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EasyHerb
EEL 4915L Senior Design II
Group 7

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1.0 Executive Summary

In a world that is growing more and more connected at a very fast pace, many people are finding that their lives are also growing busier and busier. With busier schedules, many find it hard to find time to spend outside in nature and getting fresh air. As a result, more and more ordinary people are becoming interested in bringing a little bit of nature into their lives themselves by growing plants in gardens or in their houses and workspaces. Fresh produce has also become quite expensive in recent times, leading people to become interested in growing some of their own produce in order to save time and money. This move to growing some of your own crops also has positive environmental impacts, since it decreases the need for large commercial farming systems and by removing the need for long distance shipping can help to decrease greenhouse gas emissions. Growing your own plants, especially food crops, is becoming more appealing for the average person, however, for many people they lack experience in growing plants and may not know how to start. There are abundant resources available for someone wishing to start growing their own plants, so much so that it can be overwhelming. This project aims to help solve this problem by creating a hydroponic growing system that is able to provide the essential steps for plant growth and care to a few small plants without requiring the user to learn much more than how to click a few buttons and pour some water in.

This project is specifically focusing on developing a system for the ideal growth of herbs, especially common cooking herbs. Since we are inspired by the average person who wishes to grow more plants, including crops, within and around their home we decided to focus on herbs since they do not take up much space, so they can be grown even in a small apartment, and they provide a helpful crop that many wish they have easy access to. It is incredibly common for someone shopping for some fresh herbs for a recipe to look at the price and decide on a whim that they would rather buy a whole plant in order to save money in the future. We ourselves have brought home a few unplanned herb plants after just running to the hardware store to quickly pick something up. Unfortunately, since most people are not experienced with caring for these herb plants, they do not last very long, and the person is left with a small plant graveyard. This system is aiming to reduce the number of herb casualties by providing an easy way for the average person to care for their herb plants without needing to do significant research or have excessive time to attend to them.

Most people today live very busy lives, going to and from work, caring for family, running errands, and more. They may wish to have the benefits of growing their own herb plants in their homes, but do not have the time to care for them as ideally as is needed. This project will develop a system that is able to mostly care for itself, limiting the required amount of user interaction. The user would need only plant the herbs in the growing medium and input the necessary data on the type of herb they are growing, and the system would take care of it, providing water, light, and nutrients to the plants as needed. Of course, the user would still need to add water and nutrients to the system so that it may use them, but by automating the process of providing water and nutrients to the plants themselves, the system is able to remove the confusion that could arrive from having to measure and mix the necessary amount of nutrient solution per amount of water and the hassle of remembering when the plants were last watered and when they need to be watered again. The system will also be able to alert the user when it is necessary to refill the water reservoir or nutrient compartment, so the user will not have to manually check these amounts themselves. The automation of this system also will make it ideal for use when a person goes on vacation, a work trip, or is otherwise away from their plants for an extended period of time. As long as they refill the reservoir and nutrient compartments and plug the system in before they go, it will be able to take care of the plants all on its own. The user will also be able to monitor the plants and the levels of water and nutrients by checking a webpage or app that will relay the status of these elements, as well as display a live feed of the plants.

The use of a hydroponic system has several advantages which lead to our team choosing this as our method of choice. Hydroponic systems offer an increased rate of growth as well as greater yield and this useful because a user is able to maximize the harvest from this planter. Another benefit to hydroponics is that it saves water compared to traditional agriculture practices. Hydroponics also takes up less space and allows a user to grow their plants virtually anywhere. These important factors lead to the team choosing hydroponics as the approach for this project.

Although this project requires significant research and knowledge related to herbs and plant growth, at its heart, it is an electrical engineering project. The information regarding the needs of the herbs is used to determine how the system will provide these necessities through and electronic automated process. A printed circuit board with a variety of sensors, motors, cameras, screens, and more will be necessary to implement this plant care system. The project will also require significant programming to allow it to run on its own and communicate that data it receives with the user. This document explains the design of this project and the research involved in developing it.

2.0 Product Description

The following sections will express our desire to complete the proposed project and gives a brief introduction into an overview of the plans for the project. A discussion of the purpose and goals our team would like to achieve can be found in this chapter. A schematic that depicts the envision of the completed project will be included and explained to introduce the end result of the project. The engineering specifications are addressed as these are important in presenting a satisfactory product to the customer. This allows for the group to develop a set of requirements that the system must meet in order to provide the user with an exceptional product. The specifications for each of the subsystems will be addressed. Lastly, the assignment of responsibilities for each group member is addressed. The responsibilities will be accompanied by flow diagrams of how the different elements of the hardware and software will be integrated together.

2.1 Product Background and Motivation

Keeping a small herb garden in your kitchen can be very convenient, providing fresh herbs whenever you need them and ultimately saving money in the long run. Due to these benefits, many people find themselves wanting to start their own small herb garden, but for the average person who might not have much experience with plants this can be a complicated task. Even a few small herb plants require sufficient sunlight, careful watering, nutrient supplements, and more.

The motivation behind this project is to create an automated plant care system that can help the average person grow their own plants in their home. The system is lightweight and so it can be implemented in compact spaces like a kitchen or apartment. The system focuses on growing common cooking herbs, like basil and thyme. A hydroponics system is used to water the plants and provide nutrients. Various sensors measure the ambient temperature around the plants, the water level within the reservoir, the amount of light the plants are receiving, and the pH level of the water. This data is used to determine when the plants will be automatically watered, if the grow lights need to be turned on and for how long, and if the temperature is appropriate for the plants. The system is able to water the plants, add nutrients to the water, and adjust the grow lights automatically. Additionally, the system will send alerts to the user if the water in the reservoir needs to be refilled. The data gathered by the sensors will also be displayed on a website.

Figure 1 shows a sketch of how the system is expected to look upon completion, along with desired features in the design. This design is based off initial knowledge. It may change as the project progresses due to prototyping and trouble shooting.

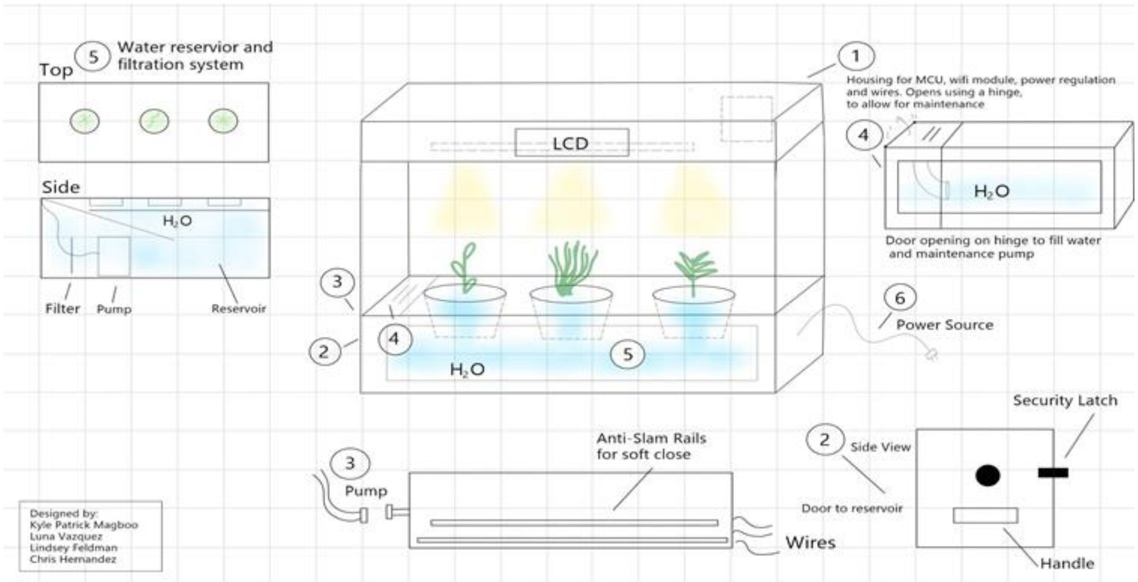

Figure 1: Design Sketch of System (by Luna Vazquez)

2.2 Project Objectives

The goal of this project is to design and create an automated plant growing system that is easy to use so that anyone can easily grow their own herbs in their kitchen. The system should be contained in one device and be powered by a wall outlet. The system is to be automated allowing for it to function using minimum observation. Data will be recorded from the sensors to determine any adjustments that need to be made in the system. The recorded data will be compiled and available for view by the user in a web-based interface. Examples of adjustments include lighting, water and nutrients. The user is alerted when a change in the system is made and if they need to do any maintenance to keep the system running properly. Another goal of the device is ease of use; the system should be user-friendly and convenient. The system's purpose is to grow common cooking herbs, keeping them alive and healthy.

2.3 Requirement Specifications

Using the nature of this project as well as the objectives established by the team, engineering specifications were set. These are to act as a checklist to not only state the product specifications, but also the goals put forth when designing and building the system. There were also general specifications that were decided involving our overall system that were made. The general specifications requirements are shown below (**Table 1**).

Attribute	**Value**
Weight (empty)	15 lbs.
Dimensions	28” x 20” x 10”
Number of Plants	2
Operating Temperature	0 ° to 45 °C
Operating Voltage	12V
Water Volume	8 liters
Sensor Measurements	1 per hour or on demand
pH Sensor Range	0 - 14
Ambient Temperature Range	15.5° to 21 °C
Water Temperature Range	18.3° to 21 °C
Water Pump Flow Rate	63 Liters per hour (16 Gallons per hour)
Camera Resolution	2 megapixels
Grow Lights Intensity	Red: 390 – 420 mcd Green: 660 – 720 mcd Blue: 180 – 200 mcd
LCD Resolution	480x320
Data Rate	6Mbps - 54Mbps
Maximum Signal Power	16dBm
Microcontroller Frequency	16 MHz
Microcontroller Flash Memory	32 KB
Microcontroller Architecture	8-bit
Working Environment	Indoor

Table 1: General Specifications

Attribute	Value
The system should measure gallons of water within a specified range	± 0.1 gallons
The light system should change accordingly within a specified time after an event triggers	5 seconds
User can remotely change state of lights within a specified time	Within 3 seconds
The PCB regulates the input power supplied down to a specified voltage that is supplied to the rest of the system	12V to 5V
Accurate ambient temperature readings within specified range	± 0.5 degrees
Bluetooth connection to speakers within specified time	Within 3 seconds

Table 2: Engineering Specifications

Table 2 above shows our engineering specifications for the hydroponic system. They were set in order to confirm that the system is able to function like how it is supposed to. Certain tests were conducted to guarantee that these specifications were met

Power Supply

The system is powered from a wall outlet.

Control

The system will handle the various technologies used for automation such as the water pump, nutrient dispenser, etc. Implementing a microcontroller will allow information to be processed and analyzed to control the many routines. This process is designed to achieve automation. Data collected by the sensors will be sent to the microcontroller. This data is then passed through a series of computational functions and a decision is made to correct any deviation from the ideal growth conditions set by the software.

Communications

The system uses two methods for communicating with the user. A touch-screen display monitor of reasonable size will be attached to the device. This will handle initial setup as well as displaying various sensor values and timers.

The second method will manage communication over a wireless network through two methods. A Wi-Fi module connected to the microcontroller sends data over the network to a non-local server. The user will be able to access information containing statistics about their device, sensor data and settings through a web interface. A Bluetooth module will also be included to allow the user to wirelessly connect to the device speakers and output audio from their personal device. In the final design, a separate Bluetooth module wasn't used as stated, instead the amplifier board had Bluetooth capability mounted onto it for the speakers.

Sensors
The system includes numerous sensors to measure the conditions of not only the plants themselves, but also the environment. A water level sensor, pH sensor, temperature sensor, and light sensor will be used.

Hardware
The system includes 3 spaces to hold different plants, a reservoir for water, and pumps and filters to water the plants, add nutrients, and maintain the water.

Software
The system handles the input from the various sensors and control the hardware used to regulate the growth of the plant. This data will be outputted to an LCD screen which is attached to the device as well as a companion web interface.

The system has a website that stores all data and settings for each device. A user will be able to stay updated on their plants' growth and device settings. The website will display the information collected in various forms of graphs. This is to facilitate the understanding of analyzed data. Photos of the plants taken by the device can be viewed on the website to also track growth.

Device routines and settings can be modified locally through the LCD screen as well as non-locally through a web interface. The system also allows users to select their level of automation. Ranging from nearly full automation to manual control, the user will be able to change how much growth automation the plant undergoes.

2.4 House of Quality
The house of quality is a way to combine the engineering specifications with the desires of the targeted customer. Thinking critically about how these two complements each other will aid in the delivery of a strong product that is able to meet the needs of the consumer. This also allows the group to consider which specifications are most important when designing the product. Another important thing that the house of quality highlights is the potential tradeoffs with making changes to certain portions of the system. The vertical column contains the qualities of the product that are most important and desirable to the user. Next to this is a column that ranks the customer desires in order based of off their importance. Horizontally are the design requirements, which have been previously specified in **Table 1**. Then a correlation between each of the traits is specified with a weight based on if the two correlates strongly or not. The roof shows the correlation between the specifications. The completed House of Quality for the Hydroponic system can be seen below in **Figure 3.**

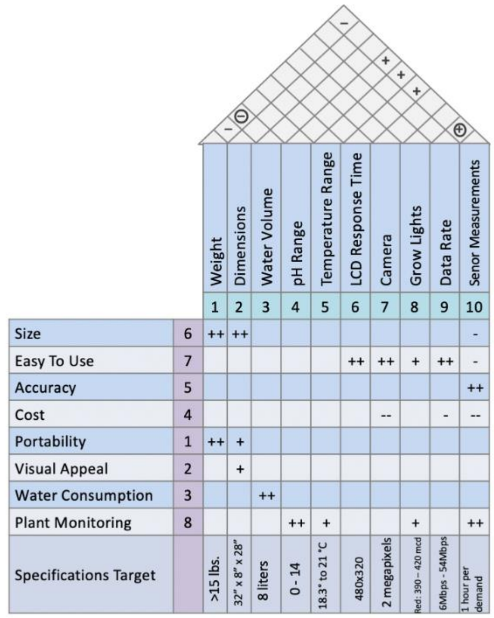

Figure 3: House of Quality

From **Figure 3**, it can be seen that the user expects to gain a system that aids in plant monitoring and the various sensors included in the system will aid the user. Inclusion of these sensors, along with the overall environment required for growing the plants will determine the size of the final product. Additional features were added to the system to allow the user ease in operating the product. Due to these features it can cause the overall price of the product, which is a negative that the consumer will face.

2.5 Assignment of Responsibilities

In order to depict the functions of our design, the system is broken down into two major block diagrams, the first is hardware (**Figure 4**) and the second is software (**Figure 5**). The following sensors will collect information: temperature, pH, photoelectric, and water level. Additionally, a camera will be used to monitor the plants and take photos. The microcontroller takes in all the data collected by all the sensors and camera. The data is processed by the microcontroller and set via wireless communications to the web-based interface. The microcontroller can use the data from the sensors to determine if action needs to be taken with the following items: the grow lights, pH regulator, water pump, and nutrient dispenser. An LCD interface will display data collected by the sensors and offer the user control of the system. The entire system is supplied power via a wall outlet.

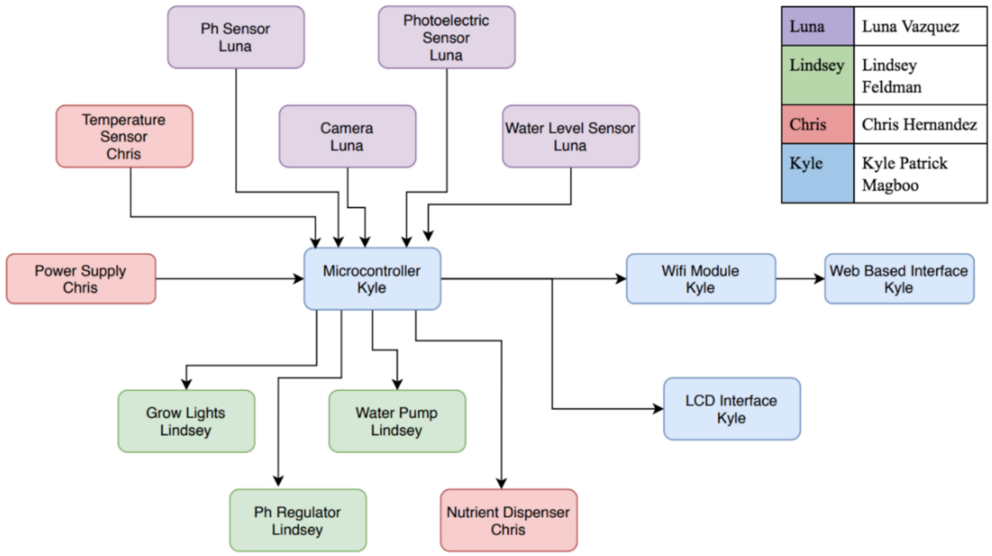

Figure 4: Hardware Block Diagram (by Kyle Patrick Magboo)

Hardware Block Status: At the time of writing, all blocks are currently *Acquired* and in the *Testing* stage.

The software block diagram begins by reading the data collected from the sensors. This data provides information about the levels of various conditions of the ecosystem. Each level has flags associated with the specified settings. Once triggered, the system will send the appropriate output to correct the triggered flag. At this point, the system will double check for any remaining flags. After each level is cleared of all flags, the software will remain on standby until the next set time interval. The system will continue to recheck the sensor levels using the implemented timer. All data collected is sent to the web interface as well as displaying on the external LCD screen. The software repeats this checking process continually, to ensure that the system is running properly.

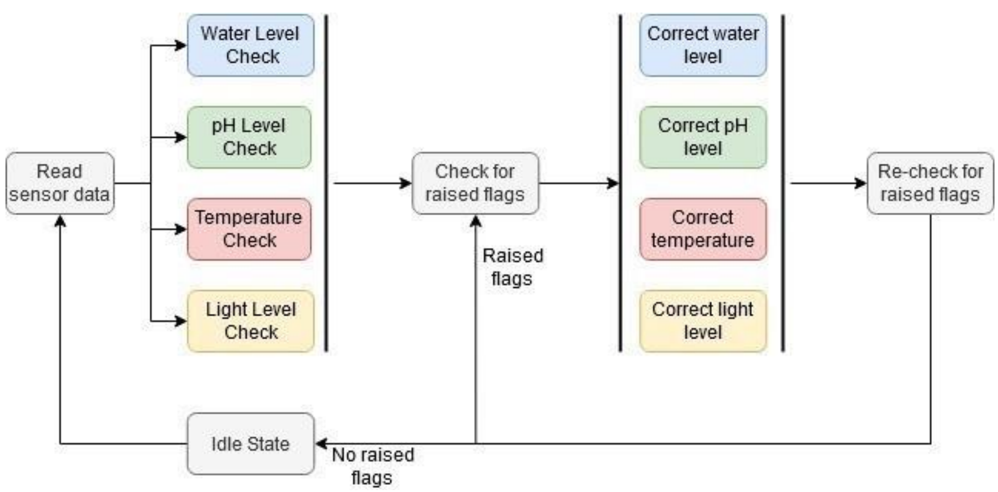

Figure 5: Software Block Diagram (by Kyle Patrick Magboo)

Software Block Status: At the time of writing, all blocks are currently *Acquired* and in the *Testing* stage.

3.0 Research

In order to further plan and design the Hydroponic Implementation for Gardening Herbs research in the following section must be conducted to determine the best practices. This section will go into detail of the things that will become useful when creating an initial prototype and carry through to the final product. This research will also help the group to achieve the specifications and goals that were outlined in the previous section. In this section the identification of different hydroponic systems is addressed. Using the information that is found the team can determine the type of hydroponic system to implement. From this information, the smaller subsections that make up the overall system are then researched. When researching these sections, the group will look at available devices to determine what technology will be used to design the final system.

3.1 Hydroponic Methods

Hydroponics is chosen as the method for the growth of the herbs selected. Hydroponics uses a nutrient solution as opposed to the traditional soil and water approach. Although in some cases, a medium is used to provide support to the roots, but this will be addressed more later. Hydroponics allows for the integration of technology and agriculture, in order to deliver a crop that allows the user minimal maintenance. While still delivering fresh herbs to their kitchen table. Hydroponics is also a more suitable system than traditional soil and water because there is an increased rate of growth and there is an increased nutrient efficiency. Hydroponics is also a more efficient way to grow plants as it reduces waste, through the decrease of water usage and space, which are important factors to consider as this does not limit the locations that plants can be grown hydroponically, and it also leads to less waste. There are several different methods for growing plants hydroponically. Below is a brief explanation of each variation of hydroponics systems. Each system is analyzed to determine if they have the criteria sought after to give the optimal control of the system that our team was looking to achieve.

3.1.1 Deep Water Culture

The first type of hydroponic system is deep water culture. This system works by suspending a plant, so the roots are in the nutrient solution and oxygen rich water. This done by using a container with either a hole in the top or a system to hold the plant in place. To provide oxygen to the water, an air pump may be used or an air stone. This method is useful for increasing the growth of the plant as the roots are receiving an increased amount of oxygen. This method did not provide an amble amount of control and monitoring that is desired by our team.

3.1.2 Ebb and Flow

Another hydroponic scheme is ebb and flow hydroponics. This system mimics the flow of tide. When the system is in the ebb stage, the water in the reservoir is draining away from the plants. In the flow stage the water rises again and floods the plant beds. Each plant is held in place on the growing table by a medium. When the table is flooded with water and nutrients, usually for a short period of time, and then the water drains. Since the plants are anchored by their roots using a medium, the medium is used to retain the nutrients and water. This system works by recirculating the nutrient water solution which trains back into the reservoir during the ebb stage. Due to this, the pH of the solution must be monitored to be sure there is a proper ratio of water to nutrients.

In order to carry out this method, a pH sensor, nutrients dispenser and a way to food and drain the growing tray. This method takes up a bit more space than our group wanted for the goal that we wanted to achieve.

3.1.3 Drip Irrigation

The next hydroponic system that is considered is the drip method, which can be seen in the figure below. This system works by having a piping and drippers that deliver the nutrient solution slowly. The nutrient solution drips onto the roots of the plants. This method can be made to be more precise than the other methods mentioned. This is because the amount of water and nutrients can be delivered to the plants in a more precise amount. Another plus to this is the time that the plants may be watered can be controlled and monitored closely. A user can decide when the best time to water their plants is. This system allows for a greater integration of electronic components. Another benefit to this system is that it may be scaled up or down and this is a very important factor when deciding which system to choose. **Figure 6** depicts what a drip hydroponic system should look like and the main components of the structure.

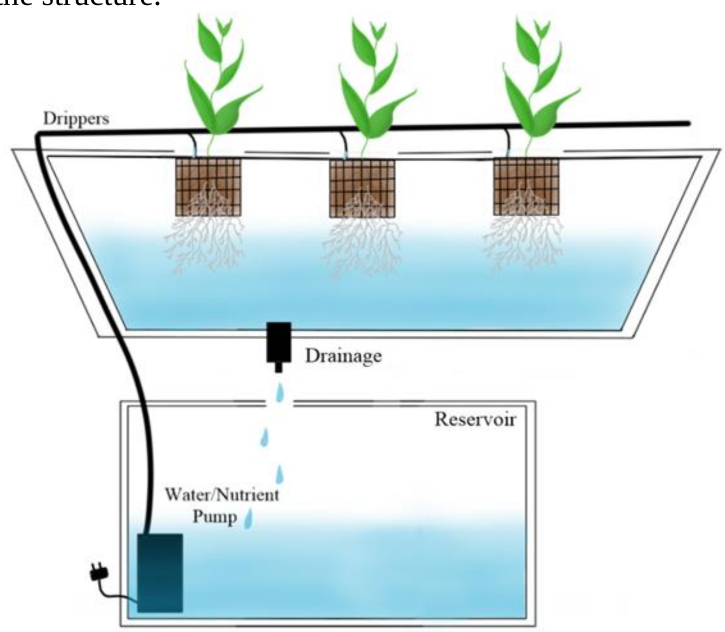

Figure 6: Drip Hydroponic System (by Luna Vazquez)

The implementation of this system uses a nutrient pump, a drip method, pH sensor, timers and any additional sensing wanted may be added. Additional sensors are added to allow the user a greater control over the system, as well as give information needed for maintenance. All the sensors used will be discussed in depth in sections to come.

3.1.4 Wick System

The wick system in hydroponics is rather simple. A reservoir contains the water and nutrient solution with a wick hanging into the solution. This wick extends to the growing medium of the plant in a container just above the solution. The water that is absorbed from the nutrients is delivered to the roots of the plant.

This system makes it a bit difficult to monitor the amount of nutrients delivered to the plants. A minimal amount of electronics can be integrated into this system, as there is no need for a water pump.

3.1.5 Nutrient Film Technique

Another hydroponic system considered is the Nutrient Film Technique. The way that this system works is by creating a channel with a slope. In this channel the water and nutrient solution flows past the roots of the plants and recirculates. This system also allows for an adequate amount of oxygen to reach the plants.

Implementation of this stem requires the use of an air pump, nutrient pump, and any other additional systems that may be added for monitoring.

3.1.6 Hydroponic Method Chosen

Now, that each system has been described the hydroponic system chosen is the drip method. The drip method is chosen over the other systems because it offers a wide range of metrics that allows for an overall better user experience. This approach offers the user an increased control in the water and amount of nutrients supplied to the plants. Another large factor is the minimal amount of maintenance that the user will have to perform. The watering times of the plants are also controlled.

3.2 Existing Similar Products and Projects

In the market there are several already existing hydroponic systems. These hydroponic systems range in size from vary large to even small systems. The purpose of our product is to have a compact design while still giving the user access to all the monitoring of a larger hydroponic system. Another aspect that plays a roll with this is allowing the user to have customization in how their system runs and the features available to them. The main thing that causes our system to stand out is that the goal is to have an all-encompassing system of every feature and electronic device. This means that our entire system can be simply picked up and moved as a singular piece. Below current hydroponic products will be discussed to highlight their features and how the system our team created is different.

An example of an already existing hydroponic system is the sprout LED with Herbs Seed Pot Kit, which can be found at Home Depot. This device is like the product our group is trying to create. One major difference is the hydroponic method being used. This Herb Seed Pot Kit used deep water culture to grow the plants. It has a control panel that turns on and off the lights. The control panel also reminds the user to add the nutrients. Our system will also have similar features, but several additional features as well. One thing that is unique to our system is how the user will receive the notifications about any updates the system has.

A large portion of existing drip hydroponic systems have the grow lights separate or any additional monitors as separate pieces. These systems typically only have thee water pump attached to turn on the drip irrigation. They do not typically come with grow lights attached.

Our system offers the user the convenience of checking on their plants without having to be in the same physical location of their planter. This is thanks to the camera system that is implemented, will be discussed more in depth later.

3.3 Plant Selection

After deciding on growing herbs in our hydroponics system, our system was setup to be able to grow different types of herbs, whether it be at the same time or growing them separately. In our hydroponic system, there is a compartment next to the reservoir where the user will be able to insert the nutrient solution into the reservoir and thus mix with the water to be able to drip the nutrient solution into the herbs. The herbs grown in our system need different conditions measured such as the amount of light they receive, pH levels, temperature, humidity, nutrient levels, and growth time in order to maximize each herb's growth The common types of herbs that are known to grow best hydroponically include basil, cilantro, thyme, mint and oregano.

Basil- Basil is one of the most common types of herbs to grow hydroponically. It requires six hours of natural sunlight or ten hours from grow lights. A mix of both will be used depending on the intensity of natural light and the grow lights will supply the rest of the light that it needs. Basil grows best in pH levels ranging from 5.5-6.5. The overall temperature range for basil is 60-80 degrees Fahrenheit overall. During the day a temperature between 70-80 degrees Fahrenheit is optimal while at night the temperature should not fall below 65 degrees. Basil needs humidity levels of 60-65%. Basil also needs specific nutrients such as magnesium and calcium which would require a specific solution that needs to go into the water. If basil is chosen, cuttings would be used in the system to decrease the length of time to grow the herb.

Cilantro- Cilantro grows best in a pH range of 6.5-6.7. The herb can grow between the temperature range of 40-75 degrees Fahrenheit but grows best in the 60 degrees range. It requires an EC level between 1.6-1.8. Cilantro needs about 12-14 hours of light. For nutrients, cilantro needs a solution rich in nitrogen. Cilantro works best in higher levels of humidity. It takes 5 to 7 weeks from germination of the seeds to harvesting the herb.

Thyme-Thyme requires a pH range of 5.5-7.0. Thyme grows best in a temperature range of 60-70 degrees Fahrenheit. It takes about 6 to 8 weeks to go from seeds to harvesting the herb. Thyme requires 10-12 hours of sunlight each day. Thyme requires about 40% of humidity. If thyme is chosen, cutting thyme plants and putting them into the system will provide a faster growth rate as opposed to growing thyme from seeds. Thyme will also need a nutrient solution like other herbs that is recommended to replace it at least once a month.

Mint-Mint requires a pH range of 6.5-7.0 to grow best. A temperature range of 65-70 degrees Fahrenheit is needed during the day and 55-60 degrees Fahrenheit during the night.

Mint can grow with some shade or direct light. If mint is chosen, cuttings would be used as opposed to growing from seeds since it is quicker to grow. It prefers EC levels of 2.2-2.6 but it can tolerate lower levels if paired with an herb that requires lower levels. Mint requires about 70% of humidity.

