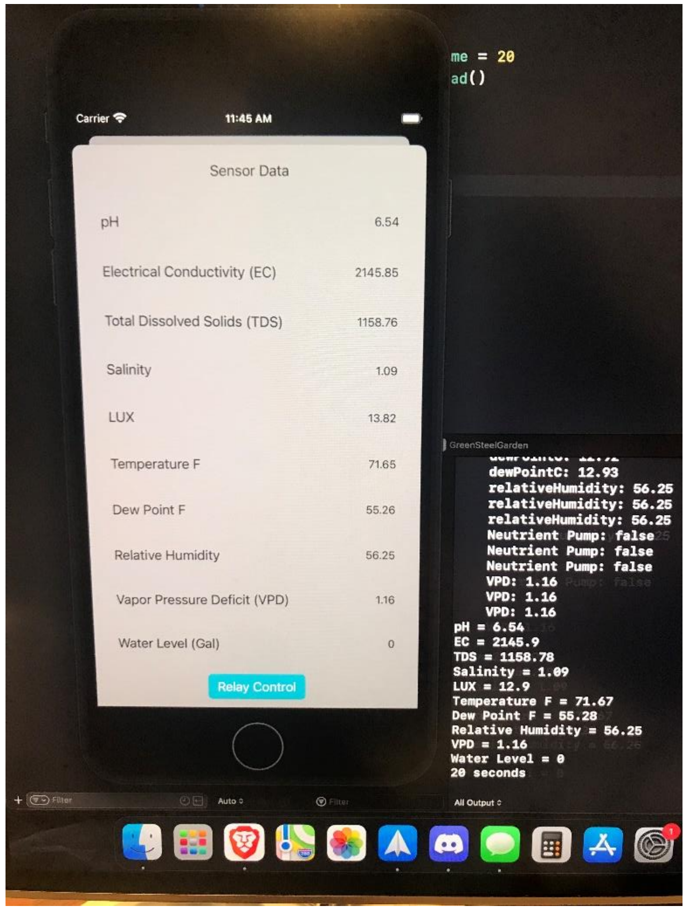


Figure 48: Mobile App Design

7.1 Project Milestones

The overall project is broken into smaller tasks, within the Project Milestones table, that needs to be completed over the next two semesters. Those different tasks also include the due date and who is responsible for the completion of them. This allows the group to physically see what is left to accomplish and when they need to be accomplished by.

Table 27: Project Milestones

Senior Design I		
Task	**Due Date**	**Responsible**
Form Group	05/20/21	Group 11
Project Idea	06/01/21	Group 11
Initial Project Document	06/12/21	Group 11
Idea Review w/ Professor	06/15/21	Group 11
Update Initial Project Document	06/25/21	Group 11
Order Test Components	06/30/21	Group 11
60 Page Document	07/09/21	Group 11
Test Components	07/10/21	Group 11
100 Page Document	07/23/21	Group 11
Final Document	08/03/21	Group 11
Senior Design I Finished		
Senior Design II		
Order PCB	TBD	Group 11
Order Parts	TBD	Group 11
Hardware Check	TBD	Jon, Ryan
Software Check	TBD	Christopher, Jehron
Manufacture Prototype	TBD	Group 11
Test Final Product	TBD	Group 11
Product in Working/Presentation Condition		
Final Presentation	TBD	Group 11

7.2 Bill of Materials & Project Budget

Table 28: Parts and Price Breakdown

Part	Quantity	Price	Total
Peristaltic Pump	3	$ 9.50	$ 28.50
Silicone Tubing	1	$ 9.99	$ 9.99
Wi-Fi Module (4)	1	$ 11.99	$ 11.99
5" Caster Wheels (4)	1	$ 29.99	$ 29.99
Main Water Pump	1	$ 11.99	$ 11.99
Main Water Reservoir	1	$ 16.47	$ 16.47
Solution Containers (6)	1	$ 11.99	$ 11.99
Arduino MEGA 2560	1	$ 19.90	$ 19.90
Wi-Fi Breadboard Adapters (5)	1	$ 9.99	$ 9.99
Water Filter	1	$ 8.99	$ 8.99
Water Level Gauge	1	$ 28.99	$ 28.99
Steel Structure	1	$ 240.68	$ 240.68
			$ -
			$ -
			$ -
			$ -
			$ -
			$ -
			$ -
			$ -
		Grand Total	$ 429.47

8.0 Results

The first engineering specification demonstrated was whether the Electrical Conductivity (EC) sensor would deliver a value with maximum 7% error. This was tested with calibration fluids with peak high and low electrical conductivity values. At both values a reading was displayed on our app that was within this threshold.