Oregano-Oregano requires a pH range of 6.5-6.7 for optimal growth. It can grow in temperatures ranging from 50-72 degrees Fahrenheit. EC levels of 1.6-1.8 are needed. From a seedling, cilantro can be ready to harvest in 50 days. It grows best under direct sun and will need extra light from grow lights if it does not receive 10 hours of sunlight. It best grows in humidity levels that do not exceed 70%.

After researching different types of herbs that are known to grow best hydroponically, it seems that no two plants have the same exact requirements in order for them to optimize their growth together. Overall, the system had sensors that can measure a water temperature range of 40 to 80 degrees Fahrenheit. The herbs in question were not exposed to such a large range throughout their growth time but the sensors had an increased range in order to make sure that if a situation does arise where the herbs are receiving water that is not in the optimal range, the sensor will send a message to the user about this so there can be changes to correct this error. Comparing the pH levels from all the herbs that were researched, the range is from 5.5 to 7.0. The pH sensor were able to at least measure this range. The plants have a similar optimal pH range but still have a slight variation. The amount of light each plant needs varies from herb to herb. The variation of number of hours of light also depends on whether the light is natural or artificial light. Therefore, for our prototype and when the system was tested, no two herbs were chosen since each herb requires different settings with the biggest difference being that the herbs rely on different nutrient solutions. This required a division in the compartment next to the reservoir to compensate for different nutrient needs that our original design does not include. As of now, it was best to grow the same type of herb for all three spaces in the system.

One stretch goal of the project includes incorporating different herbs into our system as the same time. This would first begin with having two different types of herbs in the system. These two herbs will have to have similar environmental requirements to allow both herbs to mutually grow the best. If this is achieved, the herbs that will be chosen would be mint and cilantro as they both can grow in a temperature range in the 60s. Cilantro needs at least 12 hours of sunlight and mint can do the same and with a little of shade. Mint needs a higher EC level than cilantro, but mint can withstand lower EC levels if other herbs need it. Cilantro needs a solution rich in nitrogen so there will be a solution that best fit both of these herbs. Both herbs thrive best in high levels of humidity of around 70% so because of these similar factors, these two herbs are chosen. The break in the reservoir would be implemented now for growing different herbs at the same time to guarantee each one is receiving the proper nutrients.

Incorporating a third different herb into the system will increase the challenge of the stretch goal. Basil has similar pH, EC and temperature requirements of the two other herbs. It requires less humidity than the mint and cilantro so there will be changes that will suit all three herbs for their individual optimal growth. For this to be achievable, an expansion to the system will have to be designed where different sensors and possibly a different expansion of the layout of the dripper system will have to be created in order to have different pipes lead to specific herbs since each one requires a different type of nutrient solution. The nutrient compartment will also need to be modified to handle three different nutrient solutions at the same time. The dripper system will need to be modified with the gallons per hour (GPH) value of the drippers if one herb needs more water than the other. The design change to this is minimal since it is just a means of replacing one dripper head with another depending on how much water is needed.

3.4 Growing Medium Selection

Since the drip method is chosen, a growing medium is necessary to hold the roots of the plant in place, which allow for support and holding the plant in an upright position and allow for the nutrient solution to moisten. The medium selected will also determine how much oxygen the plants are able receive. Since the medium aids in these ways, it crucial to select the proper one as it will affect the yield and overall growth of the plants. The growing medium should also be a light enough weight and relatively low cost. A growing medium is also beneficial in the event that a pump fails and will keep the roots of the plant moist for a bit longer. Below the different types of mediums are compared and the one that best fits the system is chosen.

3.4.1 Rock Wool

The first growing medium that is considered is rock wool, this medium is commonly used in hydroponics. This material is not the highly suitable for the drip system as it can hold too much moisture and not allow for enough oxygen to reach the roots. This can cause the roots of the plant to rot. A way to combat this is to irrigate the plants at less frequent intervals. This medium does not hold onto the nutrients as heavily as another medium might, which will lead to rinsing this material with just water less often. Due this, rock wool is ruled out.

3.4.2 Clay Aggregate

Another potential medium is clay aggregate. These clay spheres are light weight while also providing support for the plant. They maintain moisture in order to deliver it to the plant’s roots. An added benefit of this material is that it is reusable. This means the user could clean and use the clay aggregate an additional time. Clay aggregate also provides excellent drainage for of the water, which will allow for the system to recirculate the nutrient solution. The space that is between the clay aggregate also allows for an increased flow of oxygen to reach the roots. This increase in drainage would cause this medium to have more frequency irrigation schedule to ensure that the roots are receiving enough moisture. This medium may have to be combined with another medium to reduce the frequency of irrigation, this will be determined as prototyping is completed. Another plus is that the pH of clay aggregate is neutral. The clay aggregate has a high potential to be a suitable growing material for the hydroponic system.

3.4.3 Coconut Fiber
Another option for a medium is coconut fiber which is useful because it also is pH neutral. It is also an organic plan material. One thing to note is that coconut fiber tends to discolor the water, but this eventually goes away after several uses. This medium tends to absorb some of the nutrients. The use of this medium is also very dependent on the type of nutrients used with the medium, which will play a factor into if it is suitable for the hydroponic system. This material is very absorbent and will need to be watered less frequently. This material has the potential to be used for the hydroponic system.

3.4.4 River Rock
River rock is another potential growing medium. River rock has a lot of advantages including the fact that it is widely available and relatively cheap. Since the river rock is not a porous material it does not hold moisture. This allows for the water in the system to drain better. A downside to this is that the roots can dry out if the watering times are not adjusted properly. Another medium can be mixed in with the river rock to allow for more moisture absorption. An additional benefit is that the way the river rock sits there is a decent amount of air pockets which will allow the plants to receive oxygen to the roots.

3.4.5 Final Medium Selection
Given the current knowledge without any testing the clay aggregate is chosen and best suited for the hydroponic system. As prototyping and data collection is completed, this may change. There is a potential for there to be a mixture of mediums in order to have the proper amount of moisture for the plants roots and also to ensure the water and nutrient solution drains correctly. It is important that the water nutrient solution is draining into the reservoir as the system is recycling the water until more water and nutrients need to be added to the system.

3.5 Watering Method
The watering method is an important part of the hydroponic system. This method that was chosen decided how the plants are watered and how our watering system worked. The watering system is what kept the herbs alive as it provided the desired nutrients that our plants needed to receive in order to optimize their growth. For our prototype, it was decided to implement a drip system to grow our herbs hydroponically. The major components for our watering method included the water pump, the tubing and the drippers. The drippers and the water pump are connected by the tubing that will bring the nutrient solution from the reservoir and will be pumped up towards the drippers where the water will drip down to the herbs. After that, the water with the nutrient solution mixed into it will pass through the roots and then fall back down where it will be recycled back into the reservoir for continuous use.

3.5.1 Water Pump
A key component of our project involved the water pump for the hydroponic system. This pump is crucial in providing the herbs with the nutrient solution that they need. The solution that will be diverted from the reservoir to the herbs will be the only form of delivery of nutrients that the herbs will need in order to optimize their growth. The water

pump delivers the solution by passing it through tubes and will eventually end up at the drippers where the solution will slowly give the herbs the water with the nutrient solution. The design of the water pump in the hydroponic system will be placed either by the reservoir or submerged into it. This has been decided because of previous hydroponic system designs where the water pump is either outside the reservoir or inside it. For most hydroponic systems, there are two common types of water pumps that are used: submersible and incline water pump.

An incline water pump is found outside of the water and is used mostly in commercialized hydroponic farms as opposed to personal hydroponic systems. If this is chosen, then the pump will have to stand on a platform outside the reservoir. The original design of the hydroponics will have to be changed in order to account for an incline water pump. This type of pump will also be louder than submersible pumps. They tend to be more expensive than submersible water pumps as well. If the incline water pump is chosen, then a new design of the platform will be added in order to compensate for this specific type of pump. Since our goal is to provide a simple hydroponic system where a user won't have to do much maintenance and have it as sleek as possible to fit on a window still. For these reasons to decreases expenses and to save space around our hydroponic system, an incline water pump was not used in our project.

A submersible water pump is another option to use in the hydroponic system. A submersible water pump is a water pump that is submerged in the water reservoir that pumps the water through the tubing system and lead towards the drip irrigation system and from there it will drop the water onto the herbs. From our original design, we wanted to use a submersible water pump in order to minimize the space we need for the hydroponic system as a whole. Since the submersible water pump will not be as loud as an incline water pump that is outside of the reservoir, this is another advantage in the case that the user will not have a loud pump working at all hours of the day. By choosing the submersible water pump, this will also help with our goal of making the whole system as compact as possible while also giving it a sleek exterior look that will attract a younger age group that is interested in getting to growing herbs. Our main objective is to create a straightforward hydroponics system that will not take up as much space and a submersible water pump aids towards this goal. With this in mind, it was best to go with a submersible water pump for our prototype.

The decision has been made in deciding on a submersible water pump for the hydroponic system. For finding the best submersible water pump for our system, there are a couple of different specifications that it will need to satisfy our desired goals for growing our herbs. This includes the flow rate measured in GPH (gallons per hour) rating, head height and cost.

Flow Rate-GPH rating is the gallons per hour that the water pump will circulate throughout the hydroponics system. The correct GPH rating has to be used for the hydroponics system in order for it to properly disperse the water solution with nutrients to the herbs with the correct amount of water in equal intervals throughout the day. If a wrong GPH rating is used, it could over water the herbs or provide less water which will critically affect the growth of the herbs. Other issues with choosing an incorrect GPH rating include creating stagnant water in the system which could allow for an increase chance of algae appearing in the system. Since this is a smaller hydroponics system, the reservoir will hold a maximum of 6 gallons of water based on our decision of reservoir size to allow for the system to have enough water in the system to circulate but also maximize the space for our system. The water pump will circulate the water at certain intervals that will be programmed depending on how often the herbs will need to be watered. The GPH rating will help cut down on what kind of pump will have enough power to pull the water up against gravity and disperse into the different drippers.

The GPH rating for the hydroponic system will vary depending on certain factors such as the amount of drip emitters and the flow rate of the emitters. By multiplying these two factors, this will give us the desired GPH rating. The GPH rating for our system will depend on how our stretch goals are met. Before completing the stretch goal of including the third plant, the first version of the system will be calculated with two plants and each using two drippers. There are a total of 4 drippers and each has a 1 GPH rating so they by multiplying these two numbers there is a flow rate of 4 GPH. When the design will have three plants, the only change in factors would be if the GPH of the drippers change depending on the type of herb. To keep it simple, if the herbs use a 1 GPH dripper for all six of the drippers used in the system, then the flow rate for the system will be 6 GPH.

Head height- Head height refers to the total distance between the bottom of the reservoir to the maximum height that the water will disperse from the drip irrigation. The head height is needed to know how strong the water pump has to be in order for the water solution to be successfully transported across the whole system. Based off of our dimensions of our whole hydroponics system, our head height should be at least 3 feet in order for our pump to successfully push up water through the pipes and to our herbs. It would be better to pick a water pump with a head height that is greater than 3 feet in case there needs to be adjustments to the system in the future.

Home Depot 140 GPH Fountain Pump

This pump from home depot supports up to 140 GPH and can pump up to a height of 4 feet. The piping dimension that it requires is either ½ inch or 3/8 inch. The cost for this pump is $16.84. The pump is attached to a 6-foot power cord and works best in water temperatures between 40 to 86 degrees Fahrenheit. It has a 120 Volts/ 0.09 Amps rating. The dimensions of the pump are 3” x 2” x 1.7”. It is also able to adjust the flow of water which will help in testing whether we should increase or decrease the flow of water depending on what the herbs need.

Active Aqua Submersible Water Pump, 40 GPH

This pump’s GPH rating is 40 GPH. It has a power rating of 3 Watts. This pump is recommended for a 5-gallon reservoir and the dimensions for the pipes connected to it is 5/16 inch. It contains a 6-foot power cord and is able to adjust the flow of water as well. The price of the pump is $12.17.

Active Aqua Submersible Water Pump, 160 GPH
This is similar to the other Active Aqua pump but this one has a higher GPH rating. The pump is optimal for 15-gallon reservoir and works with ½ inch fittings. The price of this pump is $18.33. It has a 6-foot power cord. It has a power rating of 6 Watts.

OTTFF 12V DC Submersible Micro Brushless Water Pump
This submersible water pump has a max flow rate of 18 GPH. The cost of the pump is $14.99. It has a head height of 3 feet and has a tubing fitting of ½ inch. The power rating is 0.8 watts and requires a 12 V source.

Mountain_Ark 12V Mini Submersible Water Pump
This submersible water pump has a flow rate of 63 GPH. It has a head height of 9.8 feet and costs $9.99. It has a power rating of 4.5 Watts. It has overvoltage protection so that if the voltage exceeds 12V the water pump will turn off.

From these different pumps, the GPH rating varies from 18 to 160 GPH. Our head height has to be at least three feet since it is expected that there will be at least three feet of vertical length that the water solution will run through based on the design. Below in **Figure 7** is a graph from the Active Aqua website, a company that specializes in selling parts for hydroponic system, shows that based on our minimum head height of 3 feet, we'll need a GPH rating higher than 40 GPH pump but less than 160 GPH. This can eliminate the options with the 40 GPH and 160 GPH ratings. Since one aim of the prototype is to be compacted, there is no need for a head height greater than 6 feet. This leaves a water pump with a range greater than 40 GPH but less than 160 GPH to be used in our system.

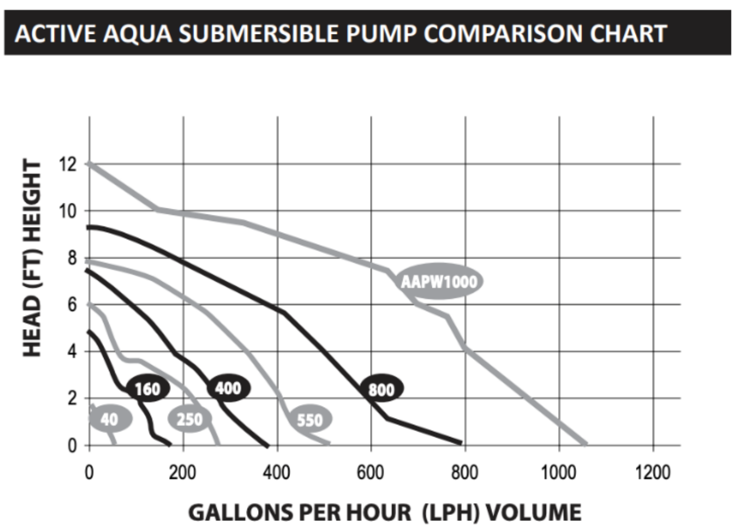

Figure 7: Head height vs GPH for submersible pumps-Permission to copy figure requested

This leaves the Home Depot 140 GPH pump, the Mountain_Ark and the Sunshower pump. The next thing to consider for these water pumps is the eventual addition of the water pumps connecting to the microcontroller that is chosen. The water pump will need to be able to be turned off and on without the user physically doing this. Therefore, water pumps more suited to already be able to directly connect to an Arduino will be chosen. This eliminates the Home Depot pump since it has to connect directly to a wall outlet. The other two that remain can both be directly used with a microcontroller. The differences between these two will be examined to find out which one is the best for the hydroponic system. The different in cost is not significant enough for it to be the main factor is choosing one over the other. The power rating of both pumps varies greatly with the Mountain Ark requiring more than the Sunshower one. This related to the GPH rating. The GPH rating of the Sunshower is 18 GPH and the rating for the Mountain Ark is 63. Both water pumps have the same fitting for the tubing which is a ¼ inch diameter. The other difference is the head height. For the Sunshower it has a head height of 3 feet while the Mountain Ark has a head height of 9.8 feet. Even though there is a need for at least 3 feet of head height, it would be better to have more room for error in case modifications need to happen to the design later on. Either one will work with our system, but the Mountain Ark submersible pump is chosen for our prototype. Below is a table comparison of the specs for the different submersible water pumps and the chosen one is highlighted in the table.

Manufacturer	**GPH rating**	**Cost**	**Power Rating**	**Head Height**	**Fittings**
Active Aqua	160 GPH	$18.33	9.5 Watts	5 feet	½ inch
Sunshower	18 GPH	$14.99	0.8. Watts	3 feet	¼ inch
Mountain_Ark	63 GPH	$9.99	4.5W	9.8 feet	¼ inch
Total Pond	140 GPH	$16.84	0.9 Watts	3 feet	½ or 3/8 inch

Table 3: Parameters for the Active Aqua 160 GPH Submersible Pump

3.5.2 Dripper System

The drippers needed for the hydroponic system is vital to the entire watering method. The drip system is connected to the submersed water pump and supplies the herbs with water and nutrients that will drip from above them and go through their roots and afterwards pass through the drainage and go back to the reservoir. This is the end route for the water solution to reach the herbs where it will supply the nutrients it will need to grow. The overall system is designed where each plant will have two drippers. There are two designs to the system regarding the number of plants. The first phase is with two plants in the system. This indicates that there will be 4 drippers. The stretch goal involves adding a third plant into the system. This means that a total of 6 drippers are needed for the prototype. Two drippers per herb were decided in case that one dripper is found to be malfunctioning or gets clogs, the herb will still receive some of the nutrient solution as opposed to not receiving any all day or until the user notices that the dripper is not working properly. The drippers will be placed on opposite sides of the herb to allow for the herb to receive even growth.

When deciding on drippers, it is important to know that the drippers that are going to be used are emitters. These emitters are needed at the end of each line of secondary tubing that are connected to the primary tubing to not overwater the herbs. When choosing our drippers, it was also important to pick a length of the tube that will carry the nutrient filled water solution to the herbs. Since this is a smaller hydroponics system and there is a desire to make is as compact as possible, there isn't going to be a need for a great length of tubing for the prototype. One specification that is needed for the tubing is that the inner diameter has to be ¼ inch in order to be able to fit into the submersible water pump. There isn't much difference when looking into different tubing for a hydroponic system except for the diameter of the tubing and the color of it. Since the hydroponics system will not be outside in direct sunlight, there is no need for concern if the color of the tubing will cause the water flowing through the tube to heat up and therefore affect the effectiveness of the nutrient solution that will pass through the herbs. Therefore, the color of the tube can either be black or clear.

The tubing that will be used in the hydroponics system is Rain Bird Landscaping Tubing found at Home Depot. The cost of the tubing is $8.69. It comes with 50 feet of tubing. This is more than enough for the prototype and will give the team extra tubing to have incase certain adjustments need to be made later on in the system. The tubing is flexible and helps in reducing algae growth which can be a concern in the case that algae appears and is being passed onto the herbs. The tubing has non-slip grip that does not allow for the emitters to accidentally fall out of the tube.

The next part of the dripping system that is needed is a valve that can shut off the flow of water and be the stopping point for the actual drippers. By using a barbed valve, this will make the hydroponic system more efficient. Certain barbed valves allow for the user to manually stop the flow of water whenever the user needs to. Below is the valves that can meet the demand for the task.

Rain Bird BVAL50-1S Drip Irrigation
This barbed valve is used in junction with 1/4" tubing. This meets the diameter demand needed to work correctly with it. The valve has a cap on the top that allows the user to change the amount of water that is flowing through or completely shut off the water passing through. This helps when the user needs to adjust the flow of water that is being passed through the system in case the herbs need a different amount of water. The bottom part of the valve also has a bottom opening where the dripper will be mounted on so the drops of the water with the nutrient solution will not exceed the amount the herb needs. The cost of the barbed valve is $1.97. Six of these barbed valves would be needed if chosen since there needs to be two drippers per herb.

The next part of the drip system is to find a drip emitter that meets the demands of the prototype. A drip emitter is connected to the tube and is the final step of when the water with the nutrients will reach the herbs. Before picking a drip emitter, there are different types that will be discussed in order to make a better decision on which one to pick that will work best for the system.

Non-pressure compensating drip emitter
A non-pressure drip emitter is made up two main parts which are the body and the nozzle. An advantage of this type of emitter is that it is low maintenance and are more resistant to getting clogged. This type of drip emitter can have different flow rates throughout the tubing if it is not on equal surface throughout the irrigation system. This is a disadvantage for systems that are straight path through. Luckily for our system design, each plant will be in series with one another and thus the tubing will lead to one after the other in a straight

line so the differential in pressure that this emitter is known to cause along the tubing won't affect this system since not one part of the area where the drippers are will be on an incline path.

Pressure compensating drip emitter

A pressure compensating drip emitter releases the same amount of water constantly regardless of the water pressure through the tubing. The flow of water that is released for either pressure compensating or non-pressure compensating emitters is based off of the flow rate in gallons per hour. That is another factor to consider when looking at different types of emitters to see which is rated best for our system. This type of emitter makes it worth more to hydroponic systems that are passing through an uneven environment as opposed to a smaller system such as our prototype that will not have this challenge.

Overall, it seems that either type of drip emitter will work for our hydroponic system and since our tubing will go through in a straight line, one type of emitter will not drastically affect our system over the other. The biggest factor for deciding on an emitter will be cost and the GPH rating. With all this in mind, it is better to look for non-pressure compensating drip emitter.

Non-pressure compensating, 1 GPH

For this drip emitter, it is non-pressure compensating and has a flow rate of 1 GPH. The cost of an individual drip emitter is $0.44.

Non-pressure compensating, 2 GPH

This drip emitter is comparable to the one above, however its only difference is that this emitter has a flow rate of 2 GPH. The cost of an individual drip emitter is $0.45.

From both of these non-pressures compensating drip emitters, cost is not a mitigating factor in picking one over the other. The decision will stem on which emitter has the better flow rate for the hydroponic system. The system that is designed has a 3-gallon reservoir. Ideally, it is recommended to have half of your tank flow through your system every hour. Since the second one might over produce more flow rate in that time, the 1 GPH drip emitter will be chosen since the flow rate of the water can be changed from multiple areas in order to ensure that the herbs are given the right amount of water.

The other part to the system is barbed tees for the irrigation system. The barbed tees would be used during the main line tube when it arrives to the section where the tube separates for each individual plant. One end would connect to the main line and continue this while the other end will separate into a different line that will connect to the barbed valve and then finally the emitter that will drip water. The barbed tees chosen are made by Rain Bird. They are used for ¼ inch tubing which is what the system uses. There is a need for 4 of them for the prototype and 6 of them for the stretch goal. The chosen tees come in a 10 pack for $3.47.

3.5.3 Water Level Sensor

Water is one of the most essential elements for plant growth. In a traditional gardening system, water is provided to plants through basic watering, where water is poured over the plants and absorbed by the soil, and the plants taken in this water as needed through their roots. Once the soil becomes dry again, more water is poured over the plants, and so on. The amount of water provided to the plants is also a crucial element of growing crops, including herbs, in a traditional growing environment. When growing plants hydroponically, the soil is removed, so the plants must get their water thorough different methods. This project will be utilizing a drip irrigation system of hydroponics, which is similar in execution to a traditional growing system. Water is pumped through a tube at a lower rate and dispensed over the plants, where the water is allowed to slowly flow down through the roots of the plants, which are stabilized in a non-soil medium. As the water drips down, the plants absorb from it the moisture and nutrients they need, then the remaining water falls into a reservoir below, and in the case of this project, is recycled into the system. This watering process will occur frequently, based on a timed schedule, data received from various sensors monitoring the plants, or via a user requested override. The system is designed to be able to run for a period of time without needing any user interaction, enabling it to be useful as a vacation plant care system, for example. For this and other reasons, it is essential for the system to be able to measure how much water is in the reservoir at any given time. Requiring the user to manually track the level of water in the reservoir would defeat the purpose of the system as a self-sustaining plant care system that can be left without user interaction for a longer period of time, since if the user forgets to check the water level, possibly before leaving for a few days, the system will not be able to water the plants. Measuring the amount of water currently in the reservoir is also necessary for the system to be able to determine the amount of nutrient solution that needs to be dispensed into the reservoir.

There are multiple different solutions for measuring the level of water in the reservoir. One type of sensor that could be used is a float level switch. These are readily available and fairly inexpensive. These parts include a small float that will move up and down with the level of liquid in a container, causing a switch to read as either on or off. This would not work for this project, since the switch can only give either an on or off status and does not provide detailed information on the level of the water at any point. If the system was only concerned with detecting when the reservoir was empty or almost empty, a float switch would be sufficient. This would not be ideal though, since without knowing exactly how full the reservoir is, a user may leave for an extended period of time based on the reservoir not being empty, when it is actually very low and will run out before the user is able to refill it. This would also not provide that information needed for the system to determine how much nutrient solution to add to the water in the reservoir, since the exact amount of water would need to be known. Continuous float level sensors are also available, which use similar technology but are able to measure continuously the exact level the liquid is at. This would solve the issues presented by the binary nature of the float switch, but these float level transmitters are very expensive and outside the reasonable budget for this project. Another possible solution would be to use a resistive liquid level sensor. These sensors are placed vertically in a container of liquid and can give continuous data based on the level of the water on the component. They are inexpensive and readily available, but generally are very small, only able to measure liquid level up to about 2 inches. This may work well for measuring the amount of nutrient solution in the separate compartment, but it would not be long enough to accurately measure the amount of water in the reservoir. The eTape Standard Liquid Level Sensor functions similarly, being place vertically along the side of the container and measuring the liquid level by sensing the hydrostatic pressure of the liquid on the component. This part is available in lengths of either 8 inches or 12 inches, which would be useful for this project. Infrared water level sensors are also available. These can be found as either contact or non-contact types and are able to sense if fluid has reached the level at which they are set. These sensors also act as switches with a binary status of either water is at the indicated or level or water is not. As such, using these sensors would present the same issues as using the float switches, where they are unable to detect the exact level of the water, which is necessary to fulfill the objectives of this project.

One more option for water level sensing will be considered, which is a waterproof ultrasonic distance measuring sensor JSN-SR04T. While not specifically designed for measuring water level, this sensor could easily be placed above the water in the reservoir and used to measure the distance between the top of the water and the sensor on top of the reservoir, which will give the system enough information to determine how much water is currently in the reservoir. Since this component is also waterproof, any splashing that may occur from the reservoir would not be an issue. The part is also low-cost and easy to find. Another ultrasonic distance sensor that would be an option for use as the water level sensor in the project is the HC-SR04 ultrasonic module. This part is a very commonly used ultrasonic distance sensor, ideal for measuring distances in the range of 10 cm to 250 cm. In this project, the sensor being used to measure the water level in the reservoir will be placed directly above it, and since the reservoir will not be very large or tall in order to keep the overall system from becoming too large, the distance range provided by this sensor would be adequate. This component is not waterproof. While the JSN-SR04T is comprised of a board and a separate waterproof cable and transducer, the HC-SR04 is only a single small part with two transducers. The HC-SR04 is cheaper, however, and more readily available. If the sensor is placed far enough above the water surface itself it should now be in the direct path of any water, so it should not be necessary for this part to be waterproof. The HC-SR04 also works better in a smaller environment. The closest distance at which the HC-SR04 sensor can measure is 2 cm, with 10 cm being ideal, while the closest distance the JSN-SR04T can measure at is 20 cm. The larger range of the JSN-SR04T may be too far for this application of measuring the water level in the reservoir, since the system is being designed to be compact, so the water level sensor may have to be fairly close to the surface level of the water. Using an ultrasonic distance sensor to measure the level of water may present some issues. The ultrasonic sensors may not be able to accurately detect the surface of the water and might not return an accurate measurement of what level the water is currently at. This could easily be solved, though, if a problem occurs by including some kind of bobber that would float at the top of the water that the ultrasonic distance sensor would be able to easily detect.

From this research, three different components have been identified as possible solutions for measuring the water level in the reservoir. These are the eTape Liquid Level Sensor, and the waterproof ultrasonic distance measuring sensors JSN-SR04T and HC-SR04. The parameters of these parts are summarized in the table below. Since the methods in which the eTape Liquid Level Sensor and the ultrasonic distance measuring sensors function are fundamentally different, some important parameters are discussed that do not have a direct equivalent between all of the parts considered for this application of measuring the amount of water in the reservoir. Ultimately, the HC-SR04 component from Adafruit was selected to be used for measuring the water level in the reservoir for this project due to its cost and availability.

Part	eTape Liquid Level Sensor	JSN-SR04T	HC-SR04
Manufacturer	eTape	KeeYees	Adafruit
Operating Temperature	-9 ~ 65 °C	-20 ~ 70 °C	-20 ~ 70 °C
Voltage	Vmax = 10 V	3.0 – 5.5 V DC	5 V DC
Distance Range	0 – 31.5 cm	20 – 600 cm	2 – 400 cm
Ultrasonic Frequency	N/A	40 kHz	40 kHz
Working Current	N/A	< 8 mA	15 mA
Resolution	0.25 mm	1 mm	0.3 cm
Dimensions	361 x 25.4 x 0.38 mm	42 x 29 x 12 mm	45.5 x 20 x 15.5 mm
Cost	$17.47	$11.99	$3.95

Table 4: Parameters of the components considered for use for measuring the level of water in the reservoir

3.5.4 Additional Materials for Water System

As the main components for the watering system have been selected there are a few additional items that will be useful for the implementation of the watering system. These items will be explained in detail in this section. The correct tubing will be necessary for the water transfer. It is important that the tubing selected will allow the water to be transferred without the tubing creating leaks. The tubing chosen should be able to handle the GPH being delivered by the water pump and that it is able to properly connect with the drippers. The section below will go into detail about the potential tubing chosen for the system, as well as how and where the tubing will be placed throughout the system.

Another component of the watering system that is crucial is the water reservoir. This reservoir will hold the water for the entire system. The reservoir needs to be designed so the excess water may return and be recycled through the system. The nutrients will be mixed in with the water in the reservoir, so it will also house the nutrient pump system. The water pump will also be housed here as well as a few other sensors, such as the water level sensor and temperature sensor. The reservoir needs to be designed so that all of these items may function together properly and safely. Extra care should be taken as certain components on the sensors may not get wet. Since this is the case, safety implementations will need to be made to ensure that the system will function in a nonhazardous way.

Figure 8: Water Reservoir Tank

For our final design, we used a 7-gallon HDX storage bin as shown above. The cost of the bin was $4.98 and provided enough space for the 6 gallons of water we had in the tank at all times. The dimensions of the tank are 19.1 in. L x 12.7 in. W x 9.8 in. H. The final dimensions of our enclosure were changed to ensure there was enough space for the tank. The tank was stagnant the whole time and contained the water temperature sensor and water pump inside. A smaller bin was used to put above the main reservoir tank that will house the water dripping down from the roots before it makes its way back to the main tank. The image below shows the 6-quart bin that was used. Holes were made on the bottom to allow a smaller flow rate to drip out. The cost of the bin was $1.98.

Figure 9: Runoff Water Tank

3.6 Moisture Sensor

Another sensor that will be useful for the hydroponic system is a moisture sensor. Moisture monitoring will be useful to determine if the plants need more water and nutrients. Although the timing of the nutrients will be set, it is useful to help adjust the watering times. Having the moisture sensor can provide additional information to help determine changes that can be made to the system to improve the plants growth. Since the plant will be on a timed drip system the moisture sensor will act as a backup to let the user and system know if the plants need water. This can make the watering cycle kick on sooner if the growing medium is not holding enough moisture for the roots of the plant. This moisture sensor can also serve as another fail safe in the event that one or more of the drippers gets clogged and is not functioning properly. This system is also useful in the event that the pump fails to turn on and can send a notification to the use that there is a problem with their hydroponic system, so that they may perform maintenance on the system. Aside from these extra safety features, let’s look at the importance of moisture of the growing medium. It is important to have a balance of the nutrients, water and oxygen near the roots, so the plant can achieve the best growth possible. The moisture is also important depending on what stage of growth the plant is in. Below are options for potential moisture sensors to be used in the hydroponic system.

The first soil moisture sensor looked at is the SparkFun soil moisture sensor. The way that this sensor works is like a variable resistor. When there is more water in the soil there is a lower resistance between the probes as there is a better conductivity. The output of the probe is SIG analog signal that is higher with the increased moisture in the soil. These readings are dependent upon the voltage that is used on the VCC pin. The operating DC voltage of the soil moisture sensor occurs between 3.3 V-5 V. This moisture sensor has a electroless nickel immersion gold to help prevent weathering. A major disadvantage of this sensor is its lifespan. This sensor has a relatively short lifespan. One method suggested for extending the lifespan of the sensor is powering on the sensor only when a reading is being taken. Another method to increasing the longevity of the soil moisture sensor is to use a conformal coating to protect the PCB. This conformal coating can be used to protect any surface mount components and any soldering points. The additional protection from the conformal coating allows for the soil moisture sensor to tolerate a vast range of conditions.

Another potential soil moisture sensor is from the manufacturer Parallax and is identified by the following number 28092. This sensor has a working voltage of 2.0-5 V. The output of this sensor is analog. This sensor uses current amplification due to a transistor. When there is enough water in the soil it will cause current to conduct between the base and positive power supply. This moisture sensor is made of a noncorrosive media.

Elecrow also has a crowtail moisture sensor 2.0. This sensor operates in a DC range of 3.3-5 V. A plus of this particular sensor is that the probes of this sensor are longer than the other sensors previously mentioned, with a length of 80 mm. This is about double the length of the other sensors.

The next soil moisture sensor considered is the Adafruit STEMMA Soil Sensor. This soil sensor is different than some of the previously mentioned sensors because it is a capacitive soil moisture sensor. A benefit of this type of sensor is that it uses the ATSAMD10 Chip to measure the soil moisture using capacitive touch, this allows for the soil moisture readings to be from very moist to very dry. This sensor also uses I2C to communicate. Instead of using typical jumper cables, this sensor connects to the microcontroller via a 4 pin JST-PH cable which ends in male jumpers that are able to connect to the microcontroller. The operating range for this sensor is 3-5 V. The output for this sensor is analog.

Manufacturer	Sparkfun	Elecrow crowtail	Adafruit	Parallax
Operating DC Voltage	3.3-5 V	3.3-5 V	3-5 V	2.0V-5.0V
Output Type	Analog	Analog	Analog	Analog
Dimensions	6 cm x 2.5 cm	40 mm x 20 mm x 20 mm	76.2 mm x14 mm x 7mm	20.0mm x 51.0mm
Cost	$5.95	$2.50	$5.90	$4.99

Table 5: Moisture Sensor Breakdown Comparison

The moisture sensor chosen for the hydroponic system is the Parallax sensor. This senor is picked because of serval of its features. Its operating DC voltage is in the 2.0-5.0 V range, this voltage range is the intended voltage range for the other electronics that will be used in the system. A factor in choosing this sensor was the cost. This sensor is on the low end compared to the other sensors looked at. The system that is planned is to have one to three plants. When the system is scaled to three plants it is important to consider the cost will increase since the number of sensors will triple. Prototyping will determine if this sensor functions as expected and if it will be the one implemented in the final design.

3.7 Nutrients System

Even maintaining a small kitchen herb planter is a form of farming, with the goal of producing a higher crop yield and having fresh food ready to harvest. In order to photosynthesize, plants need more than just water, sunlight, and carbon dioxide, they also require certain elements like nitrogen, phosphorous, and potassium. In a traditional growing system, plants are able to get these elements from the soil they are planted in, where they are either naturally occurring or supplemented with products like fertilizer. When growing plants hydroponically, soil is not used as a growing medium and the plants are instead rooted in another porous material, around rocks, or directly in water. Because of this, the plants must get the necessary elements through other means, usually through liquid nutrient solutions that are dissolved into water. These solutions can be added as needed into the water used in hydroponic systems, whether they utilize deep water methods, drip irrigation, or another hydroponic technology. For this project, a separate compartment from the water reservoir will be used to store the nutrient solution. The water in the reservoir will be monitored and the levels of essential nutrients within it recorded, and when these levels are lower than indicated by the system, the nutrient solution will be added to the water using a pump system until the levels are adequate. When the amount of nutrient solution in the compartment is low, the user will be notified that it needs to be refilled. By adding the nutrient solution directly into the water reservoir that is also being used to provide water to the plants, the system is kept from becoming too complicated since only one tube line needs to be provided to each plant, and the plants receive the nutrients they need whenever they are watered. Research must be conducted regarding which nutrients are needed by the herbs that are planned to be grown as a part of this project and which nutrient solution will provide these, how to measure the amount of nutrients in the water reservoir and which sensors will be used, the compartment in which the nutrient solution will be held, and the method and parts that will be used to administer the nutrient solution to the water reservoir.

3.7.1 Nutrient Solution

All plants, including all herbs, require some essential nutrients that they can either obtain from soil in a traditional growing system or must be provided aquatically in a hydroponic growing system. These nutrients are nitrogen, which is essential for vegetative plant growth and chlorophyll production, phosphorous which is important for cell division and root formation, potassium which is important for plant growth and development, magnesium which is a component of chlorophyll and necessary for photosynthesis, sulfur which helps in the activation and creation of enzymes, vitamins, and amino acids, and calcium, which is important for cell growth, especially the development of cell walls. While these nutrients are essential for all plants, certain plants require different levels of each nutrient. This project is focusing on designing the hydroponic system to work ideally for herbs, especially basil and mint. Basil specifically requires a greater amount of magnesium than other plants and is commonly deficient in calcium, and deficiencies in these two nutrients can frequently occur together. As such, a nutrient solution for basil needs to consist of a standard nutrient solution plus supplemental solutions of magnesium and calcium. Mint, on the other hand, is less particular and only needs a standard balanced nutrient solution. A solution high in nitrogen will cause the mint to grow leaves that are more lush and greener, but at a lower quality flavor. From this information, the best course of action for the project would be to focus on using a standard balanced nutrient solution with supplemental magnesium and calcium.

One nutrient solution option is the Miracle Gro Liquid All Purpose Plant Food, which has a 12-4-8 ratio, meaning the solution consists of 12% nitrogen, 4% phosphate, and 8% potassium. This solution is easy to use and readily available, but it is not specifically designed for hydroponic systems and is generally intended for use when watering plants in traditional growing systems with soil. This solution also includes small percentages of iron, manganese, and zinc. Miracle Gro also offers a nutrient solution specifically designed for hydroponic systems as part of its AeroGarden line of products. This solution is also commonly available at hardware stores and online, and has a 4-3-6 ratio, as well as 1% calcium and 0.5% magnesium, higher percentages than those in the solution not designed for hydroponic growing systems. Other options include the General Hydroponics Flora series, which include three different solutions with different ratios, intended to be used during different stages of a plant's growth cycle. FloraGro is recommended for use during a plant's vegetative stage, while FloraMicro is used during growth and bloom cycles and FloraBloom is used when a plant is fruiting or flowering. Since this system is being designed to grow herbs, the focus is mainly on the vegetative growth of the plants, so the FloraGro nutrient solution, with a ratio of 2-1-6, is a possible option. One more nutrient solution is considered, the Dyna-Gro Foliage-Pro Liquid Plant Food. This solution has a 9-3-6 ratio and also consists of 6.1% nitrate, 2% calcium, and 0.5% magnesium, as well as smaller percentages of many other minerals. With these components, this solution is ideal for plants with a lot of foliage like vegetables and herbs and is also recommended for plants being grown indoors. This 9-3-6 ratio is also a multiple of the 3-1-2 ratio, which is recommended by many plant specialists and organizations. Based on this research, the Dyna-Gro Foliage-Pro Liquid Plant Food nutrient solution will be used during the testing of this project. When growing basil using the hydroponic system, it is recommended to also have a supplement of calcium and magnesium as well as the general nutrient solution. For this purpose, the Cal-Mag Plus product from Botanicare is recommended. This supplement nutrient solution is composed of 2% nitrogen, 3.2% calcium, 1.2% magnesium, and 0.1% iron. It's designed to help maximize crop yield and will help the plants to better absorb the essential minerals in the nutrient solution.

Nutrient Solution	Nitrogen-Phosphate-Potassium Ratio	Other Components
Miracle Gro All Purpose Liquid Plant Food	12-4-8	Iron, manganese, zinc
AeroGarden Liquid Plant Food	4-3-6	1% calcium, 0.5% magnesium
General Hydroponics FloraGro	2-1-6	
Dyna-Gro Foliage-Pro	9-3-6	6.1% nitrate, 2% calcium, 0.5% magnesium
Cal-Mag Plus	2-0-0	3.2% calcium, 1.2% magnesium, 0.1% iron

Table 6: Data regarding the different options for liquid nutrient solution

3.7.2 Liquid Level Sensor

The official Dyna-Gro website recommends mixing ¼ to ½ teaspoon of the Foliage-Pro liquid nutrient solution per gallon of water for every watering. As such, the nutrient solution will be added in this amount to the reservoir of water the system uses to water the plants via the drip irrigation hydroponic system. The system will need to be able to measure the amount of water in the in the reservoir when necessary and use this information to determine how much nutrient solution needs to be dispensed into the reservoir and dispense this amount. Based on initial design assumptions, the reservoir would be able to hold a maximum of 8 liters of water, or about 2 gallons. In order to provide enough nutrient solution for a full reservoir, the nutrient compartment would need to be able to hold at least one teaspoon of solution. This size, however, would not be an efficient choice, since the system would then only be able to provide enough solution for one full reservoir. If additional nutrient supplements are required this would also be insufficient, since, for instance, the Botanicare website recommends adding one teaspoon of Cal-Mag per gallon of water on top of the all-purpose nutrient solution. To provide enough solution for one instance of a full reservoir, the nutrient container would need to be able to hold at least three teaspoons. Using a compartment the size of a half cup, or 24 teaspoons, to hold the nutrient solution would be more than enough to satisfy the needs of the project while also not taking up too much additional space in the base of the system. This size of the compartment would enable the system to dispense enough nutrients to a full reservoir up to 8-24 times depending on the needs of the plants being grown. In this way another point of user interaction is minimized, since the water reservoir can be refilled multiple times before it is necessary for the user to refill the nutrient solution compartment. In order to monitor the amount of liquid nutrient solution in the compartment a small liquid level sensor will be attached vertically to the wall. Two parts that will be considered for this purpose are the Mini Liquid Level Sensor from Waveshare and the SUKRAGRAHA Water Level Sensor. Both of these sensors can measure liquid level up to about 2 inches, which would be sufficient since the compartment will not be used to hold large amounts of liquid. These smaller resistive sensors are also ideal for this application since they are able to precisely measure the level of the liquid and will detect small changes in this level, which is necessary since very little liquid will be dispensed at a time. These sensors both are able to operate at 5 volts which would allow them to use the same power source as the microcontroller. The output of these sensors is an analog signal that can be communicated to the microcontroller. Since the price and parameters for these two sensors are very similar and both are able to satisfy the requirements of this project, either one can be used. At this time the SUKRAGRAHA Water Level Sensor will be used for this project due to its availability.

Part	Water Level Sensor	Mini Liquid Level Sensor
Manufacturer	SUKRAGRAHA	Waveshare
Operating Voltage	3 – 5 V DC	2.0 – 5.0 V DC
Operating Current	< 20 mA	< 20 mA
Operating Temperature	10 – 30 °C	10 – 30 °C
Dimensions	2.5” x 0.75”	2.48” x 0.75”
Cost	$5.99	$4.99

Table 7: Parameters of the liquid level sensors considered for use in the nutrients system

3.7.3 Nutrient Dispensing

The nutrient solution will be stored in a separate compartment, adjacent to the water reservoir. When the reservoir is refilled, or when the user requests, the necessary amount of nutrient solution will be released into the reservoir to create the ideal watering solution for the plants inside the system. The amount of water in the reservoir is measured using the water level sensor, and this data is used to determine how much nutrient solution must be added to the water. To add the necessary nutrient solution, the must be a pump or other device for dispensing the liquid attached to the nutrient solution compartment.

This system for dispensing the nutrients must fit several requirements. A major goal of this herb care system is that it will be fairly small and able to fit in an average person’s home, specifically even in an average sized windowsill. To accomplish this goal, each component of the system cannot be too large. Specifically, the nutrient dispensing system must be able to fit either within the reservoir itself or in a small area adjacent to the reservoir, so as to not increase the size of the system too much. As such, the size of the components used to implement the nutrient dispensing system must be taken into consideration. For each gallon of water in the reservoir, only a small amount of nutrient solution, on the scale of teaspoons, must be added. As a result, the system for dispensing the nutrient solution must also be quite precise so as to accurately dispense the necessary amount of solution. If the system implemented is not able to precisely dispense the necessary amount of solution, the plants might be provided with either too little or too much of the necessary nutrients, which could affect the health of the plants and possibly cause other issues in the overall system, such as nutrient buildup in the reservoir and watering system.

One possible type of component that could be used to implement this nutrient dispensing system is a pump. The watering system for this project also utilizes a pump to transport water from the reservoir to the drippers that provide the water to the plants themselves. In the interest of simplifying the overall project and minimizing the number of different types of parts needed, the same pump being used for the watering system was considered for use as part of the nutrient dispensing system. This will not be possible, however, since the pumps in each system must satisfy drastically different requirements. For the watering system the reservoir is fairly large considering the scale of the project and is able to contain a submersible water pump within it. The pump used for the watering system also must be able to pump greater amounts of liquid more frequently, as well as be able to pump the liquid up the height of the system, from the bottom of the reservoir to the drippers over the plants. The pump used for the nutrient dispensing system, on the other hand, does not need to be as powerful. The compartment containing the nutrient solution will be directly adjacent to the reservoir, if not included with it. As such, the pump does not need to be able to transport the liquid solution over a larger distance or up to a higher height. Also, since the ratio of nutrient solution to water is in the range of teaspoons of nutrient solution to gallons of water a much smaller amount of nutrient solution is needed to be held in the designated compartment. As a result, this compartment will be much smaller, possibly around the size of a half a cup. This would be much too small to fit a submersible water pump, specifically the pump which was chosen to be utilized in the watering system. For these reasons, a different component must be researched and selected for use as part of the nutrient solution dispensing system.

The purpose of the liquid pump in the nutrient dispensing system is not really to move the liquid solution over a far distance, but rather just to remove the necessary amount of nutrient solution from the solution compartment and dispense it into the filled water reservoir nearby. For this purpose, the pump does not necessarily need to be powerful but must be precise so as to accurately dispense the necessary amount of nutrient solution, which will be on the scale of teaspoons at a time. The nutrient dispensing system also will not need to run constantly or very frequently. The nutrient solution will only be added to the reservoir when it is first refilled with fresh water.

One type of pump that is easily available is a small submersible water pump. These are commonly sold for use in aquariums and small ponds, or for watering plants. Pumps of this kind are available as small as just over a square inch; however, they must be fully submerged to work, meaning that a portion of the nutrient solution in the compartment will not be able to be used before the user must refill the compartment. These pumps also are designed to be run constantly rather than at certain times for small intervals in order to move only a small amount of liquid and may not offer the precision necessary for the nutrient dispensing system component of this project.

A solution to the problem of needing a precise way to dispense the nutrients would be to use a peristaltic pump. Peristaltic pumps are able to move liquid by squeezing tubing that has one end in the liquid and one end at the destination. By operating in this method, the liquid being transported also never touches the pump directly, allowing for use in sterile environments. The nutrient solution being used in this project is composed of many dissolved elements and nutrients, so it is beneficial for the solution to be transported without directly touching a pump since moving this nutrient rich solution through a pump could lead to build up of the nutrients which could cause many problems and affect the ability of the system to function.

One part that could be used is the INTLLAB Peristaltic Liquid Pump. This component is available from Amazon for $9.80, making it very affordable, although this price is only for the pump itself and does not include any of the plastic tubing necessary to connect the pump with the nutrient solution compartment and the reservoir. This pump has a flowrate of 19 to 100 milliliters per minute, which is more than enough since the nutrient dispensing system does not need to function very quickly. This pump, however, requires a 12 V DC input. Most of the other components of the system run on a 5 V DC input, allowing them to share a power source with the microcontroller. If this pump were to be chosen, another power source or power system would need to be added. Another part to be considered for use in the nutrient dispensing system is the Gravity: Digital Peristaltic Pump from DFRobot (DFR0523). This direction and flowrate of this pump can be directly adjusted from the microcontroller since this part includes a driver board connect to the pump itself. The flowrate can be adjusted to a value greater than or equal to 45 milliliters per minute. The driver board runs on an input voltage of 5-6 V DC, which means this part can be powered using the same power source as the microcontroller and does not require an additional power source. The nature of this peristaltic pump allows the flow of liquid through it to be precisely controlled, enabling it to be easily used to accurately deliver the exact amount of nutrient solution needed based on the amount of water in the reservoir. This pump from DFRobot is very expensive, however, with a price of $59.50. This price does include 1 meter of silicone tubing to be used with the pump. The final part considered for use in the nutrient solution dispensing system is the Peristaltic Liquid Pump from Adafruit (1150). The flowrate and direction of this pump can be adjusted by changing the way in which it is connect to the power, but it does not include a driver board to adjust the flowrate and direction of flow directly through programming on the microcontroller. The power input for this component is 12 V DC, so it requires an additional power source. The flowrate can be adjusted up to 100 milliliters per minute. The amount of liquid nutrient solution dispensed can be controlled by allowing the pump to flow at a specific flowrate for an interval of time calculated based on the flowrate and the amount of nutrient solution that must be dispensed. This component is available from Adafruit for $24.95 and includes 20.8 inches of silicone tubing to be used to connect the pump to the nutrient compartment and the reservoir. Based on the goal and requirements of this project, as well as the ideal budget of the project, the pump that will be used for the liquid nutrient solution dispensing system is the Adafruit Peristaltic Liquid Pump. This part will allow the nutrient dispensing system to achieve its necessary functions while not spending too much of the budget on this small component.

Part	Peristaltic Liquid Pump	Gravity: Digital Peristaltic Pump (DFR0523)	Peristaltic Liquid Pump (1150)
Manufacturer	INTLLAB	DFRobot	Adafruit
Working Temp.	0 – 40 ℃	0 – 40 ℃	0 – 40 ℃
Voltage	12 V DC	5 – 6 V DC	12 V DC
Current	400 mA	1.8 A	200-300 mA
Flowrate	19 – 100 mL/min	>= 45 mL/min	<= 100 mL/min
Dimensions	3 mm ID x 5 mm OD	27.4 x 28.7 mm	27 mm diameter, 72 mm total length
Cost	$9.80	$59.50	$24.95

Table 8: Parameters of the parts considered for the nutrients dispensing pump

3.7.4 Nutrient Solution Compartment

To allow the system to be more self-automated and to minimize the need for user interaction, the system will be able to provide the necessary nutrient solution to the water in the reservoir by itself. When the water in the reservoir is refilled, the system will measure the amount of water in the reservoir and determine how much nutrient solution will be needed to be dispensed into the water, then will use the pump connecting the reservoir and the nutrient solution to dispense this necessary amount. For the system to have precise control over how much nutrient solution is added to the water and when and to make the process of providing the herbs with the necessary nutrients easier, the system will require a separate compartment to hold the pure liquid nutrient solution separate from the water in the reservoir.

To make the system more compact, the nutrient solution compartment will be located either within the reservoir itself or directly adjacent to it. This placement will also simplify the requirements of the pump used to dispense the nutrient solution, since the pump will not have to transport the nutrient solution over a far distance so it will not have to be very powerful. Based on the specifications for this project, the reservoir will be able to hold up to 8 liters, or 2 gallons, of water at any given time. Based on the nutrient solution being considered for use in this project, approximately ½ to one teaspoon of supplement is needed per gallon of water. So, in order to provide enough nutrients for a full reservoir, the nutrient compartment must be able to hold at least 2 teaspoons of nutrient solution. A size this small would be impractical, however. If the compartment is just larger enough to hold enough nutrient solution for one refill of the reservoir, the nutrient solution in the compartment would need to be refilled every time the reservoir is refilled, which would require more work from the user and would make the system more complicated to use. By making the compartment larger than the bare minimum, the system will be able to store more nutrient solution so it can provide the necessary amount of nutrient solution needed for the amount of water in the reservoir multiple times, allowing it to be able to be refilled less, which minimizes the amount of required user interaction. An ideal size for the nutrient solution compartment would be about a half cup, or 24 teaspoons. This size would allow the system to hold enough nutrient solution to provide the necessary amount for the water being refilled in the reservoir up to 24 times before the compartment needs to be refilled by the user. This size is also still relatively small, so the compartment will not take up too much space in the overall system. Plastic will be used for the material of this compartment, since it will not degrade over time or absorb as much of the solution as other materials like wood might. This part will either be constructed by the project team using existing plastic containers or will be modeled and 3D printed by the project team.

3.8 pH Sensor

The pH value of a liquid is a measurement of its acidity, referring to the potential hydrogen-hydroxyl ion content of the liquid. This value exists on a logarithmic scale from 1 to 14, where pure water has a pH value of 7 and a solution with a value less than 7 is an acid while a solution with a value greater than 7 is a base. In a hydroponic gardening system, the pH value of the watering solution affects the state of the nutrients within it, as well as that of the plants being watered with it. If the pH in the watering solution changes to be outside of the ideal range for the nutrient solution used, the nutrients might begin to solidify and precipitate from the solution, gathering along the sides of the reservoir. Not only would this present an issue since the plants would then not be able to receive the nutrients from the water, but these nutrients forming solids may cause major functional issues with the system. Build up around the pump or in the tubes themselves could cause the tubes to clog, making the system unable to perform its essential function of watering the plants. Precipitation of these nutrients from the solution would cause the system to require significantly more cleaning and maintenance for the user, which could defeat the purpose of the system as a device to care for plants even when there is no user supervision. The pH level of the watering solution also affects the ability of the plants themselves to absorb nutrients from the solution. Different types of plants have specific ranges of pH values at which they are able to optimally absorb nutrients, and if they are growing in a liquid with a pH value outside of this range they may not be able to absorb the nutrients necessary for growth, which is critical for a hydroponic system since they do not have soil to obtain nutrients from and must absorb them solely from the watering solution. For this project, the system is being designed specifically for growing the common herbs basil and mint. The ideal pH range for growing basil hydroponically is from 5.5 to 6.5, and the ideal pH range for growing mint hydroponically is 6.0 to 7.0. The nutrient solutions themselves are also labeled with an ideal pH range in which the nutrients will stay dissolved in the solution and will be easily absorbed by the plants. For the Botanicare Cal-Mag being used in this project as a supplement when growing basil, the ideal pH range is 6.2 to 7.0. Based on these values, it would be most efficient to keep the pH value of the liquid in the reservoir within the range of 6.2 to 6.5 so that the nutrients will not precipitate and will be easily absorbed by the plants being grown, whether they are basil or mint.

Component	**Ideal pH Value Range**
Basil plants	5.5 - 6.5
Mint plants	6.0 - 7.0
Cal-Mag	6.2 - 7.0
Overall system	6.2 - 6.5

Table 9: Ideal pH value ranges of different components of the system

There are a few ways to measure the pH level of a solution. The easiest and cheapest way is to use paper test strips that are made with a pH sensitive dye that changes colors to indicate the pH level of the liquid they are dipped into. While this solution is low-cost and easy, it requires the user to measure the pH level of the water on their own and check if it is within the ideal range, which would mean that measuring the pH would not be a function the system is capable of doing, and would make the system unable to monitor itself in this regard. There are also pH test kits where a small amount of the liquid that is being measured must be mixed with a dye that will change colors to indicate the pH value, and digital pen devices that will read out the pH value of a liquid they are inserted in. These methods, however, also would not be an internal part of the system itself and would require the user to measure the pH value and compare it to the desired range. Using this approach would be possible though by notifying the user to measure the pH at certain times based on a schedule and having them input the value into the system, where the system itself could then determine if it is adequate or if the water must be adjusted. It would be ideal, however, to enable the system to measure the pH value of the water itself if possible.

It is possible for the system to measure the pH value of the water itself by using a pH electrode probe. This probe is attached to a BNC cable which is then connected to a sensor module. This sensor can be used in this system by placing the probe in the reservoir and having it read the pH value constantly or at specific time intervals. Leaving the electrode probe in the water constantly, however, may present some issues, since it is possible that permeable bulb of the sensor may become clogged from the nutrients and other particles in the water. As such, it may be suggested that this part is removed from the system to be cleaned at certain intervals by the user and replaced back into the system so that it is able to function correctly. Two parts that are being considered are pH Value Detect Sensor Module and pH Electrode Probe (E-201-C) from GAOHOU and the Gravity: Analog pH Sensor/Meter Kit V2 (SEN0161-V2) from DFRobot. These parts both function similarly, with minor differences in parameter values. The SEN0161-V2 from DFRobot is available from the manufacturer’s website for $39.50, while the E-201-C from GAOHOU is available from Amazon for $33.99. For this project, the E-201-C part will be chosen due to its lower cost and wide availability.

Part	SEN0161-V2	E-201-C
Manufacturer	DFRobot	GAOHOU
Supply Voltage	3.3 ~ 5.5 V	5 V
Operating Temperature	5 ~ 60 ℃	-10 ~ 50 ℃
Detection Range	0 – 14	0 – 14
Zero Point	7 ± 0.5	7 ± 0.25
Response Time	< 2 min	< 5 s
Internal Resistance	< 250 MΩ	≦ 250 MΩ
Output	Analog	Analog
Module Dimensions	42 x 32 mm	42 x 32 x 20 mm
Cost	$39.50	$33.99

Table 10: Parameters of the pH sensors being considered for use in the project

3.9 Humidity Sensor

Humidity plays a big factor in the herb’s overall growth and health. Humidity is the measurement of water vapor that is in the atmosphere. Different herbs require different amounts of humidity levels in order to grow at a maximum rate. When designing the hydroponics system, there was a decision of whether the system should be enclosed or not. If the system was enclosed, then the humidity levels would be impacted more by the moisture in the system. This would mean that there would be different components needed to maintain the levels of humidity in the enclosure. This would include needing a fan in case the enclosure is overly humid. It would be easier to have the enclosure be closed off but it would also require more components to control the different types of variables. If the system was open where the plants are not enclosed and share the same humidity levels as the room that it is placed in, then it would be affected by factors that are outside of the system. The idea of the enclosure to be opened is for the user to be able to trim the herbs when they are ready to be used. The level of humidity of the enclosure would be easier to maintain inside an apartment or building rather than outside which is also another reason why it was better to have the enclosure be open. In the end, the decision for the hydroponics system is that it will be open, and therefore there are less factors to control in regard to humidity and the humidity levels will be based more on the room that the system is in. By having the enclosure open, this also makes it easier to facilitate other changes that might be needed in the system since there's no need to dismantle the enclosure if something needs to be adjusted. For this reason, there needs to be a constant measurement of the humidity levels the herbs are receiving and so a humidity sensor will be used to monitor it.

Different herbs require different amounts of humidity and so it is imperative that the herbs that were chosen to get a constant level of humidity to make it easier for the herb not to receive different levels of humidity if it stuns their growth. The humidity sensor will be placed close by to the herbs and will record measurements every hour and the user will receive this data. This will help the user fix any problems with regards to the level of humidity almost immediately, so it won't affect the herbs. From there, the user will know whether there needs to be any changes as such as decreasing the humidity levels for the herbs. For most herbs selected, the humidity level should not exceed 70% and if it does, the user will be notified that they need to fix it.