The second engineering specification demonstrated was whether the pH sensor would deliver a value with maximum 1% error. This was tested over time as the pH level was changed to various values and the system successfully adjusted and sustained itself at the set value within 1% error.

The third engineering specification demonstrated was whether the mobile application would update the system metrics within 25 seconds. This was tested by timing the amount of time between updates and mobile app did indeed update within 25 seconds.

9.0 Appendix

9.1 References

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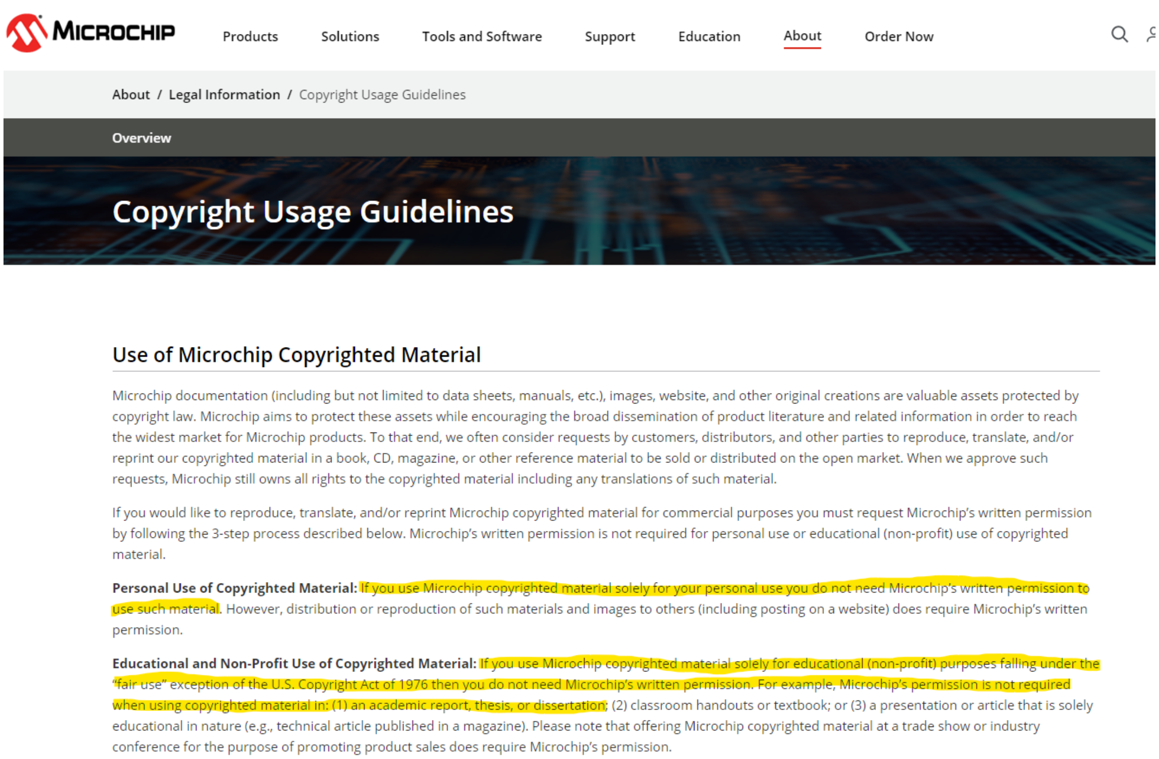
9.2 Copyright

9.2.1 ATmega2560

Figure 38: Atmega2560 Copyright



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