In general, there are three common types of humidity sensors. They are resistive, capacitive and thermal conductivity.

Capacitive humidity sensors

This type of sensor is able to measure humidity through a condenser that relies on humidity. It is one of the simplest types of humidity sensors and can withstand a large range of temperatures. It does not require as much maintenance as other types of sensors and it is known to last for the long run. This type of sensor can measure humidity levels from 0-100%.

Resistive humidity sensors

Resistive humidity sensors are known to be less expensive and smaller than other sensors but also tend to be less accurate than a capacitive sensor. It is also beneficial that the difference in distance between the sensor and the attached circuit can be greater than other types of sensors. One disadvantage that might affect it is that it is susceptible to chemical vapors that might be in the air. This risk would increase in regard to the prototype since the hydroponic system is open and not enclosed so there are more ways for chemicals to land onto the sensor.

Thermal conductivity humidity sensors

Thermal conductivity humidity sensors measure Absolute Humidity. Absolute humidity measures the water vapor that is in the air and does not take into account the temperature of the environment that it is measuring. An advantage of this sensor is that it is durable and can withstand extreme temperatures which would not be needed in this case for the prototype.

After researching the different types of humidity sensors, specific sensors were looked at to see which one would fit best into the hydroponic system.

HS1101LF Humidity Sensor
This sensor has a maximum supply voltage need of 10 V. The humidity operating range of this sensor is 0 to 100% humidity. The operating temperature range for the sensor is from –60 to 140 degrees Celsius. The type of this sensor is analog. The cost of the senor is $6.78.

DHT22 Basic Temperature-Humidity Sensor
This sensor measures both temperature and humidity. It works with a humidity range of 0 to 100%. It is able to output a digital signal, so it does not need to convert from analog to digital. The advantage of this sensor is that it can output data for the ambient temperature and the humidity level of the enclosure. The range of this sensor is from –40 to 80 degrees Celsius. It has a plus or minus 0.5 degrees Celsius accuracy as compared to the 2 degrees Celsius range of the DHT11. The cost of this sensor is $10. The dimensions of this sensor are 27mm x 59 mm x 13.5mm. It will need a resistor on the circuit in order to use it as a pullup from the data pin to VCC and also a potentiometer.

From the comparison of the two sensors, the DHT22 sensor will serve a better purpose for the prototype. This sensor will not have to convert its data from analog to digital as the sensor already can output a digital signal. When researching both the needs for the ambient temperature and humidity sensors, the DHT22 was found to be able to measure both factors. This will be excellent for the cost of the project if a sensor is used that can measure two of the settings that affect the herb growth. The humidity level needed for optimal growth in the herb is in the range for the humidity sensor that is discussed. For the reasons mentioned, it is better to choose the DHT22 sensor. The cost savings in the fact that it can measure two factors and do it with accuracy will help the prototype work more efficiently. Below are the specifications of the humidity sensor.

Manufacturer	Adafruit
Body size	27mm x 59mm x 13.5mm
Rated voltage	3 to 5 V
Cost	$10
Accuracy	Plus or minus 0.5 degrees Celsius
Weight	2.4 grams

Table 11: Parameters for the DHT22 humidity sensor

3.10 Temperature Sensor

Temperature is critical in making sure that the herbs are receiving the nutrients in a water solution that isn't too hot or too cold which could stun the growth of the herbs. For this system, there are two different temperature readings that will provide data that will be taken in the hydroponics system. The two temperature readings that are chosen is the reservoir temperature and the ambiance temperature. It is important to take accurate readings of the temperature of the reservoir every so often in order to make sure that there are no significant changes to the temperature which would make affect the health of the herbs. For most herbs, the temperature of the water needs to be in the range of 60-70 degrees Fahrenheit in order for them not to get stunned by their growth. If the water is too cold or too hot this can affect the molecular structure of the nutrient solution and therefore cause the nutrient solution to not be as effective as it can be in the right temperature range. This effect will limit the growth of the plant or in the case of an extreme situation, it will cause the herb to die. For this reason, an accurate temperature sensor has to be chosen that will be able to update the user with a temperature reading every hour. It should also be able to provide an data to review to the user in case the water temperature goes to an extreme measurement so the user can go and fix the issue before it starts affecting the plants.

The ambient temperature also effects the growth of the herbs. If the temperature of the environment that the herb is in is not in the range that the herb grows best in, then the herb will have its growth stunted. The decision to have the hydroponics in an open enclosure is what enforced the decision to have a sensor measure the ambiance temperature. Since there is no enclosed space for the plants, the herbs will be exposed to the temperature of the room that the hydroponic system is in. This will make it easier to maintain as opposed to having the hydroponic system outside where it is harder to manipulate the temperature. The sensor will be connected with the Arduino to ensure that if there is a significant change in the temperature that the user will be alerted so that the user can fix the temperature. The sensor will also update the user every hour with the data of the temperature that is measured. By having sensors that measure these two factors, the user will be able to identify if there are any changes required to help bring the temperature levels back within range. These two temperatures are critical to maintain the health of the herbs throughout the day.

For the temperature sensor that measures the ambiance temperature, the herbs that were mentioned when selection of the plants can grow best in a temperature range in the 60 to 70 degrees Fahrenheit range. This signifies that whichever room the hydroponic system is placed in, will most likely have to have the ambiance around this temperature. Due to the dimensions of the hydroponics system, it is believed that there will only be a need for one ambiance temperature sensor. This is due to the fact there won't be a significant change in the temperature of one edge of the hydroponics system to the other side. Therefore, by placing the temperature sensor in the middle of the system, this measures the average ambiance temperature that is spread out throughout the three herbs. This temperature sensor does not need to be waterproof as it will be mounted closer to the herbs and nowhere near the reservoir or in an area where it could get sprayed by the drippers. A possible addition of a container being placed onto the sensor in case of the situation that accidental water is sprayed on it.

The temperature of the water is measured with a temperature sensor. In order for the temperature of the water to be measured, the sensor will need to be submerged underwater. Therefore, the sensor will need to be waterproof. The sensor is connected to the microcontroller where it will provide the temperature of the reservoir to the user. The water will be placed stationary in one part of the reservoir. This will stay constant so that the sensor can have an accurate reading. The temperature sensor should be placed near the water pump. This decision to keep the sensor closer to the water pump was made so that the sensor can measure the water that is immediately getting transported to the tubes and to the drippers that will supply the water with the nutrient solution to the herbs. Both of these sensors will be connected to the microcontroller that will record and send the user the temperature readings of the water every hour to provide a log of the temperatures and make sure that both of them are being kept in an ideal range for the herbs. The sensors will also send the data to the microcontroller and provide data that is collected and if there's a negative trend viewed by the user; they can change the settings how they need to.

There are different types of temperature sensors that are commonly used such as the thermistor, resistive temperature detectors (RTD) and the thermocouple. Further research is conducted to see which kind of sensor is best for both the ambiance temperature sensor and the water temperature sensor.

Thermistor

The thermistor is a type of resistor that will cause a difference in its resistance because of a change in temperature. Thermistors are known to have a negative temperature coefficient for their resistance or a positive temperature coefficient of resistance. For negative temperature coefficient, the thermistor's resistance value will decrease with an increase in temperature while a positive temperature coefficient means that the thermistor's resistance value will increase when the temperature increases. Thermistors have a higher sensitivity level than other types of temperature sensors so they can detect miniscule changes in the temperature. One disadvantage of a thermistor is that it is not a suitable to use over a larger temperature range than a smaller one. Thermistors are fairly cheaper than other temperature sensors but are more easily damaged to harsh changes.

Resistive Temperature Detectors

Resistive Temperature Detectors (RTD) is a temperature sensor that relies on resistance. The device works by the changes in the electrical resistance due to the difference in temperature. This is similar to a thermistor, but it can produce a more accurate readings since the output of a RTD is linear and it also has a positive temperature coefficient RTDs are known to be more consistent than other temperature sensors. Another advantage of RTDs is their ability to be used over and over again. This is helpful for long term projects especially if it the sensor that is discussed needs to be used constantly over a certain period of time. A disadvantage of RTDs is that they tend to be expensive because of their metal composition since most are made up of platinum or copper. RTDs are also more complicated since they will need a current to run through it since it is a passive device which makes it another disadvantage when compared to other temperature sensors in regard to simplicity.

Thermocouples

Thermocouples are one of the most popular types of temperature sensors. Thermocouples work by putting together two different metals together and the junction between both of them will cause a small potential difference that is constant. The voltage difference between the measuring junction and the reference is created and known as the Seedback effect. From there, the output voltage of the thermocouple is a basis of the temperature change. Thermocouples can measure extreme temperatures and can measure temperature quickly, but it does not have as much of an accurate measurement as other temperature sensors. An advantage of a thermocouple is that the junction on the thermocouple is able to be grounded and also placed into contact with the material that it is measuring such as water.

Looking into these different types of sensors, it is best to decide on different ones for the different environments that they will be measured in. In this case, for the hydroponics system, it will measure two different environments, a water reservoir and the air temperature in a room.

For the water temperature sensor, different waterproof sensors were researched in order to find the one that has the specifications that match our needs for the project. It seems like the best option is to go with a probe since the thermometer will need to be insulated from the water. A probe is useful in that it is a longer in comparison to just the actual thermometer so it can be submerged in a sizeable reservoir like in our hydroponics system. A temperature sensor with a good amount of wire length will be needed because ideally, we want some distance between the water reservoir and the Arduino so that the electronics don't get affected by the water. Upon more research, the most popular chip to use to measure the temperature of water is the DS18B20 chip. An advantage of this chip is that it has a one wire interface, so it only needs one pin out for communication. It also has the ability for the user to have access to nonvolatile alarm settings in the case that the probe is measuring a temperature that is outside the range that the user put. The other advantage of the chip is that it is a direct-to-digital sensor so that it does not need to be converted from analog.

Hilitchi DS18B20 Waterproof Temperature Sensors Digital Temp

The Hilitchi DS18B20 is one option to use as the temperature sensor for the reservoir. The sensor can measure between a temperature range of 55 degrees Celsius to 125 degrees Celsius. It requires a power supply ranging from 3-5.5V which matches our set up. The length of the probe is 40 inches so the sensor can be submerged in different parts of the reservoir and not just the surface. The probe has a stainless-steel housing. The advantage of this probe is that it is moisture proof and rust proof. The probe comes in a pack of 5 for $13 on amazon so each probe costs $2.60. The inexpensive cost of the sensor makes it a good choice to pick it.

Based on other waterproof temperature probes, they all contain the DS18B20 chip and just have external differences in the probe. From there it seems that it is best to pick the Hilitchi temperature probe. Below is a table of the probe with its specifications.

Manufacturer	Hilitchi
Temperature Testing Range	-55 to 125 degrees Celsius
Cable length	100 cm
Cost	$12.99 for 5 sensors
Power Supply Range	3 to 5 V
Weight	3.2 ounces

Table 12: Parameters for the Reservoir Temperature Sensor

Now that there is a decision on the type of temperature sensor for the water reservoir, the temperature sensor for the ambient temperature is needed.

TMP36-Analog Temperature Sensor
For the ambient temperature, one possible sensor is the TMP36 sensor. This sensor requires a power supply with a range between 2.7 to 5.5V which works with our power supply range. The cost of the sensor is $1.50 for one sensor.

DHT11 Basic Temperature-Humidity Sensor
This sensor is a temperature sensor that measures both temperature and humidity. This works by using a thermistor to measure the air and displays a digital signal on the data pin. The advantage of this over the TMP36 is that it does not need to convert its signal to digital as you would need to with the TMP36 analog temperature sensor. The sensor can receive a new reading every two seconds which is not as useful for this type of project in the sense that we do not need to read the temperature every two seconds since the sensor will only need to measure the air temperature every hour. The price of the sensor is $5.00. The sensor has a power supply range of 3 to 5 V. It requires a max current of 2.5 mA. It can measure a temperature range is from 0 to 50 degrees Celsius with a plus or minus 2 degrees Celsius accuracy. The dimensions of the sensor is 15.5mm x 12mm x 5.5 mm so it is small enough to be easily placed into the system and not affect anything else. This type of sensor will also need a potentiometer integrated into the circuit.

DHT22 Basic Temperature-Humidity Sensor
This sensor is similar to the DHT11 sensor. It measures both temperature and humidity as well. It is able to output a digital signal, so it does not need to convert from analog to digital. Like the other sensor, it can read a new temperature every two seconds. One advantage this has over the other two sensors is that is has a larger range to measure the temperature of the air. The range of this sensor is from –40 to 80 degrees Celsius. In comparison with the DHT11, this senor is more accurate and precise. It has a plus or minus 0.5 degrees Celsius accuracy as compared to the 2 degrees Celsius range of the DHT11. As a result of it being more accurate, it has the disadvantage of cost. The cost of this sensor is $10. It is double the price the DHT11 and more than six times the price of the TMP36 sensor. It is also bigger than the DHT11 sensor in that its dimensions are 27mm x 59 mm x 13.5mm. It will need a resistor on the circuit in order to use it as a pullup from the data pin to VCC and also a potentiometer.

When looking at all three different sensors, the two DHT temperature sensors seem like the best option for the hydroponic system. The TMP36, even though it is the most inexpensive sensor, will require more components for it to work for the hydroponic system. For this reason, it is better to choose one of the other sensor options. The difference between the two DHT temperature sensors that will finalize the decision between them will be cost and the accuracy of the sensor. Even though the DHT22 sensor is bigger than the DHT11 sensor, it is not that big of the difference that it will affect the system where it will hinder something else. The difference in the accuracy of the temperature reading between both sensors plays a big part in the factor in picking one over the other. The DHT22 sensor is extremely accurate with a plus or minus 0.5-degree Celsius accuracy while the DHT11 has an accuracy of plus or minus 2 degrees Celsius. The difference of two degrees can have an effect on the growth of the herbs if the temperature is staying under or below the desired range by two degrees for a long period of time even if the temperature is saying that is at one end of the range. For this reason, it seems better to pick the DHT22. The drawback to this decision is the cost of the DHT22 when compared to DHT11. The DHT22 is double the price of the DHT11 sensor. In comparing these two factors, the accuracy of the sensor outweighs the cost. It is better to use a temperature sensor that is accurately measuring the temperature of the air even though there are other cheaper options out there. The table below shows the specifications of the DHT22 temperature sensor.

Manufacturer	Adafruit
Body size	27mm x 59mm x 13.5mm
Rated voltage	3 to 5 V
Cost	$10
Accuracy	Plus or minus 0.5 degrees Celsius
Weight	2.4 grams

Table 13: Parameters for the DHT22 Temperature sensor

3.11 Lighting System

One of the most essential necessities for plant growth is sunlight. Plants growing outside may be able to receive the full amount of sunlight directly from the sun, and this natural light has an ideal balance of the full spectrum of wavelengths. In many cases, though, it is not possible for a plant to be exposed to this natural sunlight for the entire period of time necessary, for instance, if a plant is in a shaded area or during winter months where there are less hours of sunlight in each day. Plants grown inside are especially unable to get the sunlight they may need from the sun itself. It may be possible for an indoor plant to be fully sufficient on natural sunlight if it is placed in a window or another area that receives a lot of direct sunlight, but there are generally periods of time when a plant in this situation is unable to receive the sunlight it needs. Due to the inconsistent nature of growing plants outdoors in natural sunlight, many gardeners and farmers turn to growing their crops indoors, with a variety of non-traditional growing systems. Regardless of the method for growing these plants, whether it be a hydroponic system, an aquaponic system, or a more traditional system utilizing soil and fertilizer, the plants still need sunlight. This sunlight may come naturally through windows or greenhouse walls, but it is often ideal to utilize an artificial lighting system to provide the plants with the light they need. With an artificial lighting system, it is possible to grow crops year-round regardless of their growing season, current weather conditions, or hours of available sunlight. Using artificial lighting also allows the gardener or farmer to have more control over the amount and wavelengths of light the plants receives, since they are able to control exactly what light the plants are receiving and for exactly how long.

To implement an artificial lighting system in this project, a few elements are required. These include the lights themselves and a method for sensing when the plants are receiving light. Ideally, the system will be constantly monitoring the light the plants are receiving and checking whether they are receiving light during the hours that they should be based on known knowledge. When the plants are not receiving the light, they need from other sources such as the sun, the system will turn on the artificial lights for the rest of the necessary duration. By using the artificial lights as a supplement to natural light, the system is able to save energy and the plants are able to still receive natural sunlight when it is available. The system can also be implemented to rely on the artificial lighting full time, in the case that the user wishes to have more specific control over the light being provided to the plants. Research has been conducted into the color of light needed, the type of lights that should be used, and specific parts that fit these criteria. Research was also conducted regarding the light sensor, including which internal element is ideal for sensing the light in this application, and specific parts that utilize that element and can be implemented into this project. This research concludes in identifying a part that meets the necessary criteria for this project.

3.11.1 Grow Lights

This system is designed to be easily accessible to the average person who is interested in growing herbs indoors, but it also has the goal of optimizing growth of the herbs and allowing the user to have more precise control over the system if desired. The system also needs to be able to function both in a place with sufficient natural light and without natural light. To achieve these goals, research into grow lights was conducted.

Generally, grow lights refer to artificial lights used to simulate sunlight for growing plants. They are commonly used when growing plants indoors since it may be incredibly difficult or even impossible for the plants to get sufficient natural sunlight through a window. Growing plants indoors with artificial light also allows for plants to grow and be harvested year-round, even when the plant would be out of season. Basil specifically requires many hours of sunlight and warm weather, which would not be possible in a cooler location without the use of artificial grow lights. Also, the ideal temperature for basil is higher than the usual room temperature, so using grow lights would create extra heat and contribute to an ideal growing environment. Using artificial lights also allows more precise control over the environment of the plants, which allows the user to customize the growth of the plants based on the desired outcomes. Including artificial grow lights in the project will make the system more convenient by allowing it to be easily used inside and placed wherever the user desires. It also will make the system more stable, since the light received by the plants will be controlled through the system, rather than relying on natural sunlight that can limit when the plants are able to be grown. Artificial grow lighting allows the system to be customized by adjusting the amount and type of light provided to the plants based on the needs of the user and the plant themselves, even making it possible for the system to be set up to grow the herbs specifically for a certain end result, like larger leaves or more aromatic herbs.

The initial design for the system focuses on using the artificial grow lights as supplemental lighting. The system will be capable of detecting the amount of sunlight that the plants are receiving, and this data can be used to determine if the amount of light is sufficient. If the plants are not getting enough sunlight when they should be, the grow lights will turn on and provide light as long as they are needed. By taking this approach, the system will use less power, since it will make use of natural sunlight when available. This feature may be very convenient for a system that is placed in a windowsill or on a porch but would be rendered useless if placed inside a house away from the windows. The system would still detect the lack of natural light, however, and would provide the necessary light with the artificial grow lights. In this way, this feature is ideal for casual users, so that they may place the system wherever they desire, and they necessary light for plant growth be provided to the herbs without the need for user interaction. The sensors will also act as a check to make sure the grow lights are functioning properly when turned on. By default, the system will use the artificial light as a supplement to any natural light, but this feature may be turned off and instead the user can opt to have the grow lights on for the entire length of time needed for the plants daily. By doing this, the user is able to have more precise control over how much light the plants receive, and when the lights are on. This enables more experienced users to customize the growing environment for their herbs, adjusting conditions to grow herbs in certain ways for specific outcomes, or to use the system to grow different types of herbs that were not originally planned by the project team.

The wavelength, or color, of light received by a plant can also affect its growth. Natural sunlight is all around the best option for plant growth, since it is composed of balanced amounts of all the different colors of visible light, as well as infrared and ultraviolet light. Infrared light provides necessary heat to the plants, while ultraviolet light helps them to produce essential oils and antioxidants, which are of particular interest when growing herbs for cooking purposes. When growing plants indoors, however, sufficient natural sunlight may not be available, so artificial lights will need to provide the ideal wavelengths of light instead. Artificial lights are unable to provide the complete full spectrum of light that natural sunlight can, and instead will emit more of certain color wavelengths. As such, it must be decided which color of light to prioritize when selecting artificial grow lights to be used in the herb growing system. Blue light can help the vegetative growth of plants in early stages, and as such is useful when growing plants from seeds. An experiment conducted by John H. Loughrin and Michael J. Kasperbauer for the US Department of Agriculture observed the growth of sweet basil plants and how they were affected by receiving light reflected off of different colored mulches. The results concluded that the leaves of the plants grown with red light were the largest and had the most moisture compared to the leaves from plants grown with white light, which had a smaller area and lower moisture percentage. Plants grown with green lights also yielded leaves with a lower dry weight than those grown with white light. Since basil is used as a cooking herb, the aromatic and antioxidant compounds in the leaves are also of interest. The experiment found that levels of these compounds were lowest in basil plants grown with blue light and highest in those grown with yellow and green light. Another experiment, conducted by the YouTube channel Growing Answers, compared the growth of lettuce plants under a white LED panel versus under a red, blue, and white LED panel. The lettuce plants under the white LEDs grew much faster than those under the red, blue, and white LEDs. The overall plant mass was also greater for those under the white light, and the leaves of the lettuce grown with the red, blue, and white light tasted more bitter than those grown with the white light. While different colors of light may be beneficial for growing different plants, at different stages of a plant's growth, or for growing plants that yielded a crop with specific characteristics, for the purpose of this project white light would be ideal. White light provides the most balanced combination of different wavelengths of light, and as found in the research plants grown with white light have a greater mass of leaves, which is appealing for growing herbs used for cooking since it creates a larger crop.

Now that the color of the artificial light has been decided, it is necessary to determine the type of lighting that will be used in the system. The lighting will be included in the overhead portion of the system, directly above the space where the plants will be. The common possible options for lighting are incandescent grow bulbs, fluorescent grow lights, and full-spectrum LEDs. Incandescent grow bulbs provide the cheapest solution, but also have the shortest lifespan and do not provide full spectrum light that the plants will benefit from. Fluorescent grow lights are an improvement, having a longer lifespan of around a year. However, they are also very fragile which could make them difficult for the user to replace, and the light they produce is mostly yellow and green, which is not ideal for the herbs that the system is being designed with in mind. T5 fluorescent bulbs would provide a better spectrum of light, but these bulbs can be expensive and are generally much larger than needed for the system. LEDs have a significantly longer lifespan than the other options and are much more energy efficient, using less electricity and generating little excess heat, however, they are generally more expensive initially than the other options. Based on these traits, an LED grow lighting system is ideal for this project. The herb gardening system is being designed to function for an extended period of time without user interference and to be very accessible to users of all experience levels. If a light bulb with a shorter lifespan were used, the user would be required to replace the bulb more frequently, which would not only be less convenient but also could create a hazard since fluorescent bulbs are fragile and contain toxic components that would be dangerous if the bulb is broken. LED lights, however, would be likely to last for the entire life of the system, and if a failure occurred they would not be dangerous to fix or replace.

Many LED panels marketed as grow lights are readily available. On amazon.com, multiple brands offer white LED grow light panels with the price varying based on the wattage and size of the panel. These systems also typically include a cooling mechanism for the LEDs, like a fan or aluminum plate, as well as a switch and clips for hanging the device. For example, the CXhome LED grow light is 75 W, full spectrum, and costs $25.99. The panel consists of 169 white LEDs, uses an aluminum plate for cooling, and is powered by being plugged into an outlet. The dimensions of the device are 11” x 11” x 0.5”. These products offer an easy solution for consumers to set up their own plant growing systems and are fairly low cost, just needing to be attached above the plants and plugged into the wall. Devices like this could be used as a part of this project as a quick solution, but since they are already existing systems they may be difficult to incorporate into the complete gardening system on the programming side and would be more expensive than purchasing the LEDs on their own. For LED strips, two options to consider are WS2811 and WS2812b LEDs. Both of these types of LED strips are easy to use and can be directly controlled by the microcontroller, allowing the color of the LEDs to be changed. For the WS2811 strip, the LEDs are controlled in groups of three while in the WS2812b strips they can each be controlled individually. Using programmable LEDs like these would allow the system to easily be customized in the instance that it was being used to grow herbs besides those planned in this project, since it would be possible to change the color of the LEDs as needed. LEDs like this would also make it possible to control the lighting over each plant in the system separately, which would make it easier to provide a more ideal growing environment for each plant if more than one type of plant is being grown at a time. The WS2811 strip costs around $25 for 5 meters, while the WS2812b strips costs around $35 for the same 5 meters. WS2811 also uses 12 V while WS2812b uses 5 V, a value used more commonly by microcontrollers, making it easier to use a shared power supply. For this reason, a WS2812b LED strip would be the better choice for this project. The LED density of 60 LEDs per meter will also be chosen in order to provide more light in the space used. Another option would be an SK6812 LED strip. This provides a more accurate white color, which would be closer to natural light for plant growth but is much more expensive at about $52 for 5 meters. The cost outweighs the benefits from using this type of LED strip, so this project will stick to using a WS2812b LED strip. The waterproof level of the LED strip should also be taken into consideration, since the lights may be exposed to water from the watering system. By design, the lights should not directly come into contact with the water, however, they may still be exposed to moisture. Having a certain level of waterproofing on the LED strip will also help to protect the LEDs in the instance that water is splashed onto the upper portion of the system by the user or by the system falling over, for example. An IP rating beginning with 6 as the first digit indicates the strip is dust-tight, which is common in commercially available LED strips. The second digit indicates the level of moisture protection. For this project, at least a level 4, indicating that the LEDs are protect from splashing in all directions, is necessary. The product chosen for use in this project has a rating of IP65, indicating that it is protected against low-pressure jets from any angle.

Brand	BTF-LIGHTING	BTF-LIGHTING	BTF-LIGHTING
IC Type	WS2812b	WS2811	SK6812 RGBW
Addressable	Individually addressable LEDs	Addressable in groups of 3 LEDs	Individually addressable LEDs
Length	5 m	5 m	5 m
LED Density	30 LEDs/Pixels / m	30 LEDs/Pixels / m	60 LEDs/Pixels / m
Color Order	GRB	RGB	GRBW
Input Voltage	5 V (DC)	12 V (DC)	5 V (DC)
Power	0.3 W/LED; 45 W total	0.3 W/LED; 45 W total	18 W/m; 90 W total
Operating Temperature	-20 °C ~ +40 °C	-20 °C ~ +40 °C	-20 °C ~ +50 °C
Dimensions	5000 mm x 10 mm x 3 mm	5000 mm x 10 mm x 3 mm	5000 mm x 10 mm x 3 mm
Wavelengths	Red: 650 nm Green: 520 nm Blue: 460 nm	Red: 650 nm Green: 520 nm Blue: 460 nm	Red: 650 nm Green: 520 nm Blue: 460 nm
Light Intensity	Red: 390 – 420 mcd Green: 660 – 720 mcd Blue: 180 – 200 mcd	Red: 390 – 420 mcd Green: 660 – 720 mcd Blue: 180 – 200 mcd	Red: 700 – 1000 mcd Green:1500 – 2200 mcd Blue: 700 – 1000 mcd
Gray Level	256	256	256
Color	Full color 24-bit	Full color 24-bit	Full color 32-bit
View Angle	120 degrees	120 degrees	120 degrees
Waterproof Level	IP65	IP65	IP65
Cost	$22.88	$15.99	$52.88

Table 14: Parameters of the LED strips considered for use in this project as grow lights

3.11.2 Photoelectric Sensor

An important sensor for our hydroponic system is the light sensor. The hydroponic system will provide light to the plants via grow lights and natural sunlight. The goal of the system is to give the user the option to use sunlight when available and the grow lights when the available sunlight is scarce. This is useful for regions and times of the year when the sunlight is limited. It is also useful on days where the weather is not the best and the sun is covered by clouds. The lights will turn on when no sunlight is available and remain lit until the on interval is over and the plants have received a sufficient amount of sunlight for the day. If there is an ample amount of sunlight, then the grow lights will remain off. This lighting system is in place in an effort to consume less energy. A user may also opt to only use their grow lights in the even that they do not place their device near direct sunlight. In this situation the light sensor would function as described in the following sentences. Another added benefit of the system is that it acts as a safety to alert the user if the grow lights are functioning improperly. An alert can be sent to the user if the grow lights do not turn on when they are supposed to, and the user can use this information to preform maintenance on the system. To achieve this, light sensors need to be used to be know when the grow lights should turn on and off. Below the methods for light sensing are explored and a method is chosen.

3.11.2.1 Photoresistor

The first component that can be used to achieve light sensing is a photoresistor. A photoresistor is also known as a light dependent resistor (LDR). An LDR has an increased resistance when exposed to a dark surrounding and a decreased resistance as exposed to more light. The LDR may be combined with a few other components to create a light sensing circuit. Typically, has a bit slower of a response time to changes in light.

3.11.2.2 Photodiode

A photodiode is like a PN-junction diode with a clear casing that allows light to pass through. This diode has an increased leakage current as the junction is exposed to an increased level of light. The light intensity experienced correlates to the current that is produced by the photo diode. This type of sensor can be fast to respond to light changes.

3.11.2.3 Phototransistor

The next type of light sensor considered is the phototransistor. A phototransistor functions almost the same as photodiode, but it has amplified current. The current on the phototransistor has an increased gain and causes the phototransistor to have a greater sensitivity. When there is no light on the junction the phototransistor experiences normal leakage current and when light increases there is an increased current, which is then amplified by the transistor.

Using the knowledge gained about different types of lights sensors a light sensing module is chosen that fits the needs of the project. First, the available options for photoresistors is looked at.

3.11.2.4 Light Sensing Modules

The first photoresistor module that is looked at is the LM393 Photosensitive Light-Dependent Control Sensor Module. This module has a photosensitive resistor with a potentiometer to allow the adjustment of the brightness of light detected, as well as adjusting the light intensity. This module has an operating voltage of 3.3 to 5 V. The module also has a light that indicates the signal output, which is a useful indicator that the module is working properly. The output of this module can be either analog or digital. Another useful feature of this module is that it has a hole for mounting, which will allow for the installation of this piece to be easier.

The next photoresistor considered is the photoswitch light sensor. This module has a built-in relay which can be used for switching on and off the grow lights. This module also has an operating voltage of 12 V. A plus of this module is that the photoresistor is at the end of a wire as opposed to being directly connected to the module. This gives a greater flexibility in the placement of the module. This module has four mounting holes for the ease of installation.

The next set of light sensing modules looked at work with the use of photodiodes. The first photodiode module looked at is the four terminal light detection photodiode module for Arduino. This module has an operating voltage in the range of 3.3 V to 5.5 V. A single mounting point on this board will allow for ease of installation.

Light Sensor	LM393 Photosensitive LDR	Photoswitch light sensor	4-terminal light detection photodiode module
Operating Voltage	3.3-5 V	12 V	3.3-5.5 V
Type	Photoresistor	Photoresistor	Photodiode
Switching Relay	No	Yes	No
Cost	$8.59 (5pk)	$9.99	$6.34

Table 15: Light Sensing Breakdown Comparison

The sensor that is chosen based on the comparison of specifications done in the table above is the LM 393 LDR module. This sensor is chosen because of the low cost compared to the other modules that were looked at and the number needed for implementation. This sensor will be tested to determine if it is the best fit for the intended design. A disadvantage to choosing this module instead of the other modules looked at is the installation of the module will be a bit more difficult. This module does not have the extended LDR, so it will need to be carefully placed.

Another potential option if the testing of the light sensing module is not successful and is not able to perform as wanted is the implementation of a light sensing circuit design. This design will only be necessary if the light sensing modules available are not able to satisfy the needs of the hydroponic system.

The placement of the light sensors is important to determine that an accurate reading of the light available. An initial design is planned, but the design will likely develop as testing is done. A total of eight light sensors will be placed in different areas of the planter to determine if the overall light is enough for the plants. Four of the sensors will be placed on each of the support poles at the corners of the planter. The other four sensors will be place in different areas at level with the plants. These sensors may be moved to different locations as the testing is done because it is likely that the growth of the plants will cause shade over the sensor. Prototyping will need to be done to ensure that the sensors are working properly. A procedure will need to be developed on how the sensors test for light and determine if the grow lights should turn on. A threshold sensitivity and timer will need to be in place in the event that a sensor is exposed to a change in light, such as a shadow. An initial diagram will show the placement of the light sensors.

3.12 Power System

For the hydroponic system created to function it must have a source of power. The power supply may be in the form of a battery or supplied from a wall socket. In order to correctly integrate all the electrical parts that are in our system, the power supplied must be properly matched. That is an understanding of the whether AC/DC or DC/DC conversion is needed. Another important factor is that the power rail voltages of each component are matched, this means that voltage regulation is necessary. Consideration will need to be made when placing some of the electronic components near the water reservoir and other moist portions of the system, discussed at a later time. Due to this extra care and caution will need to be taken as well as implementing way to protect the system from the water. Below each topic is addressed in depth in order to determine a power supplying method for the entire hydroponic system.

3.12.1 Power Supply

The power supplied to the hydroponic system may be AC or DC power. First, let's look at how AC power from a wall outlet would be supplied, including the necessary components. The power supplied in homes and other buildings from a wall plug is supplied from an alternating current (AC) of 120 V and a frequency of 60 Hz for North America. In order to supply the power from an outlet to the hydroponic system an AC/DC conversion is needed. To achieve this an AC/DC adapter is necessary. This adapter will power on the power circuit, which will in turn distribute the power to the entire system. The adapter should regulate the input AC voltage to an output DC voltage of 9-12 V. The adapter will connect to the PCB power circuit via a barrel connector. The 9-12 V supply will need to be regulated in order to power the rest of the electronics needed. The other electronics used will likely have a rail voltage of either 5 V or 3.3 V, due to this the voltage will need to be stepped down. The voltage supplied will be chosen when the AC/DC adapter is chosen.

3.12.2 AC/DC Adapter

An AC/DC adapter will be used to allow use of power from a wall outlet and convert it to the proper DC voltage. Below a comparison of different AC/DC adapters is made and the one best suited for the herb planter is chosen. The following criteria are analyzed in order to make a decision of the adapter most suitable: the output DC voltage, operating current, size of the barrel plug, correct polarity and cost.

The output voltage of the adapter should match the rated input voltage of electronics that it is powering. The input voltage of the system is determined to be within the 9-12 V range. It is important to select an adapter with a current supply greater than or equal to the current rating of the device being powered. If the current supplied is lower than the current rating of the device, then the adapter will not be able to properly power the device. The last thing to consider is the size and polarity of the connector. Since a barrel connector will be chosen to connect the adapter to the rest of the devices, the size and polarity are not as high on the list of specifications.

The first adapter that is looked at is an AC to DC 9V 1A wall Arduino power supply. This means the output DC voltage is 9 V. The operating current is 1 A. This adapter has a barrel connector size of 5.5 x 2.1 mm. The polarity of this center positive.

Another option for a power supply is the TMEZON 12V AC power adapter. This power adapter converts to an output of 12 V DC. The output current is 2A. The connecting barrel has a size of 5.5mm x 2.1mm. This adapter has a center positive polarity. A bonus of this adapter is that it has an 8 ft long cord.

The LE power adapter is also considered. This adapter has a DC output of 12V and an output current of 2A. This adapter also has a 5.5mm x 2.1mm connecter. This adapter has a positive polarity.

Manufacturer	Arduino Power Supply	TMEZON 12 V Adapter	LE power Adapter
Output DC Voltage	9 V	12 V	12 V
Output Current	1 A	2 A	2 A
Barrel Connector Size	5.5 x 2.1 mm	5.5 x 2.1 mm	5.5 x 2.1 mm
Polarity	Center Positive	Center Positive	Center Positive
Cost	$6.49	$7.99	$10.99

Table 16: Power Adapter Specifications Breakdown

The TMEZON 12 V adapter is chosen because the 12 V DC output voltage should be large enough for the electronic components being powered. A benefit of this power adapter is the extra length of the cord. This additional length will allow for greater versatility in the location that the hydroponic system will be placed. Another reason the length of this power adapter is beneficial is the electronic components in the system will be housed at the top of the hydroponic system, which will allow for the AC adapter to reach.

From the adapter chosen, the barrel connector that connects the adapter to the rest of the power circuit may now be chosen. The adapter has a barrel connector with the following dimensions 5.5 x 2.1 mm, a relatively common barrel size.

The following barrel connector is considered as an option for the power circuit. The first is the DC Barrel Power Jack/Connector. This jack is compatible with the barrel size of the chosen adapter. This piece runs for $1.25.

3.12.3 Voltage Regulation

A voltage regulator will need to be used alongside the adapter above. This is because the 12 V will need to be lowered to a voltage that is able to be used by the rest of the electronics in the hydroponic system. A voltage regulator will maintain a constant voltage over varying load currents. The type of regulator needed for the application is a buck converter, also known as a step-down regulator. A buck convertor will step down the voltage to the necessary rail voltage. For the other electronics used a potential rail voltage will be either 5 V or 3.3 V. A few different types of regulators will be analyzed and the one best suited will be chosen. It is important when selecting a voltage regulator that the maximum ratings of the regulator are observed, so that it is able to function properly. The specifications that are considered to pick a regulator are the following: drop out voltage, cost, size, minimum input voltage, output voltage and if the regulator is switching or linear.

The first voltage regulator looked at is the LM7805, a commonly used linear regulator. A linear regulator functions at a constant operation point. This varies from a switching regulator because switching regulators rely on the varying of the duty cycle of a pulse to function. This regulator is in the 78XX three terminal family. This voltage regulator will regulate the 12 V input to an output of 5 V, which can be determined by the 05 portion in the name of the regulator and also from the datasheet of this regulator. The minimum input voltage needed to maintain the line regulation is 7.5 V. That means the 12 V input from the AC/DC convertor will be high enough for this regulator to function properly. This regulator has a drop out voltage of 2 V. For the TO-220 package the body size of part is 14.986 mm x 10.16 mm. This part has a price range from about $ 0.50-1.00.

The next voltage regulator considered is the ld1117v33 linear regulator. This regulator regulates to an output voltage of 3.3 V. The max input DC is 15 V. The dropout voltage of this regulator is about 1 V. The size of this regulator is 29mm x 10mm x 4mm and is the TO-220 package type. This part has a price around $ 1.25.

Regulator	LM7805	LD1117V33
Manufacturer	Texas Instruments	Texas Instruments
Output Voltage	5 V	3.3 V
Input Voltage	7.5 V	12 V
Dropout Voltage	2 V	1 V
Size	14.986 mm x 10.16 mm	29mm x 10mm x 4mm
Cost	$0.95	$1.25
Switching or Linear	Linear	Linear

Table 17: Voltage Regulator Specifications Breakdown

Both regulators listed in the table above will be used in the design of the power circuit. A regulator with a 5 V output will be necessary for the electronics that have an operating voltage of 5 V. Likewise, a 3.3 V regulator will be necessary for the other electronics who have this operating voltage instead.

Now, that the regulators for the system have been chosen, below will explain closer look at the circuits used to implement them. Each regulator will have the necessary peripheral circuits implemented to ensure that the regulator is functioning correctly, such as bypass capacitors which will eliminate any AC signals that would cause the output of the regulator not to be a constant DC value. When implementing a regulator circuit, care must be taken to ensure the regulator is not executed in the wrong fashion. The polarity of the input must be correct because the regulator will not function correctly, and it will also not work properly if the voltage output is greater than the voltage input. Additional circuitry that may be added to the regulator is short circuit and thermal protection.

A potential plan for the future is for the power portion of the hydroponic system is the implementation of a on and off switch. An on and off switch will be advantageous for the user to allow them to switch the system off while it is plugged in.

Another possible implementation that can be added to the system is a backup battery feature. Adding a battery to the system would allow for the device to function in the event of a power outage or temporary removal from the main power.

3.12.4 Relays

The following systems will need a relay in order to properly implement them: water pump, nutrients pump and the grow lights. The function of the relay in each of these systems will be the same, so once an overall understanding is gained, it is able to be applied to each of the systems without a problem.

The relay will act as a switch to turn on or off the desired system. The way that this relay works as a switch is that it is electronically operated. The type of relay that will be implemented in the hydroponic system is one that use an electromagnet that is responsible for opening and closing the contacts. When connecting the lights and pumps to each relay the normally open configuration will be used, this means unless a signal is sent from the microcontroller than the circuit will remain broken. An input signal will be sent to the relay which will switch the contact to the proper position allowing for the circuit to close. Below is a picture showing the pin connections of the relay along with the contact positions.

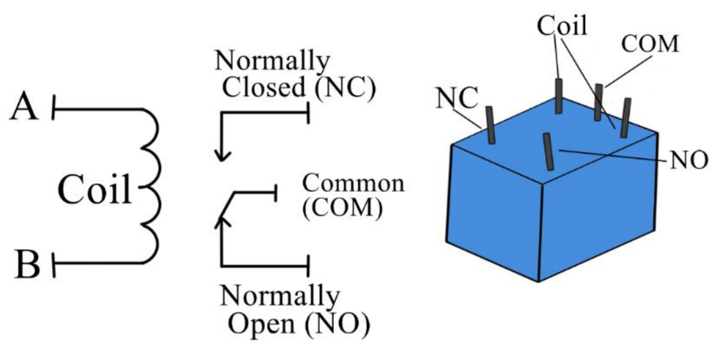

Figure 10: Relay Pin Diagram (by Luna Vazquez)

In order to implement this relay, there needs to be additional circuitry. For this there is two potential approaches, the relays may be used as a module which will have the additional circuitry necessary or this will be implemented on the PCB. In either case, the necessary circuitry will be almost the same. This circuitry will be described in more detail in the design chapter. The relay module that will be used for testing is the KY-019 5V. This relay can handle either an AC or DC load which will allow for flexibility of the parts chosen. Below is a table showing some of the important specifications for this relay module.

Manufacturer	Songle
TTL Control Signal	5-12VDC
Maximum DC	10A 30VDC
Maximum AC	10A 250VAC
Contact Types	NC/NO
Dimensions	27mm x 34mm
Price	$1.64

Table 18: KY-019 5V Relay Module Specifications

3.12.5 Battery

Another source of power for the system can be a battery. A battery would be useful to implement in the system as a backup source of power in the event that the system is unable to be powered by the wall outlet for a short period of time. A few considerations need to be taken when determining what type of battery should be used in the system and if a battery is something that should be included in the system. The following things are considered when choosing a battery. First is type of battery used. Important because the battery needs to function properly with the system as desired and hold charge. The next thing that needs to be considered is the ampere-hour capacity of the battery. It is important to consider this to ensure that the battery lasts for the desired amount of time, so that the system can continue to run properly without any interruptions guaranteeing reliability. A few other considerations when choosing a battery are that it safely functions with the system and the cost. Since the desired system is desired to be relatively compact as far as the overall design, the weight and size of the battery will also be a determining factor of the battery chosen.

When searching for the right battery for the hydroponic system, it is important to consider the power capacity and capability of the battery. When discussing power capacity, that determines how much energy can be stored within the battery, where the power of the battery is typically expressed as watt-hours (Wh). This is the amount of voltage times current a battery can supply for a fixed amount of time. Another important measurement for batteries is the Amp hour value usually in mAh and the amount of current that can be drawn from a battery at a time. These factors are important in ensuring that the electronics will be able to function properly using a battery.

Before looking at the types of batteries, it should be defined that the rechargeable batteries are sought as it is not desired to constantly replace the batteries in the system. The battery should also be able to sustain the system for a decent amount of time, which will be determined by the following research along with the considerations mentioned above.

When trying to determine if a lead acid battery would be appropriate for our desired hydroponic system design this type of battery was determined to provide the following advantages: easily rechargeable, have a high-power output and they are low cost. Unfortunately, this type of battery has a con that cannot be ignored. They are very heavy which is not desired as our system is intended to be compact, also a battery of this size would not be desirable indoors.

Nickel Metal Hydride batteries are another common type of rechargeable batteries that could potentially work in our hydroponic system. These batteries are popular among rechargeable batteries. These batteries have high self-discharge, which in turn leads to a reduced shelf live for these batteries because they won't be able to hold as much charge as they are continually used. This results in this type of battery needing to be replaced more frequently, as eventually the charge held by this battery will not last as long as it had previously. The cost for this type of battery falls around the midrange as far as rechargeable batteries are concerned. This type of battery is typically safer to use.

The next type of rechargeable battery considered is lithium-ion polymer. A benefit of this battery is that it provides higher energy density than other lithium batteries. Another thing to consider about this type of battery is that it is light weight which is very crucial to the design that will be implemented by the hydroponic system. A downside to this type of battery is that is can be unsafe. This type of battery is sensitive and need to be kept under certain conditions to prevent it from exploding. This can lead to a dangerous situation if not installed properly, which must be a major consideration as safety measures need to be met when designing the project. Since this is an issue with this type of battery, protective circuitry is usually included in the design to accompany this type of battery. Another thing to consider is that this type of battery is a bit more expensive.

If a battery is to be implemented in the system alongside the AC adapter that will supply power from the wall outlet, an additional battery charger will be necessary. This is so they battery may recharge when the system is receiving the power from the wall outlet, so the battery will be ready to use when the system is no longer connected to this additional source of power. In our final design, we decided to not implement a battery source and just rely on the wall outlet.

3.13 Control Unit

To handle all the various sensors and hardware components, a control unit is needed. With the goal of automation, a dedicated piece of hardware is required to manage routines and process information. There are many types on control units that can perform the requirements put forth by the system design. The primary goal for this decision was to find a control unit that fits our system requirements without going overboard and underutilizing its' max performance.

3.13.1 Control Unit (Hardware)

The design of our system is dependent on many routines and checks to determine what appropriate action needs to be taken. A control unit is able to handle these routines and checks. Both microcontroller units (MCU) and microprocessor units (MPU) were researched and compared to determine which control unit fits our needs. Microcontrollers and microprocessors share many commonalities with some key differences. Microprocessors consist of a central processing unit (CPU). Other peripherals are not included in standalone microprocessors. When developing a system around a microprocessor, additional components such as RAM and ROM need to be accounted for. Microprocessors and microcontrollers that were considered are as follows:

Texas Instruments MSP430

The TI MSP430 Microcontroller was the first control unit that was researched. Its exact specifications are shown in the table below. This microcontroller is a great option since the group has some experience with programming and setting up this specific board. The additional option to expand with an LCD screen directly compatible is another useful quality.

Texas Instruments ARM Cortex-M3

Texas Instruments ARM Cortex-M3 is a very fast microcontroller with much more capability than the MSP430. This does come at the cost of power consumption. Its exact specifications are shown in the table below. This microcontroller would be great in an application requiring high processing speeds and all the flash memory that comes with it.

This microcontroller is able to handle intense processing speeds as well as fast memory access due to the flash storage. Under careful consideration, the microcontroller was found to be overpowering for our design. The specifications would make for an excellent control unit. However, the power of the microcontroller would go to waste, so another control unit was researched.

Atmel Atmega328

The Arduino Uno development board includes an Atmel Atmega328 microprocessor. The Atmega328 is able to communicate to other devices using Universal Synchronous and Asynchronous Serial Receiver and Transmitter. Its operating voltage is 5V with decent clock speeds. Our design can be managed by the amount of IO pins however more may be added in the future. Its exact specifications are shown in the table below.

Atmel SAM3X8E ARM Cortex-M3

The Arduino Due development board comes with the Atmel SAM3X8E ARM Cortex-M3 microprocessor. Its exact specifications are shown in the table below.

This microcontroller is very powerful with specifications that are the best out of the options previously researched. This would make it the clear choice. However, the requirements of our system do not need that much CPU power, memory or I/O pins. This means that we underutilize a lot of power that this microcontroller is capable of.

	CPU Frequency	Memory	Additional Features	Communication*
Texas Instruments MSP430	25 MHz	512 KB	Low power consumption	Serial
Texas Instruments ARM Cortex-M3	150 MHz	1 MB of flash EEPROM		I2C/SCI/SPI
Atmel Atmega328	16 MHz	32KB flash memory 2KB RAM	14 digital I/O pins	USART SPI TWI
Atmel Atmega2560	16 MHz	256 KB of flash memory 8 KB RAM	54 digital I/O 16 Analog inputs	USART SPI TWI
Atmel SAM3X8E ARM Cortex-M3	84 MHz	512 KB flash memory 2KB RAM	54 digital I/O pins	USART SPI TWI

Table 19: Control Unit Specification Comparison

**(USART) Universal Synchronous and Asynchronous Serial Receiver and Transmitter*
(SPI) Serial Peripheral Interface
(TWI) Two-wire Serial Interface
(I^2C) Inter-Integrated Circuit

After comparing the different specifications of the microcontrollers and microprocessors, a decision was made. Our requirement specifications dictate that the Atmel Atmega2560 microprocessor fits our needs. The primary decision was due to the software development and resources for the Arduino board are much more extensive. The amount of IO pins fits our design specifications and can handle the number of sensors we have. The clock speed is fast enough to process the software without going overboard. This saves time and resources that can be shifted to other areas of the system. The communication protocols of the Atmega2560 also fits our design. This choice fits our requirements and is very cost-effective. C++ has a lot of capabilities through its libraries. This programming language paired with the power of the microcontroller can thrive in our system and is why we chose this microcontroller. The other options were also manageable in our system but ultimately did not suit our needs.

The microcontroller that was chosen for the final design is the Atmega2560. This microcontroller has a CPU frequency of 16 MHz. This MCU is chosen because it has 54 Digital I/O pins and 16 Analog input pins, this allows us to be able to connect all of the various sensors in our system while other potential microcontrollers have less I/O pins available. Another benefit to choosing this microcontroller is that it is able to be programmed using the Arduino Software IDE. The code used to run the system is able to be uploaded using in-circuit serial programming (ICSP). The microcontroller initiates the sensor check routine and makes changes to the specified sub-system to return the device back to ideal conditions. Upon receiving a request from the web server, the device initiates that change. The device then continues with the sensor check routine until another change is requested.

3.13.2 Control Unit (Software Environment)

Each type of control unit has its own software environment in which to program the device. This is very important to consider since experience and familiarity with certain software can prove to be beneficial to the efficiency of our overall system design. Two software environments were researched. Arduino uses Arduino Software (IDE) whereas Texas Instruments uses Code Composer Studio. Both can achieve similar outcomes but have some differences.

3.13.2.1 Arduino Software (IDE)

Arduino Software (IDE) is an open-source programming software used to write code and upload it onto the board. This software is compatible with Windows, Mac OS and Linux. This software codes in C++, a language like C but with more capabilities. This is primarily due to the library of functions that are available for C++ when compared to the C programming language.

3.13.2.2 Code Composer Studio (CCS)

Code Composer Studio (CCS) is the software used by TI control units. The group is most experienced with CCS from prior classes that dealt with programming onto microcontrollers. This made it the first choice when deciding what programming software to choose. However, it is limited to the versatility. The software programs in the C language. While the group is familiar with this language, its libraries are limited when compared to C++.

3.14 Communication

Communication plays a big part in the software of the device and the system. Any device technology that utilizes communication technology can expand the overall reach and capability.

The decision for implementing communication between the user and device was unanimous. This design is built around monitoring and automating the growth of plants. Therefore, communicating with the device is extremely crucial to the longevity and efficiency of these plants' life cycle. However, this raises the question, "Which communication technology solution suits our design?".

Usable technology that can be implemented into our design was then researched. Two methods found use a wireless connection that can communicate to the non-local server. A third method uses physical input from the user to communicate to the device. Technology that was researched to handle the communication of the device are Wi-Fi, Bluetooth, and a local display monitor.

3.14.1 Wi-Fi

Wi-Fi is a wireless communication technology popularly used in everyday products. It consists of many different parts that work together to achieve its main function of communication between devices without the need for a physical link.

3.14.1.1 Radio Frequency

Radio Frequency technology is “a frequency within the electromagnetic spectrum associated with radio wave propagation” (link). Using an antenna supplied with a radio frequency current, an electromagnetic field is generated and used to pass through the air.
(RF 1). This is the key to create a wireless connection. RF transceivers allow a device to transmit and receive RF signals. There are many components of RF transceivers. These include amplifiers, mixers, and many others. These make up the main purpose of communicating wirelessly.

3.14.1.2 WLAN

Wireless Local Area Network (WLAN) is a system that transmits data. This provides data access to many different devices in a given area. High frequency radio waves are used to propagate wireless and communicate on frequency bands. The Federal Communications Commission (FCC) has unlicensed frequency bands that allow WLAN to move through.

3.14.1.3 IEEE 802.11

802.11 is a digital communications standard created and managed by the Institute of Electrical and Electronics Engineers (IEEE). It is made of two layers, Media Access Control Layer and a Physical Layer. These layers contribute to the Open System Interconnect (OSI). This sets up the governing rules to allow systems to communicate with each other. Devices that can utilize the 802.11 module are able to set up wireless communications. As the amount of systems and devices grow, a network is created.

There are many different frequency bands that devices with IEEE 802.11 modules can move through. Wi-Fi wireless technology operates between the frequency of 2.4 GHz and 5 GHz.

3.14.1.4 Wi-Fi Antenna

A Wi-Fi antenna operates by sending radio transmissions on certain frequencies. Any device that can receive the transmissions are able to “listen” for the signal. Electrical power can be converted into radio waves that move through radio frequencies. Wi-Fi antennas are also able to convert received radio waves into electrical power. Most devices with Wi-Fi capability include antennas. They are the replacement of physical wires that would otherwise connect two devices. Antennas can be internal and provide small form factors. External antennas sacrifice form factor for modularity, expandability and upgradability. When considering the design of our system, a Wi-Fi module should have a range of a typical house.

When researching the different Wi-Fi modules for our system, a model seemed to dominate the others in terms of resources to troubleshoot as well as popularity due to its compatibility to our microcontroller. The ESP8266 Wi-Fi module is a hardware component that can take advantage of the radio frequency used to connect devices through a wireless network. It uses the 802.11 standard with an integrated TCP/IP protocol stack. It operates with a normal data rate between 6Mbps – 15Mbps and up to 72.2Mbps. The maximum output power at max data rate is 16dBm. These specifications were found across the different components found. The primary decision was based on availability and cost of the different makers of this module.

3.14.2 Bluetooth

Bluetooth is a wireless communication technology popularly used in everyday products. It “...is a standard for short range, low power, low cost wireless communication that uses radio technology” (**Bluetooth 1**). Both Bluetooth and Wi-Fi operate using radio frequency signals to propagate through the environment, wirelessly. The overall idea is “to connect to devices across short distances using short-wavelength radio waves” ...” from 2.4 and 2.485 GHz” (**Bluetooth 1**). Bluetooth is widely used to develop the Personal Area Network (PAN).

Devices that can take advantage of Bluetooth technology form connections in the form of master-slave relationships. Given at least two devices with Bluetooth capability, one device acts as the “master”, controlling the other device, otherwise known as the “slave”. An example would be a smartphone and a wireless speaker. Both devices are Bluetooth capable and can be paired to each other. The smartphone is able to act as a master to the speaker, controlling how the speaker operates. The smartphone is an audio source and outputs to the wireless speaker, through Bluetooth. The connection between devices using Bluetooth is called a “piconet” (**Bluetooth 4**).

Two types of Bluetooth modules were compared, the HC-06 and HC-05. The Bluetooth modules that were researched are as follows:

HiLetgo HC-05 Bluetooth Module

The HiLetgo HC-05 6-pin Bluetooth Module can connect to Bluetooth capable devices in slave mode by default. However, it does have the capability to be set to master mode. It has a working voltage of 3.6V to 6V. Its Default baud rate is 9600.

DSD TECH HC-06 RS232 TTL

The DSD TECH HC-06 RS232 TTL 4-pin Bluetooth module has similar specifications. It has a working voltage of 3.6V to 6V. Its Default baud rate is 9600. The primary difference between the HC-05 and HC-06 Bluetooth modules is that the HC-06 operates solely in slave mode.

When comparing the two type of Bluetooth modules, the slave/master option is the main point of consideration. At a high level, our system design does not require the device to run wireless Bluetooth connection in master mode. Upon price comparison, it was found that the HC-05 Bluetooth module ended up being more cost effective than the HC-06 version.

This helps the overall budget as well as the ability of possible future expansion using the master mode.

In the final design of the project, our amplified board for our speakers had Bluetooth capability and therefore our project does not have a Bluetooth module.

3.14.3 Wi-Fi vs Bluetooth (Primary Method of Communication)

Bluetooth has the capability to communicate with the user wirelessly, which serves the goal of the system design. However, the limitations outweigh the simplicity. Bluetooth is held back by the proximity of the user to the system. Anytime the user would want to wirelessly communicate with the device, they would have to be within the acceptable range of the device itself.

On the other hand, Wi-Fi does not bound the user to a Personal Area Network. The device can communicate wirelessly to a server housing the control protocols and information of the device. The user is then able to access the protocols and information from a much greater distance.

The limitations of Wi-Fi mainly include the connection of the device to a router. A change made over Bluetooth can be implemented in milliseconds with high reliability. That same change over Wi-Fi can result in a greater delay overall when compared to Bluetooth.

3.14.4 Wi-Fi vs Bluetooth (Resolution)

When designing the system, a Wi-Fi module fits our needs better than Bluetooth does when it comes to communicating with the device to modify the settings and routines. However, an additional feature for our device is being able to output audio from an outside source. This feature can thrive when using a Bluetooth module. The Wi-Fi module is able to handle changes to the device itself while the Bluetooth module is able to communicate with an outside, local device to play audio through the included speakers. Since the cost of both modules is within reasonable range, we can take advantage of multiple pieces of technology to communicate to the device.

3.14.5 Local Display Monitor

Wireless communication is great at transferring information across devices without the need for physical wires. However, physical communication will almost always beat wireless under normal circumstances.

A local display monitor provides access to the same control protocols and device information that wireless communication would provide. The decision to include a local display monitor in our system was based on the system design of a wireless printer. Many wireless printers utilize a small display monitor. This screen allows the user to connect the device to any wireless network in range, manage settings and other additional features. Our system is designed to use a touchscreen monitor which works in a similar fashion. Upon startup, the user will be able to connect the device to local wireless networks, manage the routines and modify the system settings. There are many attributes of display monitors that are important when comparing them. The main attributes that were compared are the resolution, refresh rate and cost.

3.14.5.1 Resolution

The resolution of a display monitor refers to the number of pixels that make up the display. Resolution measurements are typically in the form of pixel amount for the width and height of a display. For example, a display that has a resolution of 1920 x 1080 is 1,920 pixels wide and 1,080 pixels high. Resolution is also found with just the pixel height as a measurement. In that same example, the resolution can be described as “1080p”. The higher the pixel amount, the better the resolution is. This results in a higher definition image.

3.14.5.2 Refresh Rate

Images on screens are displayed as “frames”. The time it takes for a frame to change is known as the “refresh rate”. Refresh rates on the lower end tend to have image transitions that produce a “jittery” effect. This is because under a certain threshold, we are able to identify individual frames of the transition. As the refresh rate of a monitor speeds up, the transition between images becomes smoother. When the transitions between frames surpasses the threshold, our eyes are not able to see the individual frames. This gives off the effect of motion. A higher refresh rate produces smoother motion. Upon further research, it was decided that the overall refresh rate of the monitor is negligible because small form factor displays tend to have similar refresh rates. This component is extremely important when working with larger displays and higher resolution images. However, our design is built to provide a cost-effective display that the user has the option to use. Moving forward, the form factor, resolution and cost were the primary points of consideration.

There are many parts that make up display monitors. The display itself, the light source and the screen. The combination of these different parts creates the many different types of display monitors that we see today. It is important to understand how these parts work and how they contribute to the affect the attributes we are comparing.

3.14.5.3 Liquid Crystal Display

Liquid Crystal Display (LCD) technology operates by housing liquid crystal in between two pieces of polarized glass (LCD 1). Light is shown through the polarized glass which then produces the images shown on the screen.

3.14.5.4 Light-Emitting Diode Display

Light-Emitting Diode (LED) Displays can be categorized as an LCD since all LED monitors use a Liquid Crystal Display. The primary difference is that this specific type has LEDs to shine light through the glass as opposed to a fluorescent lamp. The change in light source affects the energy consumption of the device. LEDs are more energy efficient, which contributes to the overall cost. The cost upfront is typically higher than standard LCD displays that use fluorescent lamps. However, fluorescent lamps as a light source are harder to find for the form factor that we are looking for.

3.14.5.5 Thin-Film Transistor Display

Thin-Film Transistor (TFT) displays are another type of LCD. They include sheets of transistors that control each individual pixel on the display. Each pixel on the display can be lit up individually. This is known as an “active-matrix” [LCD 3].

Touchscreen TFT monitors are cost efficient and relatively simple to implement into our design. Many are available in small form factors, which suits our design. The TFT displays that were researched are as follows:

ELEGOO UNO R3 TFT Display
ELEGOO’s TFT touchscreen display has a screen size of 2.8 inches and is compatible with our microcontroller. It has a display resolution of 480 x 320. It utilizes LEDs as a backlight.

Kuman TFT Display
Kuman’s TFT touchscreen display has a screen size of 3.5 inches and is compatible with our microcontroller. It has a display resolution of 480 x 320.

HiLetgo TFT Display
HiLetgo’s TFT touchscreen display has a screen size of 2.8 inches and is compatible with our microcontroller It has a display resolution of 320 x 240. It utilizes LEDs as a backlight.

3.14.5.6 Comparison

All three TFT displays were within the same range of price points. The Kuman display has a good form factor combined with the best resolution out of the three choices. Moving forward, we decided to use The Kuman TFT Touchscreen display as our local display monitor for our system.

3.14.6 Bus Communication

There are many ways that components and devices can communicate directly with each other physically. Choosing the correct method that fits our design is important so that communication among the different devices are clear and efficient.

3.15 Software

With all the hardware components working together, they make up the physical layer of the system. Every part can be controlled in one way or another using electrical signals and pulses. However, the system is bound to progress into a more complex system with numerous outcomes and parameters. This, in turn, makes it difficult to keep track of all the different state changes and routine calls. Therefore, another layer is required for our system design, a Software layer.

3.15.1 Software Design

The design of the software was based on the needs of the system and the user. With the goal of automation and real-time communication, a Minimum Viable Product (MVP) was determined. Minimum Viable Product determines the simplest solution to the problem given. In our case, the software MVP would take in input from the various sensors and take the necessary measures to correct any deviation from the ideal growth conditions. From there, the software can be expanded to include many other features that fit our requirements. These expansions, although required, are not needed to run the software. Any additional features, whose absence does not compromise the overall structure of the system, are considered auxiliary.

3.15.2 Software Architecture

There are numerous types of software architectures that can be implemented in our design. Choosing the right one assisted in the traceability of our overall system so that we are able to understand the inputs, outputs and modifications of the software. Fitting architecture makes testing streamlined and efficient. The software architectures that were taken into consideration are as follows:

Pipes-and-Filter

Pipes-and-filter software architecture uses data as the input and output or “pipes.” That data is then passed through “filters” which modify or transform the data into usable forms. Using this architecture is advantageous since developers can see how the data is passed and modified throughout the entire cycle. Expanding and evolving the system is also manageable with the modification of filters.

Client-Server

The client-server architecture style consists of two parts. A server houses all the data and can provide the necessary functions for the system to operate. A client can request the data and services so that the server can send the appropriate reply.

Peer-to-Peer

Peer-to-peer architecture style is similar to client-server except that each peer can act as a client or server. Peers can communicate amongst each other to request and reply data and functions. This structure scales very well as the number of users increases. However, this does not cover the overall functionality of our design nor does it have use for a local user.

Repository

Repository architecture style uses a designated collection of different components that operate on a core data structure. The many different components include the unit tests, analysis, planning, etc. This core data structure is known as the repository.

The software fulfilled the MVP requirements using a pipes-and-filter architecture. As stated above, input data consists of the various sensor readings of the system. All the sensor data is passed through functions that check whether the readings are within a preset range. If any data is outside of that range, a flag is raised. Flags, in our system design, are data variables that are associated with a sensor reading. As data becomes variable and modified, flags help keep track of state changes. Instead of constantly checking each piece of data, the system can wait for a flag to be raised. This helps to organize the overall structure of the system so that state changes are transformed from ranges into states. As we progressed and implemented all the different sensors and hardware, we simplify the readings into a list of flags that the software knows to check for. This acts as a checklist the system must complete before returning to an idle state. Any flags raised must be addressed before the system completes its pass. If the system raises a flag, then the appropriate action is taken automatically. The software runs the respective function that is only triggered by the specific flag raised. This function outputs the necessary signal to the hardware assigned so that corrective measures may be taken. The result of this function is to re-check that specific condition once more and reset the flag if the check function can return an unraised flag. Re-checking is imperative so that accountability is increased.

Since we are working with hardware, there is a chance for an unintended event that the software is not able to correct. An example would be when water levels are too low, so the software sends a signal to the water pump to refill the reservoir. However, if the water pump runs out of water, then the system will attempt to pump water and then re-check the condition. This leaves the system in a state of constant re-checking and attempting to refill the reservoir without any water. This state is also known as an endless loop. The overall system can be viewed as an endless loop, except with some variability and exit conditions. The endless loop we are discussing in this case is an unintended consequence of not being able to exit the loop. Typically, functions that call themselves or refer to a secondary function that calls the first function is prone to enter an unintended endless loop. There are many ways to prevent a program from entering an unintended endless loop. An option was to add a variable that keeps track of repeated function calls or creating an exit condition by default.

3.15.2.1 Endless loops/Flag Re-check

If the re-check does not reset the raised flag, then the flag will enter the third state. This state is associated with an event where the software attempted to run the function to correct the raised flag, but the sensor data taken is still not within acceptable range. From this point, the software will notify the user (either locally through the LCD screen or over the network) that the system is attempting to correct a fault but there may be an outside factor affecting its correction (e.g. low water levels, sensor faults, etc.). The design of our system tries to limit the chances of flags reaching this third state through the inclusion of multiple sensors for a given condition. Keeping with the example, multiple water sensors can prevent flags from reaching the third state. The respective function to correct the water level can also notify the user of the water level. This can delay and sometimes prevent the system from reaching an unintended endless loop.

Once every single flag is checked and none remain raised, then the system goes into an idle state where the internal variables associated with correction are locked. After a given interval, the system goes into an active state and repeats the process over again.

This architecture facilitated the variability of our system. Although there are preset check ranges for the sensors, the user is able to modify these ranges to fit their specific needs. Since every filter is a check condition, we can group all the filters together so that any range is easily modifiable. This is commonly known as the system settings. A goal of this system was to have preset settings so that a user can set up the device, input certain parameters about the plant and not have to readjust settings over and over. On the flip side, this architecture allows users to modify check conditions and routines to tune the device to their specific parameters. The following flow charts show the overall software cycle:

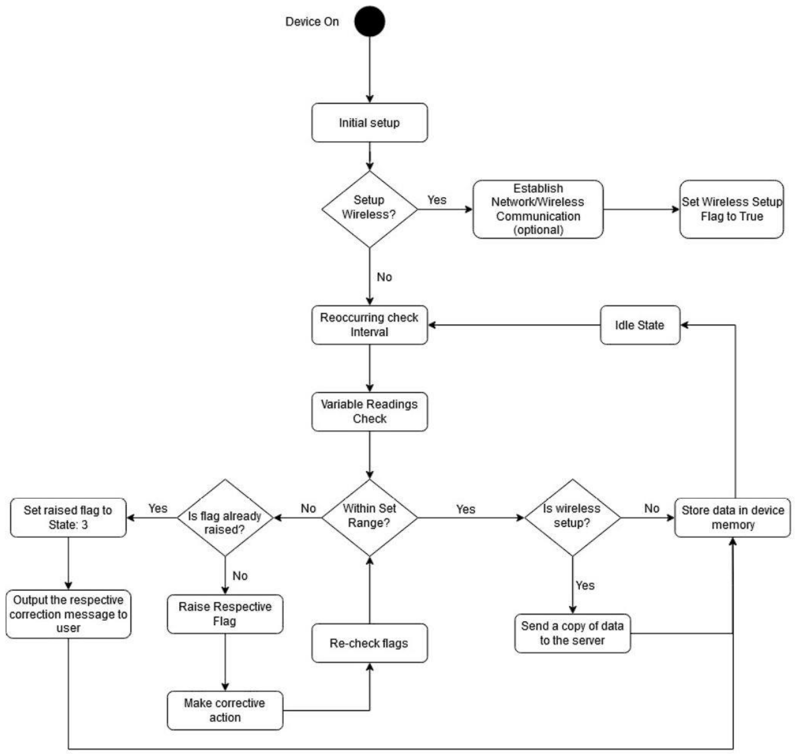

Figure 11: Software MVP Flow Chart (by Kyle Patrick Magboo)

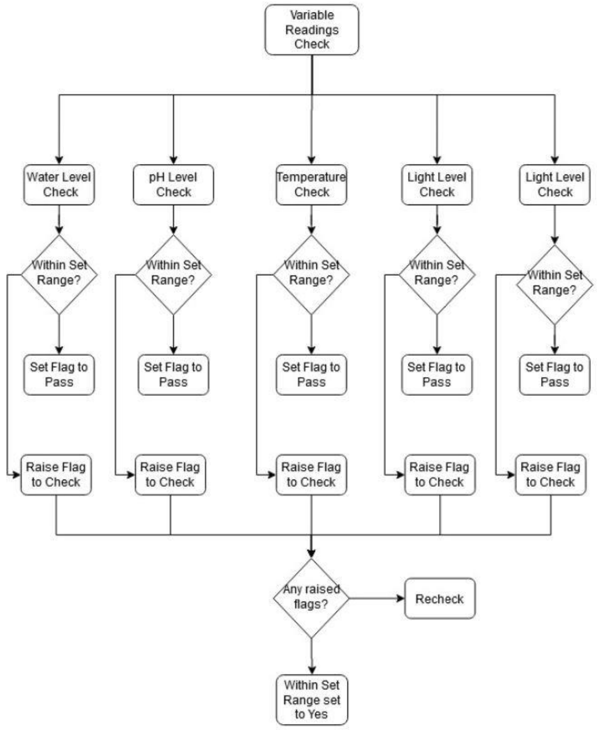

Figure 12: Software MVP Check conditions Flow Chart (by Kyle Patrick Magboo)

3.15.2.2 Software Architecture Considerations

The pipes-and-filter architecture is ideal for the software design to fulfill the requirements for an MVP. However, the networking and wireless communications requirements do not fit into that architecture. After some consideration, it was decided that the wireless communication and network design should have their own separate architecture.

3.15.2.3 Wireless Communications/Network Architecture

The development team concluded that the client-server model suits our network layer design. The device acts as a client that can connect to the server through the wireless communication modules put in place. After connecting to the server, an account can be set up and linked. Once the set-up process is complete, the client will send a copy of any data collected to the server to house all the statistics. The user will also be able to access their device settings through a web-interface. An example would be a browser on a smartphone. The smartphone would act as another client that can connect to the server. If the user logins with the same account information, they can access their device through the server. Request can be made so that a function is sent to their device. This process will provide users with wireless control of their device, even if the user is out of physical range to the LCD screen. As for the secondary wireless communication, a modified client/server architecture model applies. The device itself will act as a server that a secondary device with Bluetooth capabilities can connect to. Once connected the secondary device can play audio that will be sent to the device wireless and outputted through its' external speakers. The wireless communication and network flow chart is shown below:

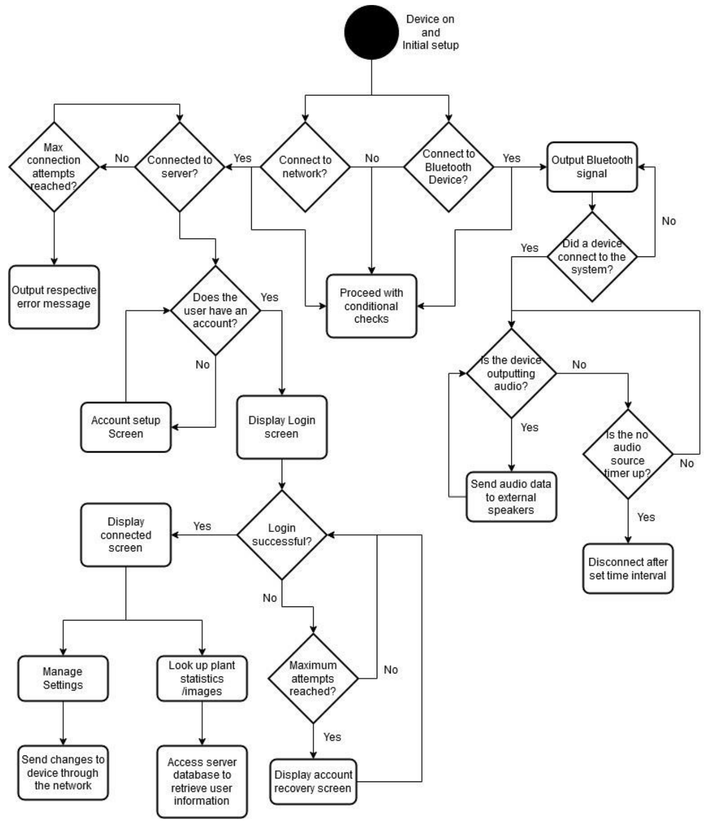

Figure 13: Wireless communication/Network Flow Chart (by Kyle Patrick Magboo)

3.15.2.4 Auxiliary Features Software Architecture

To handle the auxiliary features of the system, a separate modified pipes-and-filter and client/server architecture was chosen. This was done to help keep track major component systems as well as identifying the three different subsystems: MVP, Wireless Communication and Auxiliary Functions. Although the entire system interacts throughout and between the subsystems, it is important to identify them so that we can develop an entire subsystem and then build off it to complete another. Auxiliary functions such as taking images and outputting audio to the external speakers from a separate audio device were put into their own subsystem and the flowchart is shown below:

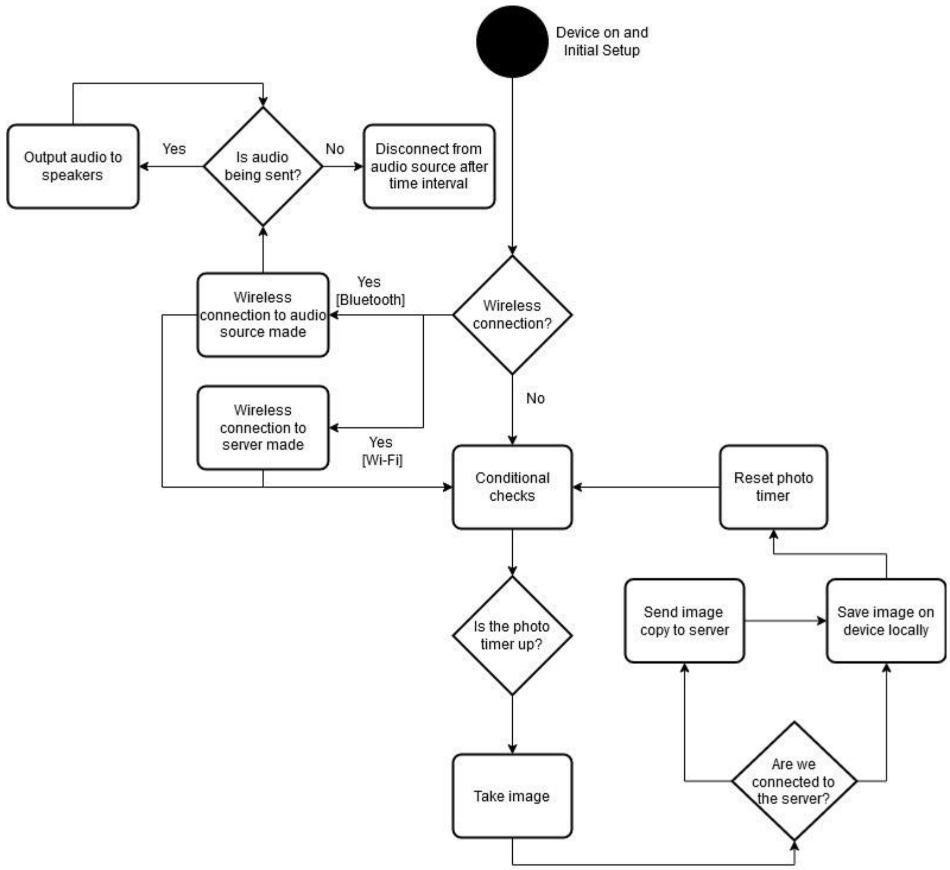

Figure 14: Auxiliary feature Flow Chart (by Kyle Patrick Magboo)

3.15.2.5 Web Server

The web server acts as a graphic user interface wrapped around an online database to house the analyzed data, control any settings and display plant growth statistics. A user is able to access this web server from a browser to have access to their device without the need to be in proximity.

Account setup is available upon initial setup of the device. This option can be bypassed for users that do not want to connect their device to a wireless connection. Once an account is made, the user is able to log in and sync their device to their account. This works by having the user connect the device to a wireless network. The device then is considered "online". Once the device is online, the user can link their account by inputting a code displayed on the local display monitor. After account setup and device sync is done, the user is able to modify the routines and settings as well as track the overall statistics of their plants wirelessly.

The web server acts as a hub for the user when the device is out of physical reach. The goal was to mimic all the features that can be accessed through the local display monitor. This gives users more than one method to communicate to their device. The web server is also be able to handle reminders that can be sent to the user to notify when a change outside of the system needs to be made. This may include reminders such as refilling water sources, nutrients or errors in routine maintenance.

There are many different approaches when creating a web server. Node.js can make web servers, dynamic webpages, and databases using JavaScript. Apache, on the other hand, has a steep initial learning curve and needs an understanding of PHP. SQL was also harder to implement in the time constraints of the project. Node.js offered a fast runtime that is beneficial for real-time operation and status checks. This can be due to its asynchronous design. Extracting data and variables and writing to them is straightforward and even allows the application to expand into full servers in the future.

With fast runtime and modularity, Node.js was a perfect choice for applications and programs. This allows the project to be expandable in the future. Changes such as increases in the number of users, settings and data is much easier. Scaling up is not as daunting on resources. Data is read and written at fast run times and the only major bottleneck comes from network speeds.

The final design of our system utilized hmtl and Javascript that was ran on a esp32 web server. This was done due to the ISP security protocols that prevented data transfer to the server. The esp32 had simple libraries that were able to run our web server for demo purposes.

3.15.2.6 Data Collection

The software collects data from all the various sensors and readings. This data is stored so that users are able to access it upon request. Collected data is grouped and presented in a way that makes it easier to understand all the different readings. Graphical representation will also be displayed as a visual aid. Such statistics that are collected and displayed include, but are not limited to, water levels, light levels, and nutrient levels. The goal of collecting these statistics is to provide useful information to users who want to have more insight on the system operation.

The final software design collected the water and light sensor data and was able to display them using graphs.

3.15.2.7 Database

"Database is a systematic collection of data." **(Database 1)** They are used to house and modify data. An example of a database structure would be an online roster that stores the information of every UCF student. Since the data of each student is different, they need their own section. Every individual in the database would have a dedicated section that shows the name, ID, address, etc. Anytime a user of the database would need to access information, they would be able to find what they are looking for much more efficiently with a database. The specific structure of a database ranges, but the general goal is to make managing large amounts of data easier. The inclusion of a database in our system allows the web server to access user information and data in a much more organized manner.

Instead of developing a complex algorithm to store data, we can use a database and keep track of all the different components more efficiently.

Users can retrieve their data and information more effectively in a database. If the device is put into production, many users have the same device but different environments, plants, etc. Therefore, the data collected will almost always be different. A database can store each individual user's data and give access to those who have access to the user's account information. Implementing an account system provides some privacy among multiple users so that information is not given unwillingly.

The final software design was not able to implement a fully integrated database but stored user data locally for demo purposes.

3.16 Additional Features

The following features were not required in our hydroponics system but were added to enhance the user experience. A camera was added and has the following features available to the user. The camera has a continuous live feed that the user is able to access at any time. Another addition available for use was a growth tracking system using the camera module. This is done by taking a picture every day to show the overall growth of the herbs. These photos are sequenced together to create a time lapse available to the user to view. This feature is very useful once the user has grown several plants through the complete harvest cycle. They will be able view older growth cycles and compare if the current plants growing are growing at approximately the same rate. This will be a standalone system separate from the hydroponic set up and not affect the growth of the plants but will allow the user to gain additional information about their plants. Another feature added to the system is speakers.

The speakers that were added to the system offer a few additional features to the user. The first purpose is recreational in the sense that the speakers allow the user to connect via Bluetooth and play music when the user's phone is connected. This system is very useful when the user is performing maintenance on the system, because it provides them additional entertainment while doing so. Another potential feature of the speakers is a security system. This was planned to be integrated with a motion sensor and when turned on by the user it will set off an alarm or make a startling noise in the event that a pet or other animal tries to harm the system. This noise will scare the animal away to protect the system.

The final design was able to implement the speaker system but did not feature the motion detection alarm system. The camera system was able to take photos and upload them however the limitations of the Wi-Fi module caused issues to the rest of the system. We opted to ensure that the system met our set requirements without the camera but featured its functionality in the middle term demo.

3.16.1 Camera

A feature included in the structure of the herb drip culture is a camera. The purpose of this camera is to provide the user with a few different extra features which can provide the ease of use. A camera system allows the user the benefit of checking their plants without physically having to go up to the system. The first feature available is the ability to access a live feed of the plant, this can be useful to check the growth of the plants and that the watering system is working correctly. The live feed option has a few other uses as well, the live feed can be used to see if pets are disturbing the plants and if any other parts of the system are functioning correctly, such as the grow lights turning on and off properly. The camera will also be used to take a picture of the plant daily. The daily photos of the plant will be available to the user as a time lapse that allows the user to track the progress of their plant growth. This feature will become more useful as they continue to grow additional herbs, the cycles of the plants will be able to be compared to see if the herb is growing at the proper rate or if there needs to be an improvement in the system. This feature is also useful in the event that the user is away from the plants for an extended period of time. When the user is away from the hydroponic system for a while the camera can let them monitor their system for any irregularities. Since the arrangement of the system is limited in size to allow for versatile placement for users and not obstruct the appeal of the overall system. The camera should not take up a lot of space and should also not take away from the overall appearance of the planter. Due to these constraints, the camera used must be small. Based on the specifications of the system, the following cameras specifications were compared to find the one that is best suited for the plant system: cost, resolution, communication protocol, and features.

Arducam OV7670 0.3 Megapixel Camera

The first camera that is looked at is the Arducam OV7670 0.3 Megapixel Camera Module. This camera module has 0.3 Megapixels and I2C communication. This camera does not provide a video recording mode, but it can take several pictures and continue to refresh like a video, up to 30 frames per second. Another plus to this camera is that it offers a color image. The problem with this is that is does not provide a good enough quality to the user. This camera module has an operating voltage of 3.3 V.

Arducam 2MP OV2640 Mini Module SPI Camera

The next camera that is looked at is the Arducam 2MP OV2640 Mini Module SPI Camera. This camera module has 2 megapixels. Both I2C and SPI communications are used for the camera. The operating voltage of the camera is in the range of 3.3-5 V. This camera can record continuous footage and offers a higher quality than the last camera described. Color image is also included as a feature of this camera.

Arducam 5MP Plus OV5642 Mini Module Camera Shield SPI Camera

Now, the next camera that is considered is the Arducam 5MP Plus OV5642 Mini Module Camera Shield SPI Camera Module. This camera is high definition with 5-megapixel resolution. The communication protocol for this module is SPI. This camera has the added feature of recording short clips of video. It also offers both single and burst pictures. An operating range for this module is between 3.3-5 V. Image and video for this module are in color.

Raspberry Pi Camera Module V2-8 Megapixel
Another potential option is the Raspberry Pi Camera Module V2-8 Megapixel,1080p module. This module offers 8 megapixels and video recording. This module connects via a ribbon cable. This camera has a dedicated camera serial interface and is used with the raspberry pi interface for communication.

The table below shows a comparison of all the specifications that are considered most crucial for choosing a camera module.

Manufacturer	Arducam OV7670	Arducam 2MP OV2640 Mini	Arducam 5MP Plus OV5642 Mini	Raspberry Pi Camera Module
Megapixel	0.3	2	5	8
Video Capability	No	Yes	Yes	Yes
Color Image	Yes	Yes	Yes	Yes
Cost	$10.99	$25.99	$39.99	$27.91

Table 20: Camera Module Specifications Breakdown

A breakdown comparison of all the cameras looked at can be seen in the table above. Based on all of the parameters looked at for each camera, the camera module that would be best suited for the hydroponic system is the Arducam 2MP OV2640. This camera is reasonably priced compared to some of the other camera modules on the market. Price is a driving factor in this project as it is self-funded by the group members. As far as the resolution of this camera, 2 MP should be plenty to monitor the progress of the plant's growth. An advantage to having a color image is being able to see if the plant is experiencing any discoloration and having health issues. The benefits of this camera include a hardware interface that is rather straightforward and uses an open source library. Another benefit of this camera is the several different platforms that is able to integrate with using SPI and I2C. This camera's IO ports are 5V/3.3V tolerant which is desired for the system being created. Prototyping will confirm that this camera is best suited for this application. Now that a camera has been chosen, the next thing to consider is how the photos the camera takes will be stored. A more detailed look at this can be seen in the following section.

3.16.1.1 SD Card Module

The camera that will be used to monitor the plants will need a place to store the photos that will later be sent to the database. This will allow the user to pull up a photo at a later time. In order to do this, an SD card will be needed. An SD card provides nonvolatile memory storage. To connect to the SD card to write and read the photos, an SD card module will be used. Including the SD card module will allow for the storage of pictures and can also be useful to save any logged data recorded by the hydroponic system. This module has a DC operating voltage of 3.3V because of this, the module includes a voltage regulator to ensure the SD card receives the correct converted voltage. Another component on the module is the 74LVC125A chip which is used as a level shifter. The purpose of this chip is to ensure that the logic received from the microcontroller is at the 3.3 V that the SD card operates on, known as logic level shifting. The MicroSD card connector is additionally on the module. The SD card module will communicate via SPI mode. The table below lists the specifications for the SD Card Module that will be used.

Manufacturer	Arduino
SD Card Type	MicroSD
Operating Voltage	3.3 V
Communication Protocol	SPI
Package Size	3.4 x 3 x 1.1 inches
Price	$1.50

Table 21: SD Card Module Specifications

Since both the camera ad storage method have been chosen the next thing to consider is the placement of the camera. An initial plan is in place to mount the camera to one of the four support posts, but this may change. Upon prototyping the placement of the camera will be decided, as the post may not provide a good enough vantage point of the entire system. This will be discussed in depth at a later time.

3.16.2 Speaker

An additional feature to the prototype that would be added and is part of a stretch goal is adding speakers to the hydroponic system. This extra feature will entice people as the system will have a feature that is not usually found in a hydroponics system.

The use for the speakers that are implemented provides no beneficial role of the speakers to the system but instead are used to add entertainment for the user. Many people enjoy listening to music around the house and knowing that a useful system that is growing herbs can also provide music to listen to will make the user more interested in the product. There is a minimum of two speakers implemented into the hydroponics system. The issues with only using one speaker and with the design aspect of this also includes the problem that we do not want the speaker to be too big with its dimensions where it will hang off from one of the walls of the system it is connected to. This leads to the thought process of having two speakers on opposite sides of the hydroponic system where the music that is being played will sound more balanced coming from the prototype. The use of two speakers will help with the keeping the dimensions of the speakers smaller and keeping the system more symmetrical. The environment in which the speakers will be in is a factor to consider when deciding on what speakers to use. The speaker also needs to be waterproof. The reason for this is that the speakers will be in an area where there is a chance that it could be humid or if for some reason there happens to be a leak in the drip irrigation system, there won’t be any chance that there will be damage to the speakers. Another solution to this problem would be to have the speakers in their own containment in the system where the electronics are covered and only the outside portion of the speaker is shown. This will make sure that they do not have to be waterproof if that is deemed too expensive for the project since normal speakers can be protected or once the system is finished being built, there could be an area where the speakers that are not waterproof can be placed where it looks like there is no chance that water damage will occur. The speakers work by connecting them to the user’s phone via Bluetooth. The user will be able to select music on their phone and the speakers will be able to play it when the user is nearby and is connected to the speakers. This also works the same when the user wants to use the alarm sound to scare off their pet that gets too close to the hydroponic system. When deciding on what kind of speakers would be used for the prototype, factors such as cost, dimensions, availability to connect to the Bluetooth module, how loud the speakers are will help on deciding what kind of speakers are needed.

The simpler part of the stretch goal is to have the speakers be able to play a sound or an alarm to scare the animal. This will not require a speaker with a need for an amplifier connected to it in between the microcontroller. The ideal speaker for this task where the user will have an alarm programmed to scare the pet away is a piezo speaker. A piezo speaker works by an applied mechanical motion from the initial voltage and from there that is being applied to the speaker, this mechanical motion that was created is changed into sound through its resonators. A piezo speaker is commonly used for Arduino projects to emit a small alarm or sound. Since the project is using an Arduino Leonardo microcontroller, this is perfect for the first part of the stretch goal involving the speaker. The chosen piezo speaker will be based on cost and how loud it will play the sound.

ToToT 2PCS DC 3-24V Active Piezo Buzzer Electronic Buzzerphone Beep Tone Speaker Alarm

This piezo speaker is manufactured by Totot. It is a continuous alarm buzzer with a working voltage of 3-24V. This fits the specs for the range of the operating voltage of the Arduino of 5V. The speaker can produce a sound of up to 85 dB. The cost of two speakers is $7.99. There is also an option to buy five of these speakers for a cost of $9.99. This type of speaker is able to work in a temperature range of –30 to 80 degrees.

Cylewet 5Pcs SFM-27 DC 3-24V Electronic Buzzer Alarm Sounder Continuous Sound Beep (Pack of 5) CYT1083

These piezo speakers are manufactured by Cylewet. It has a rated voltage of 12 V and has a range of voltage from 3 to 24 V. It has a rated current of 15 mA and can generate a sound up to 100 dB. It comes in a pack of 5 of these speakers for $7.99. The speaker can operate in a temperature range from –20 to 45 degrees Celsius.

Upon comparison of these two speakers, the Cylewet speaker will be able to produce a louder sound by about 15 dB. The cost option of these two speakers for a pack of 5 speakers has a difference of two dollars which should not be a major factor in deciding to get one over the other. They both have a working voltage that will work in the range of the Arduino. Both speakers can work in a range outside of the desired temperature range for the herbs to grow in so either one will be sufficient to use. Looking at both speakers, the Cylewet piezo speakers will be chosen for the prototype mostly due to the speaker’s ability to play sound up to 100 dB. Neither of the speakers are waterproof, therefore for the first part of the stretch goal, each speaker will have to be properly placed in areas where the is a low risk of it getting water on them while also coming up with a protective container for both of the speakers. Below are the specifications of the Cylewet speaker that is chosen.

Sound rating	100 dB
Diameter	3 cm
Rated voltage	12 V
Cost	$7.99 for 5
Length of wire	11 cm
Weight	2.4 ounces

Table 22: Parameters for the Cylewet speakers

In the final project, we ultimately didn't work on the first part of the stretch goal and instead went straight to the last half of the stretch goal and get the speakers play music.

The second part of the stretch goal involves more complex speakers for the Arduino for them to play music through Bluetooth with the user's phone. This will require the use of the Bluetooth module along with other components for the speakers. If there is enough time to modify the system by implementing these other speakers after the successful use of the piezo speakers that just play an alarm.

Visaton FR 7-4 2-1/2" Full Driver 4 Ohm speakers

The first speaker that is researched is the Visaton FR 7-4 2-1/2" Full Driver 4 Ohm speakers. The speaker has a 2 1/2" diameter with a depth of 1.14". The impedance of the speaker is 4 ohms and the frequency response range for the speaker is from 130 to 20,000 Hz. The speaker also has a moisture resistant cone that allows it to work in damp conditions. The cost for one speaker is $4.68. The max rated power for the speaker is 10 Watts.

Foster 96D9405 2-1/2" Mini Full-Range Speaker 8 Ohm

The second speaker is the Foster 96D9405 2-1/2" Mini Full-Range Speaker 8 Ohm. The speaker cone is made out of paper and has an 8-ohm impedance. The max rated power for the speaker is 13 Watts and cost of one speaker is $0.95. It has a diameter of 2.5" so it is compact enough for a smaller project like the prototype. The frequency response range is from 300 to 15,000 Hz.

Comparing both of these speakers, they have the same diameter of 2.5" which is useful in this case since there is no need for a speaker with a large diameter being implemented into the prototype. Since there is no need to have the speakers to be big, the dimensions of both work for system. The impedance difference between both does not make one significantly better than the other. A lower impedance for a speaker usually means that it is rated for more personal items while an extremely large impedance relates to a commercialized speaker. The cost difference between each speaker is drastically different since the first speaker is 5 times more expensive than the second one. This could stem from the fact that the first speaker has a moisture resistant cone while the Foster speaker has a paper cone. Based on this project, the speakers could be exposed to a humid environment or be accidentally sprayed by water from the drip system depending on where the speakers will be placed.

For this reason, it is better to go with the first speaker, manufactured by Visaton, since the speaker will be more durable as opposed to the other speaker that has a paper cone. With the paper cone, it could degrade over time especially in a system that has water circulating throughout the day. Even though the desired speaker is more expensive, it will be more beneficial in the long run if the speaker can withstand a humid environment better than the other one. Below is a table of the specs for the speaker that is chosen.

Brand	Visaton
Cost	$4.68
Nominal Diameter	2.5”
Max Rated Power	5Watts
Impedance	4 Ohms
Frequency Response	130 to 20,000 Hz
Depth	1.14”

Table 23: Speaker Specifications Breakdown

The next step for the speakers is to find an amplifier board that will connect with the speakers. The first step in looking for an amplifier board is making sure that the amplifier board and the speakers have the same power rating so that the speakers do not get damaged by a surge of power they are not rated for. The amplifier will receive a signal from the user’s phone via Bluetooth and will amplify the signal where the speakers will output the music the user is playing. Below are different boards that were researched in for the decision on which to pick.

Icstation Bluetooth Receiver Board BT 5.0 Stereo Audio Amplifier
This amplifier board requires 3.7-5 volts which is in the desired range. It is a dual amplifier board so both speakers will be able to be powered from just one board. The price of the board is $10.99. The interesting thing about this board is that it already has a Bluetooth module connected to the board, so it won’t need to be connected to the Bluetooth module that the design already has. It has a standby mode that where the board will turn off after ten minutes when it is not in use. It has a USB port but this will likely not be used as it can be used to charge a battery if used as a power supply, but this module will be connected to the microcontroller. It has a maximum transmission distance of 15 meters which is more than enough for the prototype. 2-8 ohm and 3-10 Watts speakers can be used with thus product. This fits with our range for the speakers that are chosen. The dimensions of the board are 1.6 x 0.8 x 0.4 inches.

Hyuduo Bluetooth Amplifier Board Audio Amp Board Audio Receiver 4.2
This board is a dual channel for 2 5 Watts speakers. Therefore, we can connect both speakers to just one board like the other choice. It will handle an output impedance of 2 to 8 ohms and output power of 3 to 10 Watts. This will match the speakers that are chosen for the project. The board also turn off after ten minutes if the amplifier board is not being used. It can be supplied by a battery or a 5V power supply. The dimensions of the board is 1.6 x 1.3 x 0.5 inches. The price of the board is $8.99.

Comparing both amplifier boards, they have the same specs in terms of what speakers they can be used for and the power supply voltage that is needed. The Icstation speaker has a maximum transmission distance of 15 meters which is excellent while it is unknown what the transmission distance for the Hyuduo is. The price difference between both amplifier boards is about two dollars which is not a big factor in considering one over the other. They both have a Bluetooth capability which will make the design simple since it will not need to connet to another Bluetooth module. The dimensions are relatively the same as well so the size of the board is not a factor in the decision. Ultimately, the Icstation board will be chosen. The fact that there is more information regarding the specifications such as the transmission distance and will be able to arrive earlier considering the situation makes it a better choice. Below is the comparison table of the two boards and the highlighted one indicates the board that was chosen.

Manufacturer	Hyuduo	Icstation
Cost	$8.99	$10.99
Dimensions	1.6 x 1.3 x 0.5 inches	1.6 x 0.8 x 0.5 inches
Rated Power	5 Watts per speaker	5 Watts per speaker
Supplied Voltage	3.7V-5V	3.7V-5V

Table 24: Speaker Amplifier Board Specifications Breakdown

3.17 Parts

The following section will include the parts that have been selected for prototyping and that have arrived. Given the circumstances the group members were unable to come together and have their parts in a single location for the purpose of the following pictures. Instead each member was responsible for ordering and testing certain parts that are to be used within the system. Below are the individual parts laid on white sheets of paper, along with labels that correspond to their descriptions in **Table 25.**

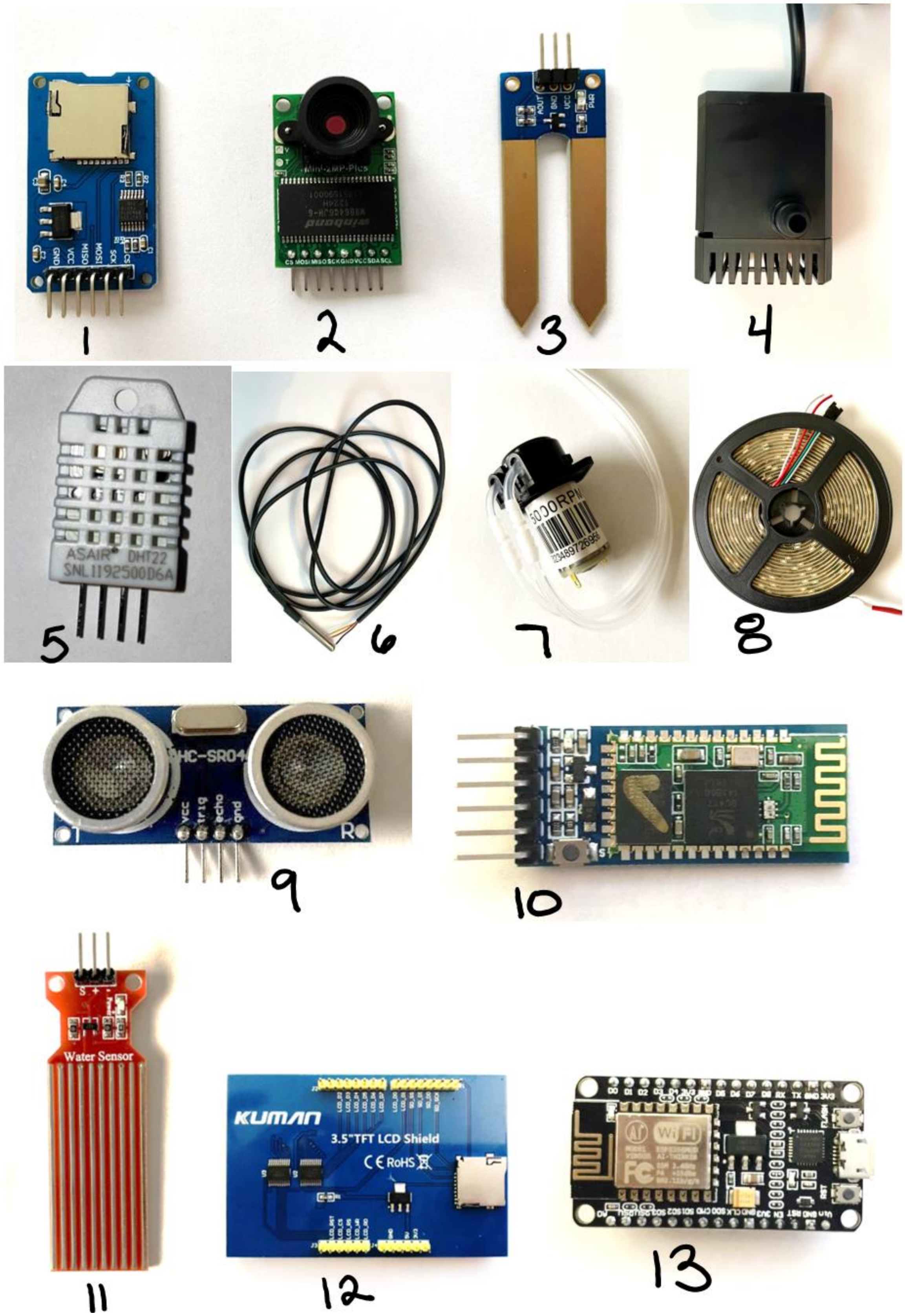

Figure 15: Parts Received for Prototyping

Identification Number	Part Description
1	MicroSD Card Reader Module
2	Arducam 2MP OV2640 Camera Module
3	Parallax Moisture Sensing Module
4	Mountain Ark Submersible Water Pump
5	DHT22 Temperature and Humidity Sensor
6	DS18B20 Water Temperature Sensor
7	1150 Peristaltic Liquid Pump
8	WS2812b LED Strip
9	HC-SR04 Ultrasonic Distance Sensor
10	HiLetgo HC-05 Wireless Bluetooth Module
11	SUKRAGRAHA Water Level Sensor
12	Kuman 3.5 inch TFT Touch Screen
13	HiLetgo ESP8266 Wi-Fi module

Table 25: List of Obtained Parts

Due to recent events there are a few items that were ordered that have yet to arrive because of shipping delays. At the time of submission, the parts included in **Table 26** below have not yet arrived. Tracking information and additional details for these items will be included in the appendix. As soon as they arrive, the testing procedures outlined will be implemented and results will be collected.

Part Description	Expected Arrival Date
LM393 Light Sensor Module	04/23/2020
E-201-C pH Sensor Module and pH Electrode Probe	04/29/2020
2 5W 4 Ohm Speakers	04/24/2020
Icstation Amplifier Board	05/12/2020
2 5V Relay Module Shield	04/27/2020

Table 26: Delayed Parts Information

4.0 Standards and Constraints

The following section discusses the engineering standards that were considered and followed when making this project. The purpose in discussing these standards is to ensure that the product being made adheres to the guidelines that establish safety requirements, minimum performance, and guarantee compatibility with the proper equipment. Following standards also ensures wide compatibility for the product being developed and in turn leads to higher customer satisfaction because it ensures quality. For this project the following systems needed to be assessed to make sure that they followed all the proper engineering standards. Along with these standards, considerations about the potential constraints that would have an impact on the design of the project were examined, such as safety measures that need to be implemented. This ensures that a quality product is delivered to the user.

4.1 Wireless Communication Standards

Since the hydroponic system sends the data collected by the sensors, data had to be presented to the user in some form, which ended up being sent via Wi-Fi. To ensure that the subsystems implemented meet minimum performance, the following wireless standards were considered when implementing the design of the system. IEEE has standards that ensure a universal quality level is met. The IEEE 802 wireless standards were considered when implementing a device that makes use of a wireless network.

The first standard that is important is the IEEE 802.11 standard which gives specifications regarding Wi-Fi. This standard specifies physical layer protocols and media access control when implementing wireless communication in certain frequency bands. The channel frequencies allowed for WLAN communications along with the allowable transmitter power must be met. This standard discusses the type of protocol techniques that are used to transmit the data. Subsections of this standard go into detail about the standards that are met by a Wi-Fi certified device.

Another standard that is important to consider is the IEEE 802.15 standard for wireless personal area networks. Following the standards for WPANs is important in this project because the hydroponic system makes use of short distance wireless network through the use of Bluetooth devices. Subsections of this standard go into Bluetooth and short-range wireless sensor networks, which our device needed to be compliant with.

4.2 Serial Peripheral Interface

Serial Peripheral Interface (SPI) is a communication bus protocol used to allow different components to interact with each other. Typical SPI connections have a master and slave connected to each other through different inputs and outputs. These include serial clock (SCK), Master Out Slave In (MOSI), Master In Slave Out (MISO) and Slave Select (SS).

Signals are sent through these communication lines and data can be passed using these signals. There are two states that are read during communication. High and low signals represent a 1 or 0 bit, respectively. These bits can be sent in groups to represent different symbols and characters. As the complexity of these messages grows, the more data can be sent. Using different standards and conventions, we can translate data in a language that the devices can understand so that the data is passed correctly. An example would be using the American Standard Code for Information Interchange. This standard allows 1's and 0's to represent characters that we use every day. These include letters, numbers and symbols. Each character can be translated into signals that are sent to another device. The receiving device can translate the signals back into the original characters and understood by the user.

The clock signal keeps all the bits that are being transferred synchronized. As the signal changes state from high to low, there is some latency. Because the signal does not change instantly, there is some delay. The clock cycle ensures that each bit that is sent is bounded by the frequency of the clock signal. This is known as synchronous. Other communication protocols use asynchronous methods, which do not use a clock signal. UART communication is a good example of an asynchronous communication method.

When a master and slave device connect using SPI, the master must first send the clock signal to the slave device. The Slave Select pin is then turned on and the slave device is now activated. Once these initial connections are made, the data is now able to be sent through the Master Out Slave In pin. That same pin is read by the slave, bit by bit. If needed, the slave device can send a signal to the master device through the Master In Slave Out pin.

When using Serial Peripheral Interface, it is important to understand its advantages and limitations when compared to other methods of communication. SPI can send data continuously since there is no need for a start or stop bit. This results in a faster data transfer rate than other communication methods. However, its limitations were something to consider when implementing this in our design. The amount of wires used is more than typical communication methods (4 wires as opposed to 2). The data being sent does not come with a protocol to handle error checking. When communication between devices, there is always a chance that data can be lost in translation. Other communication methods can check that the data is correct using certain algorithms. SPI is also unable to understand when the data has been sent successfully. The advantages of SPI make it suitable for our design. Its limitations, however, are factors that need to be addressed so that issues down the line can be prevented. The issue of data error checking and understanding when data has been transmitted can be solved through software checks from the input and output during the prototyping portion of the system build. Initial checks can be implemented outside of the communication protocols so that the system, itself, understands that the communication between the various devices are not lost in translation.

4.3 Inter-Integrated Circuit

Inter-integrated Circuit (I^2C) is a communication bus protocol used to allow different components to interact with each other. Typically, I^2C involves devices with low-speed that communicate using a single pair of wires. They are made of a Serial Data Line (SDA) and Serial Clock Line (SCL).

In I^2C, the master node is in control of the Serial Clock Line. Data can be transferred after being initiated by the master node. Each slave node waits and listens for the call from a master node. During communication, the master node sends out an 8-bit signal to the slave nodes when the clock signal is on HIGH. From there, the slave nodes can receive the start sequence from the master node. This start sequence signals that a data transfer is about to occur. Then, the master node sends the next signal, indicating which slave node the master will send the data to. This signal represents the address of the selected slave node. From there, the slave node responds to the master at the next HIGH clock signal. The last bit in the signal represents whether the master node will read or write to the slave node. The slave node can then begin to either prepare data to be read or written.

Inter-Integrated Circuits are comparable to Serial Peripheral Interfaces in that they are both synchronous. They also have similar clock speeds (between 100kHz and 400kHz). The primary difference between I2C and SPI is that I2C can handle multiple masters and multiple slaves whereas SPI is limited to one master. I2C is more geared towards smaller projects that use low-power consumption. For our design, more than one master is not necessary since the microcontroller will be able to handle all other components as a singular master. Moving forward, the team decided that SPI was the best primary communication protocol for our system.

4.4 Coding standards

There are many standards and conventions that are used when writing programs. Although some of these conventions may not greatly affect the performance of the code, it is important to implement certain standards so that the code is more readable and easier to understand for other members of the development team. Some of the coding standards and conventions our team is utilizing are as follows:

4.4.1 Function separation and organization

Our program operates on different variable checks and routines. These can be separated into different functions so that most of the code is not embedded into the main function. The main function would be able to call each auxiliary function separately. Dividing the functions creates modularity in the software development. Each module can be tested, prototyped and implemented separately. As the software development becomes more and more complex, additional functions will be created so that similar operations that are done numerous times can be called separately. This will save on time and code space. The overall structure of the software will call a timer function that acts as a loop, indicating when the system should perform a routine or check. From there, each check function will be called, and the appropriate flag will be changed. These flags will be used throughout the entire system. The parameters passed through these functions will also act as modifiable variables. Since these variables can be changed, they can be grouped together in a separate function that acts as the software’s “settings.”

4.4.2 Miscellaneous Coding conventions

There are many other conventions that can be used in the development of our program, however the primary rules that are being used as the primary guidelines in our software are as follows:

Expressions forming bodies were separated into sections with brackets ({}). All functions addressed variables at the start as opposed to right before it is modified. This is to help readability and traceability. Variable names were Camel cased and function headers were Pascal Cased. Any comments were left on top of the expression it was describing. Users, at default, are not be able to access variables that are not within range of acceptable values in the system. This is to ensure that the user does not unintentionally break the system while trying to modify certain settings. This was handled by using break statements that pad the user from entering a function with a parameter that will cause a system crash or bug.

4.5 Federal Regulations Regarding Hydroponic Systems

Although there are not strict guidelines for hydroponic systems, there are a few federal guidelines for hydroponic systems to be mindful of. The act of "organic hydroponic" production has been closely scrutinized over the years. There are a few groups such as the U.S. Department of Agriculture (USDA) and National Organic Program (NOP) that want to ensure anyone who is practicing hydroponic production can prove that they are following the Organic Foods Production Act (OFPA). For this reason, the National Organic Standard Board (NOSB) has prohibited hydroponic production with minor exceptions, as there needs to be "sufficient organic matter" in accordance to the standards brought forth by the OFPA. Knowing this information, it is important to note that any herbs or plants grown in the hydroponic system designed by this team is not claiming to organic. Since hydroponic methods are not yet widely implemented there is not a lot of regulations and guidelines of most suitable practice, but this will continue to develop over time.

4.6 Safety Constraints

When constructing and designing the desired final system, the following safety considerations must be made to ensure that the product is one that meets all standards and reduces any risk of hazards. Due to the nature of this project, there will be relatively large amount of water near electronic components. The water near these electric components can lead to short circuits and equipment failure, which could even potentially lead to a dangerous situation such as a fire. Care should be taken to reduce the number of electronics near the water, for that reason the design of the system is intended for a large portion of the electronics to be located on a platform far above the water in a separate enclosure. The electronics such as the water sensors and pumps will need to be in closer proximity to the water, for these components additional precautions will be taken. Items like the moisture sensors will likely need additional weatherproofing. A way to do this is by adding conformal coating to cover the solder connections and surface mounted components. This is useful for protecting against potential moisture, but also protects against any chemicals and dust. Ensuring that all electrical connections are secure and waterproofed through the use of liquid electrical tape is also important. By taking these additional steps, the team can ensure a safer product is created.

4.7 Time Constraints

As this project must be entirely completed in two semesters per the ABET requirements, it is crucial that all design considerations are scaled appropriately to be finished during the alloted time. Any additions or major design considerations that would lead to an extended production time should be adjusted accordingly. If any major portion of the system is unable to be deisgned during the two semester time period, then it would lead to a setback for either the entire team or an any of the indivial members. Due to the severity of the events that would follow such a misstep, the members need to make careful consideration to meet the requiements in the time given. For that reason a schedule has been created to keep the project moving in a timely manor. Any additional design considerations must be weighed to determine if they are a suitable accesory to the original design. The original design is constructed to be completed in a timely manor according to the aforementioned guidelines.

Given the recent events, some items intended to be implemented in the project have experienced shipping delays. This has lead to portions of the orginally intended timeline to be shifted to a later date. As a way to make up for this the group intends to review the previously set milestones and adjust accordingly. This might lead to having to do more than one process of the project simultanouesly, which in turn will have a greater work load in the period that is used to make up for the postponment of certain project tasks.

4.8 Economic Constraints

When creating and implementing the design for the hydroponic system major considerations were made about the overall cost of the ability to carry out the final product. As this project is self-funded by the participating members some potential items were consider alongside another component that had all of the same features or slightly less, without sacrificing the previously stated engineering specifications. As the final product is intended as a household item and not something that would be used to mass produce crop for the agriculture industry, the accuracy of certain sensors did not need to be of the highest quality. The sensors and additional components are chosen to meet the intended engineering specifications.

Another major factor playing into the availability in selection of parts is the current situation. In certain case a specific part had to be purchased from a distributed in the United States. Since this is the case, the originally planned budget has to be flexible as some parts from the United States may have a significantly higher price than if it were to be ordered from elsewhere.

5.0 Design

Following the research of the individual subsystems of the overall hydroponic structure and the engineering standards that must be adhered by, the intended design for the herb monitoring system is discussed in this section. The design decisions made in this section are determined by the previously stated specifications and the implementation that produces the proper results while keeping the overall cost relatively low. The decisions made in the process were decided after thorough testing of the components of the system to guarantee that it will be successful in implementing it with the other subsystems so that the herbs will be in an optimal growing environment. The section includes possible problems that arose during the testing portion of the subsystems and how solutions came above it to combat them. The design section will include an in-depth explanation about how each subsystem interacts to achieve the goal of the overall system, along with helpful block diagrams and schematics to aid in explanation.

5.1 Moisture Sensor Design

A moisture sensor will be used in each of the plant holders and will be inserted into the medium. Since there will be two separate plant holders in the system, two moisture sensors will be required to monitor each of the plants. The individual moisture sensors will be used to monitor the volumetric content of the soil. If the clay aggregate is getting too dry before the next phase of water nutrient solution dispersion occurs, then the value read from the sensor will trigger the water pump to turn on and deliver the water nutrient solution to the plants.

The image below shows an example of how the inserted moisture sensor will look when taking measurements from the growing medium of the plant. This concept image does not show the wires or pins that will connect the moisture sensor to the sensing module that connects to the microcontroller but provides a conceptualization of how the sensor will look in the system.

Figure 16: Moisture Sensor Testing Concept (by Luna Vazquez)

5.1.1 Moisture Sensor Final Design

For the final design of the moisture sensors used for the watering of the herbs, two moisture sensors were used. Theses sensors were used to determine the moisture of the soil that the herbs were in and decide when to turn on and off the watering system for the herbs. Once the data for each of the sensors was collected, the code that handled the data was similar to the one used for the light sensors. It used an average to determine when to switch the water pumps relay, which in turn turned the water pump on and off at the appropriate times. The water pump remained on for the correct duration to ensure that the plants were receiving enough of the water nutrient solution and then the system repeated as necessary to make sure the plants were receiving sufficient amounts of water.

5.2 Water Level Detection

Regardless of the method with which they are grown, all plants require water. In a hydroponic growing system, water is the sole way in which plants are provided with many of the components they need to survive and grow. This watering solution used in drip irrigation hydroponic systems like the one being implemented in this project not only provides the water that is essential for plant life, but also the nutrients that are needed by the plants as well. In a drip irrigation hydroponic system, the watering solution is dripped on to the plants and allowed to trickle down through the roots, which the elements needed by the plants are absorbed, and the excess water flows out of the plants and into a container below. This system aims to collect and reuse as much of this excess water as possible.

The reservoir containing the water and watering solution that will be provided to the plants is located below the plants themselves, in the base of the overall system. This way, the excess water that naturally flows down from the plants is collected back into the reservoir of watering solution to be reused. The watering solution is provided to the plants by being pumped up through a tube along the side of the system and released directly on to the plants through drippers. Any water that is not absorbed by the plants falls back down into the reservoir and the cycle continues. The watering system will run frequently for designated periods each time based on the needs of the plants being grown in the system. As a result, the amount of water currently within the reservoir is constantly changing. To measure and monitor this level of water in the reservoir, a sensor is used.

The water reservoir is a square shape, so with knowledge of the dimensions it is possible to calculate the volume of liquid in the reservoir based off of the height of the liquid surface in the reservoir alone. This height of the liquid is measured using an ultrasonic distance sensor. The sensor is located directly above the water reservoir, at least 10 cm above the maximum level the water in the reservoir will reach in order for the measurement to be most accurate. This ultrasonic distance sensor is not specifically designed for detecting the surface of water, so problems may arise. In the situation that the sensor could not able to accurately detect the surface of the water, a kind of bobber would be included. By placing an object that will float, ideally something flat like a sponge, on the surface of the water in the reservoir and constraining it to a specific location within the reservoir where it is only able to move up and down, a solid object can act as a marker for where the surface of the water is. This object may be easier for the ultrasonic distance sensor to detect than the ever-changing surface of the water, allowing for more accurate measures of the distance from the sensor to the surface of the water in the reservoir. Due to how this object would be used, it would need to be placed directly below the ultrasonic distance sensor. Whether or not this method would be used and this bobber object would need to be included was determined during testing and prototyping. After testing the accuracy of the ultrasonic distance sensor in measuring the distance to the surface of a water in a container, it was determined that the bobber would not be necessary, since the sensor is able to detect the water's surface correctly as needed for the project.

The system is designed to be able to operate for extended periods of time with minimal user interaction. The system includes an automated watering system that provides the water and necessary nutrients to the plants, so long as there is water available in the reservoir. The user only needs to fill the reservoir with water and the system will care for the plants being grown in it. However, once the system is out of water, it is unable to function, and the plants will die. The user could manually monitor the amount of water in the reservoir by frequently checking it, but this would be very tedious, since it would require the user to open up the base of the system every time. This would also defeat the purpose of the system to be able to operate for a while on its own, since frequent user supervision and interaction would be required. Instead, the amount of water within the reservoir is continuously measured by the ultrasonic distance sensor. When the amount of water in the reservoir drops below a certain threshold, the user is alerted that the reservoir needs to be refilled. It is also possible to check the current level of the water in the reservoir at any time via the display screen or the companion app. This way, the user is able to know exactly how much water is currently left in the reservoir and figure out if the water will need to be refilled soon, before leaving for an extended period of time perhaps. This sensor helps to automate the system and minimize the necessary amount of user interaction by telling the user when they need to refill the reservoir, rather than relying on them to be actively checking the water level. The measurement obtained from this sensor can also be used as a check to determine if the pump and the watering system overall is functioning properly. If water should be leaving the reservoir and being pumped up to the plants, the distance sensor should detect a change in the distance from the sensor to the surface of the water. If there is no change, then it can be determined that the pump and overall watering system is not functioning properly, and the user can be alerted. Without this check, it is possible that the system will continue to be unable to run for a while before anyone notices that the plants are not being watered, and the plants may die.

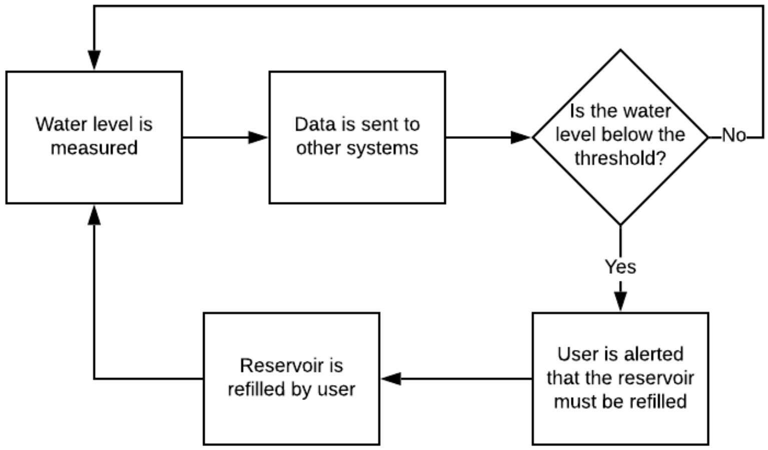

Figure 17: Flowchart showing the water level detection process. (By Lindsey Feldman)

5.3 Nutrients System

In order to grow and live, all plants need a few basic things: air, water, light, and nutrients. In traditional growing methods, plants are able to get the nutrients they need by absorbing them from the soil they are planted in. For this system a traditional growing method using soil was initially considered, but ultimately it was chosen to use the hydroponic drip irrigation method for growing the plants. Hydroponics systems like this generally require less care than a traditional growing method and are cleaner since they don't require soil. These characteristics made the choice to implement a hydroponic system ideal, since a major goal of this project is to design a build a plant care system for herbs that can function for extended periods of time on its own without requiring user interaction and can easily be used indoors, like in a kitchen or living room window. Using a hydroponic growing method brings up its own set of new problems, however. Growing plants hydroponically means growing plants without the use of traditional substrates like soil, and since there is no soil, the plants cannot obtain the nutrients they need by absorbing them naturally from the substrate. Instead, the necessary nutrients must be included in the watering solution that is provided to the plants. These nutrients typically come from liquid nutrients solutions. These solutions contain concentrated amounts of the nutrients required by plants along with water and are added to the water that the plants are grown with, typically on a ration of a teaspoon or so of nutrient solution per gallon of water. The required nutrients can vary from plant to plant, so for this project research was conducted regarding the needs of common herbs, like the basil the system is designed for use with, and a general balanced liquid nutrient solution was selected.

A major goal of this project is to design a plant care system specifically for herbs that can operate for an extended period of time without the need for user interaction. To accomplish this goal, the addition of nutrients to the watering solution must be automated, and for this to be possible a smaller system that is a subset of the overall device specifically for managing and dispensing the nutrient solution must be designed.

The purpose of this system is to dispense the necessary amount of nutrient solution needed into the water in the reservoir depending on how much water is in the reservoir. It was considered to have a sensor or series of sensors that would constantly be monitoring the nutrient levels in the water in the reservoir to determine if more nutrient solution was needed. While a system like this would be helpful in maximizing plant grown and crop yield of the herbs, it would be very complicated to implement and would require many new sensors. This level of intricacy is outside of the scope of this project, so this concept will not be executed. Instead, the system will dispense the necessary amount of nutrient solution based on the amount of water in the reservoir whenever the reservoir is refilled by the user. The water that is added by the user is initially not sufficient for providing the necessary elements for growth to the plants, while water that has been circulating through the watering system already may still have some nutrients within it that have yet to be absorbed by the plants. As such, providing more nutrient solution to the water upon the reservoir being refilled should be sufficient to provide the plants with the nutrients they need. Since the nutrient solution is added to the water only immediately after the reservoir is refilled by the user, it would be possible to just require the user to add the nutrient solution themselves and not include the nutrient dispensing system as a part of this project. However, this would require the user to have more knowledge of the needs of the plants and the system, needing them to measure exactly how much water they are adding to the reservoir and calculating the exact amount of nutrient solution they need. This would defeat the purpose of the system as an easy way for inexperienced gardeners to grow herbs easily in their house. For this purpose, it is necessary to include this nutrient dispensing system as a part of this project.

When the reservoir is refilled by the user the system will determine how much nutrient solution must be dispensed into the reservoir and will dispense it. This system must take an input from the sensor measuring the level of water in the reservoir. The water level recorded will be used to determine the amount of water in the reservoir based on the dimensions of the reservoir. From this information, the system can calculate the amount of nutrient solution to dispense based on the programmed ratio of nutrient solution to water. Based on the general balanced nutrient solution chosen to be used for testing in this project, the ratio is ½ teaspoon per gallon of water. The liquid nutrient solution is stored in a separate compartment from the water reservoir. This compartment is to the water reservoir in order to minimize the distance the liquid needs to travel. This way, the requirements of the pump used to dispense the nutrient solution are also kept from being too extreme, which allowed for more options in selecting a pump, and ultimately allowed the use of the peristaltic pump. It also minimizes the amount of tubing that is needed for this system. The overall project is designed to have a sleek appearance and to fit easily on a table or in a windowsill. For this purpose, efforts were made to keep the system as compact as possible. The water reservoir and related systems components are housed in the base of the system, below the area where the herbs are being grown. This presents another reason why the compartment containing the liquid nutrient solution must be kept close to the water reservoir. For this reason, as well, the nutrient solution compartment cannot be too large. Since only about ½ teaspoon of nutrient solution is required per gallon of water in the reservoir, and the reservoir only holds up to 2 gallons at a time, a smaller compartment is more than sufficient. A compartment size of about ½ cup, or 4 ounces, is still quite small and would not take up much space in the base of the system, while still being able to hold 24 teaspoons of liquid nutrient solution, which is enough to provide nutrient solution to the reservoir when it is refilled up to 24 times. This compartment is square in shape with a flat bottom in order to make it easier to calculate the volume of liquid in the compartment. The compartment is made of plastic since it holds the liquid for a long period of time without causing any damage to the compartment, like rot or mold that could occur if the compartment was made of wood. The nutrient compartment would either be constructed using existing material or containers to fit the needs of the project or will be 3D modeled and printed with ABS plastic if a specific design is needed that cannot be accomplished with existing components. A small square plastic container fitting the dimensions required for this component was purchased and included in the base of the system as the nutrient solution compartment. Since the container already met the necessary shape and dimension requirements, no construction or changes had to be made.

Within the nutrient solution compartment itself there is another sensor to measure the liquid level of the nutrient solution. This sensor is resistive, so it is attached to the side of the compartment. The sensor constantly records the level of the liquid in the compartment, and this data is used to calculate the total volume of liquid nutrient solution in the compartment. One purpose of keeping track of this liquid level is to inform the user of how full the nutrient compartment is. Notifications are sent to the user if the solution drops below a certain level, letting them know that it is time to refill the nutrient solution, or the user can easily check on the level of solution via the app or display screen without having to open up the entire base of the system. Since the nutrient solution compartment does not need to be refilled as often as the water reservoir, it may be common that the user does not actively keep track of the amount of liquid in the compartment, and maybe even forgets about this feature all together. Having the system monitor the liquid nutrient solution level automatically allows it to keep track of the amount of solution currently available and notify the user if it needs to be refilled, decreasing the necessary amount of user interaction.

The most important function of the nutrient system is the dispensing of the nutrient solution into the water reservoir. This is accomplished using a peristaltic pump that is attached to the inside of the base of the system. One end of the tube running through the pump is placed in the liquid nutrient solution within the compartment, and the other end is above the water reservoir. When the reservoir is refilled with water and the nutrient solution must be dispensed into the water, this pump transports the necessary amount of nutrient solution from the compartment into the reservoir. To dispense the correct amount that is needed depending on the amount of water in the reservoir, the system runs the pump for the necessary length of time based on the amount of solution needed and the flowrate. The flowrate of the pump is kept constant, and the controller takes information from the water level sensor in the reservoir to determine how much water is in the reservoir, then uses the information about the nutrient solution to amount of water ratio to determine how much nutrient solution must be dispensed. This necessary amount of solution is divided by the flowrate to determine how long the pump must run for to dispense exactly the correct amount of liquid nutrient solution into the water in the reservoir. The system depends on calculations done regarding the flowrate and the amount of time the pump will run to dispense the correct amount of nutrient solution, but the liquid level sensor within the nutrient compartment can act as a second check that the system is running properly. If the liquid level sensor detects that the amount of solution by which the level in the compartment has decreased is different from the amount of solution that should be dispensed, the system can alert the user that something is not working properly. This check will help to prevent a situation in which the correct amount of nutrient solution is not being dispensed and it goes unnoticed by the user, causing the plants to receive too little or too much of the nutrients they need.

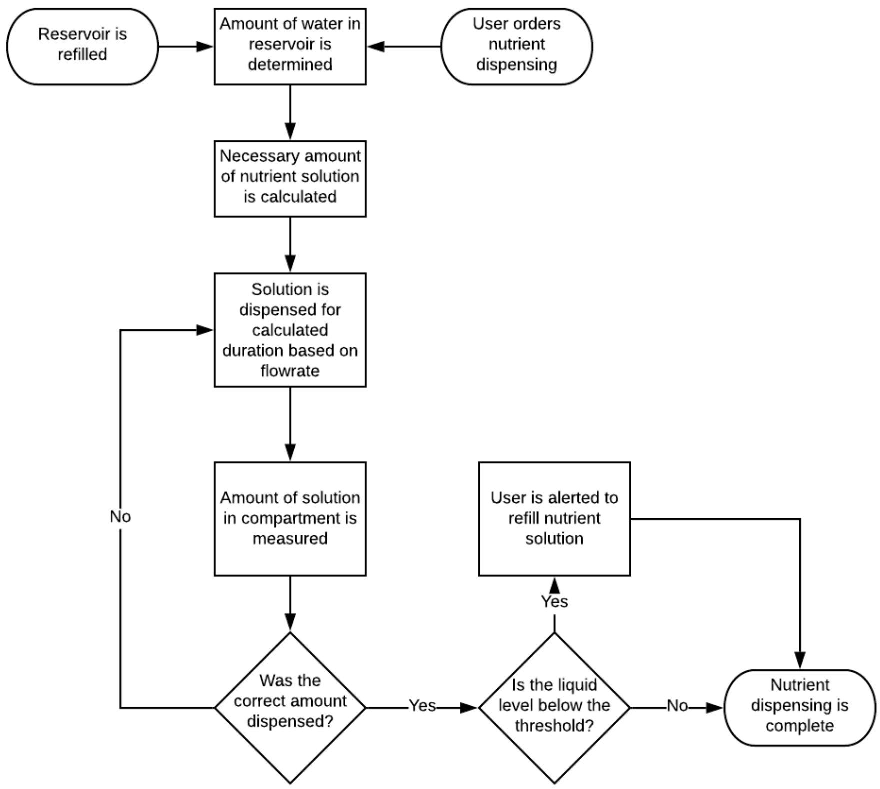

Figure 18: Flowchart of the operations of the nutrients system. (By Lindsey Feldman)

5.4 pH Sensor

The pH level of the watering solution within the system affects both the ability of the nutrients within the solution to remain dissolved and the ability of the plants to absorb the necessary water and nutrients from the solution. As such, it is important to monitor the pH level of the watering solution in the reservoir within this system. This is done using a pH sensor module and probe. The probe is attached to the module via a long cable, so the module does not need to be placed near the probe itself and can instead be included in the top of the system along with the majority of the electronic components in this project. This probe will be mounted to the side of the water reservoir using a clip of some kind that will allow the probe to be removed from the reservoir if necessary. The pH probe is not necessarily designed for prolonged exposure to liquid, especially the watering solution, which contains many dissolved nutrients. The electrode at the tip of the prob that is used to measure the pH level of the liquid may become clogged with the nutrients in the solution, so it is necessary for the probe to be easily removed from the reservoir so the user can clean it if needed. The measured pH level can be displayed to the user via the display included on the system or via the companion app. If the pH rises above or falls below the ideal range for the nutrient solution being used or the plants being grown, the user can be notified. Having the system automatically adjust the water to raise or lower the pH value would be ideal, but this would require significantly more components, systems, and control loops, so this is outside of the scope of the project. Nevertheless, it is essential that the user is aware if the pH value of the water in the reservoir is outside of the recommended range, as this could cause complications in the operations of the system or harm the plants themselves. If desired, the user can add solutions to the water to adjust the pH back into the desired range if they alerted that it has fallen out of that range.

Due to the issues that could arise if the pH probe is always left in the water reservoir, it was decided for the pH probe to be outside of the water by default. The hook from which the probe hangs is attached to the side of the inside of the bottom portion of the system next to the water reservoir. When the user needs to measure the pH value of the water reservoir, they must take the probe off on the hook and place it into the water while the measurement is being taken. They then place the probe back onto the hook.

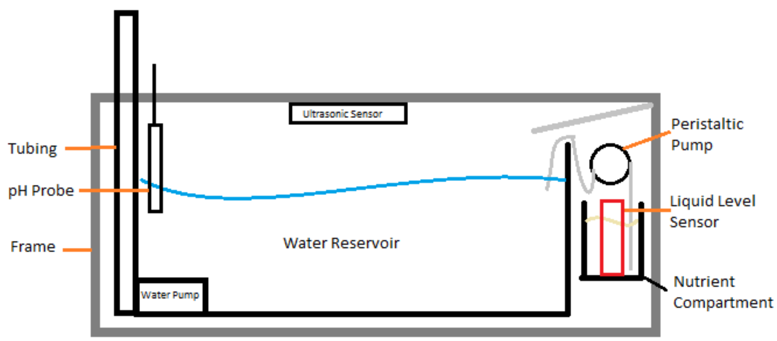

Figure 19: Diagram showing the layout of components within the base of the system. (By Lindsey Feldman)

5.5 Grow Lights

Since this system is designed to operate both outdoors and indoors, artificial grow lights must be included. These artificial grow lights provide the plants with the light they need to live and grow, even in areas where they are unable to receive natural sunlight, like on a kitchen counter or in the middle of a living room. The artificial grow lights also allow more experienced users to have more control over how much light the plants receive, and of what color.

For the herbs this system is designed to grow, the research conducted led to the conclusion that, overall, white light is the most effective wavelength to grow these plants at. As such, by default the light provided to the plants in the system is white light. However, the LEDs that are used to provide this light are full-color spectrum, so if desired the user can change the color of light being provided to the plants. An LED strip is used as the artificial grow lights for this project. LEDs use much less energy than other lighting options and produce less heat, which could be an issue since heat emitted from the lights could change the growing environment of the plants. LED strips are easily available and allow the LEDs to be arranged however is necessary for the design. For this project, the LEDs are arranged in rows of strips to create a kind of array of lights. This layout provides light to the plants from multiple directions and creates ample coverage of light for both of the plants growing within the system. The diagram below provides a visual reference of how the LED strips are arranged.

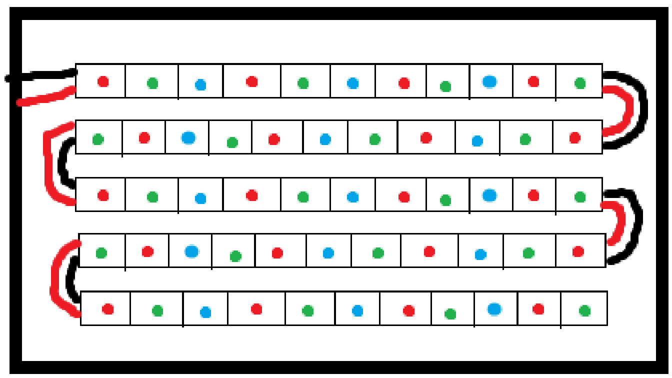

Figure 20: Layout of LED strips (by Lindsey Feldman)

The LED strips are attached to the bottom of the overhead potion of the system, so that they are directly above the area where the plants are being grown. They are attached using the adhesive backing that is already included on the strips purchased from the manufacturer. If this is insufficient, other methods of attaching the LED strips will be considered during testing and prototyping. The LED strips are connected to the microcontroller, which is housed very close inside of the overhead portion of the system.

The LED strips that are used in this project have a waterproofing of IP65, which, while not essential, is helpful. Since the LEDs are located above the plants and the watering system is below, the LEDs should not become wet at all during normal operations, but having this waterproofing provides more security in the event that an outside force disrupts the system, such as in the event that it is knocked over.

The lights are designed to be turned on automatically if it is detected that the plants are not receiving sufficient sunlight from natural means. This allows the plants to get as much natural sunlight as possible if the system is located somewhere where it is available, while also ensuring that the plants receive enough light. Once the lights go on, they will remain on until the length of time sunlight is needed for the plants is reached, at which point they will turn off. If no light is detected when the time period in which the plants should receive light begins, the artificial grow lights will turn on and remain on for the duration of the daily time period. The user is also be able to override the system’s default to natural light if available and have the system supply light via the artificial grow lights at all times. Through this, the user is able to have more precise control over how long the plants receive light for and what type of light they are receiving.

Four LED strips were attached in parallel to each other on the bottom of the top portion of the enclosure. These lights provide sufficient light coverage based on the dimensions of the system. The adhesive the was included with the light strips was not strong enough to hold up the LEDs alone, so electrical tape was used for added support, especially at the edge where the strips were connected to each other.

5.6 Light sensor Design

The light sensors determine if the grow lights should turn on or off and offer the user the ability to determine if the grow lights are not functioning properly. A few different light sensors are placed around the hydroponic system to get an idea of the overall light being received by the plants. The light sensors will check to see if the light is above the expected threshold and if so they will not do anything, until it is time for them to check the light intensity again. If the sensor checks and see that the light intensity is below the desired threshold for all of the light sensors, then the grow lights will turn off, if it’s during the allotted day time grow light hours. The light sensors will not turn on the lights outside of the allotted grow light time because plants need portions of their time, nighttime, without light.

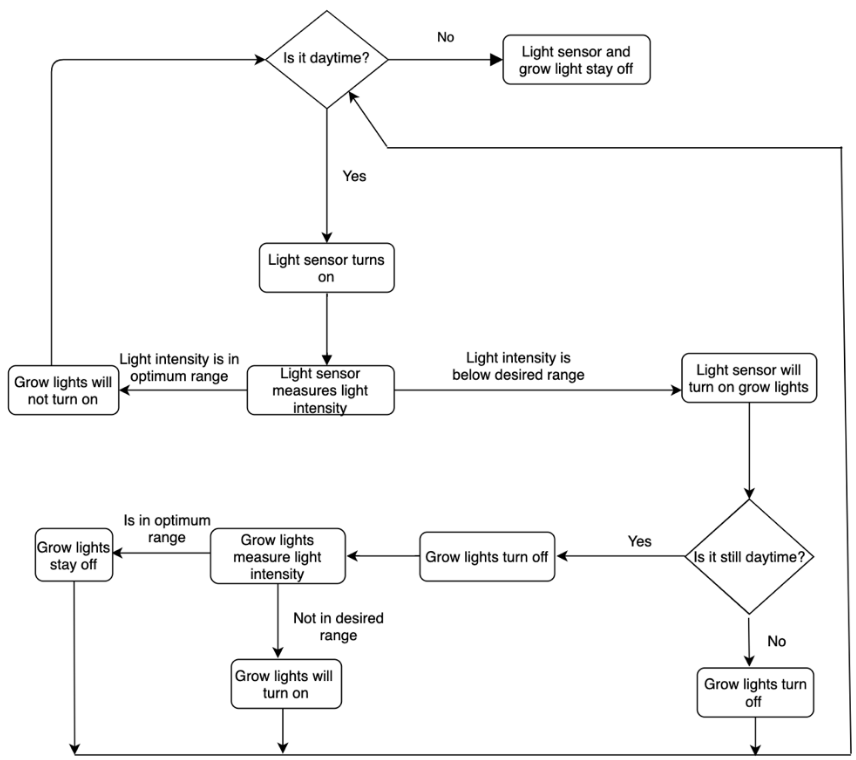

Figure 21: Light Sensor Check Scheme (by Chris Hernandez)

5.6.1 Light Sensor Final Design

For the final design of the hydroponic system a total of three light sensors were used. The light sensors were placed in the following manner: one to the left of one of the plant holders, one in the center and one to the right of the of the second plant. These light sensors collected data of the light intensity in the surrounding environment of the plants. Once the data is collected from all three sensors, an average of the light sensitivity is calculated. When the testing was done for the light sensors it was determined that a dimly lit room is around 700 as the analog value returned by the light sensors. Using this value as the threshold. The light intensity average is then used to determine when to turn the LED grow lights on or off.

5.7 Humidity Sensor Design

A humidity sensor will be used to monitor the level of humidity in the enclosure where the herbs will be placed in. Although there will always be two plants prior to the addition to the third herb added for the stretch goal, there will only be a need for one humidity sensor. This is decided because there won't have to be one humidity sensor per plant. This decision came from the reason that it seems highly unlikely that one end of the enclosure where the herb will be will have a different level of humidity when compared to the other side of the enclosure.

The distance between both herbs will not cause one herb to experience a different level of humidity between the other. Therefore, the placement of the sensor should be considered when agreeing that both herbs will experience the same level of humidity when they're are grown in the enclosure. The best decision on where to mount the sensor seems to be that it should be placed in the middle of the two herbs. From there it will take a correct measurement of the levels of humidity that the herbs are receiving. Now that the location of the plant has been decided, it needs to be tested to guarantee that it is taking accurate readings that will notify the user of the humidity levels that the herbs are experiencing. In order to test that the sensor is working correctly, the person must know the level of humidity of the room that the user is in before testing the humidity sensor. This can be done by the user having a separate humidity sensor. A digital humidity sensor from a local hardware store can provide this data in an instant since it does not need to be configured like the desired humidity sensor to an Arduino to capture humidity readings. Once the user has a digital humidity sensor that can give them the humidity level of the room, the user should turn it on and read the value that the humidity sensor displays. They should turn the device off and turn it back on and make sure that it portrays a correct value. Now that it is known that the digital humidity sensor is working, the user should also go somewhere else such as outside to make sure that a different value is being read so that this solidifies that the humidity sensor is working. Next it is time to test the humidity sensor that will be placed in the enclosure of the hydroponics system. By powering up the humidity sensor through the Arduino and that it is connected to it, the sensor should be able to measure the humidity levels of the room that it is being tested in. The value that the humidity sensor sends to the Arduino should match the value that the digital humidity sensor had. If both values match, then the user can guarantee that the humidity sensor for the herbs does work. To further increase certainty that they humidity sensor does work, the user should turn off the sensor and turn it back on and make sure that it does output the value. The final testing before guaranteeing that the sensor works is to go outside and measure the level of humidity and make sure that the level of humidity that the sensor measures is the same as the level of humidity that the hardware store humidity sensor measures. If all humidity levels match, then the user can guarantee that the humidity sensor works and that the placement of the humidity sensor in the middle of the two herbs will correctly measure the humidity levels surrounding the enclosure.

Below is a flowchart describing the logic design of the humidity sensor. It shows how the humidity sensor will measure the humidity of the environment once an hour and from there will alert the user if the humidity levels are optimal for the herb growth. If the levels are within range, then the user will not have to take any corrective measure. If the sensor measures levels out of range, then the sensor will alert the user that it is out of range. From there, the user will have to take measures to make sure that the humidity levels go back in range in the surrounding room. The sensor will then measure the humidity level again and if it measures it in the optimum range, then the sensor will let the user know. If the levels are still not in range, then the sensor will alert the user until it satisfies the humidity range.

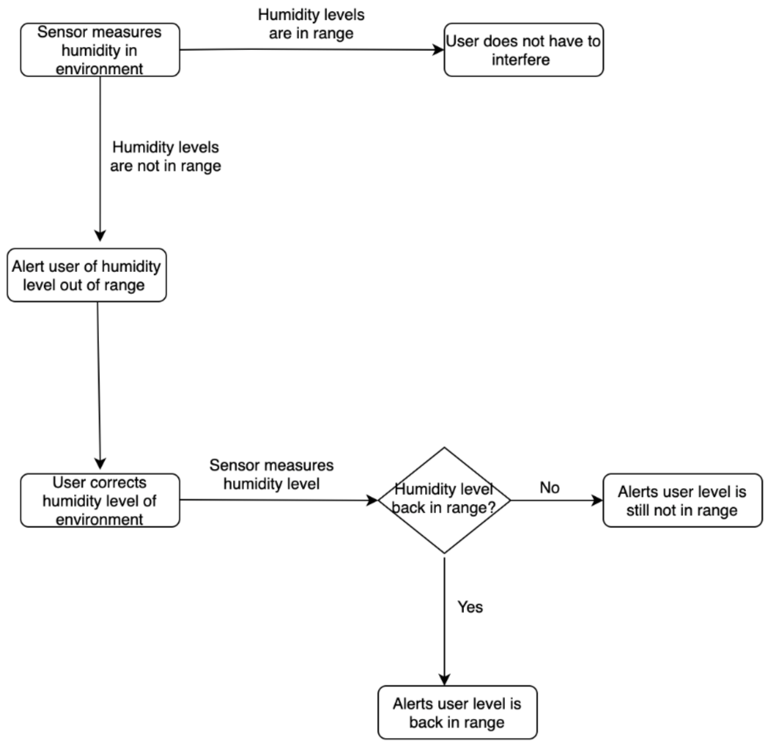

Figure 22: Humidity Sensor Flow Chart (by Chris Hernandez)

5.8 Temperature Sensor Design

Two different temperature sensors will be used to measure temperature. The two different temperatures that are measured in the enclosure is the water reservoir temperature and the ambient temperature. A single temperature sensor will not be able to measure both readings at the same time due to being unable to measure two different mediums at the same time especially since data will need to be pulled about both every hour. It would be a hindrance if the user had to constantly move around one temperature sensor between these two environments in order to get data. For this reason, there will be two sensors that will measure the temperatures that need to measure to guarantee the health of the herbs.

The placement of both temperature sensors will need to be decided so that these sensors can receive accurate measurements surrounding the temperature. For the ambient temperature sensor, this sensor will measure the air surrounding the herbs. Upon further research of different temperature sensors, the temperature sensor that was chosen, can also measure humidity. This is beneficial in the fact that that means that only one sensor will be needed to measure both the humidity and temperature of the air. As suggested before, the humidity/temperature sensor will be placed in the center between both herbs. The other temperature sensor will need to be submerged in water, for this reason the temperature sensor will need to be waterproof. The type of temperature probe has already been decided so now all that is left is finding the placement of the probe in the reservoir. The temperature probe should measure the water that will be circulating through the system that will lead to the herbs. For this reason, the probe should be placed submerged in the water close to the water pump. This is decided because the temperature should measure the water that will be flowing immediately to the herbs since there is an unlikely chance that the water will heat up and fluctuate to a higher or colder temperature than what is recorded by the water pump. The temperature sensor will need to be mounted down so that the sensor does not move around the reservoir because of the movement of the water pump.

Now that the placement of the temperature sensors has been decided, the next step is to test the sensors before mounting them on the enclosure permanently. The ambient temperature sensor will receive the same type of testing as the humidity sensor since they are the same sensor. From research, it seems that the sensor will output both data about the temperature and humidity of where it is. The user can use any kind of thermometer that they have laying around their house to measure the inside of the first room that they are testing. Once the user records a temperature with a thermometer, they can start measuring the temperature with the temperature sensor. Once the sensor is powered up, the sensor should be able to check the temperature of the room. The reading should match the thermometer. If it does, then you can continue with the next step of testing. The next thing to do is to measure an environment that has a different temperature value then the room that was measured. In this case, measuring the temperature outside will work. The thermometer should measure the temperature before turning on the temperature sensor. Once the thermometer has an accurate reading, the temperature sensor can be turned on and receive a temperature reading. If the temperature reading is the same as the thermometer than it is safe to assume that the temperature sensor is working correctly. Since the humidity and temperature sensor are the same, then the humidity level and the temperature can be tested at the same time since it is not complicated to measure both, and the sensor outputs the temperature and humidity level at the same time anyways.

Below is the flowchart for the ambient temperature sensor. This flowchart describes the logic design for the sensor. Every hour the sensor will measure the ambient temperature and alert the user if it is not in range. If the temperature is not in range, the user will receive an alert to fix the temperature. Since the system will be indoors, this will be done by a means of increasing or decreasing the temperature of the room that the system is in. The sensor will then measure the range again and will let the user know if the temperature is back in range or not.

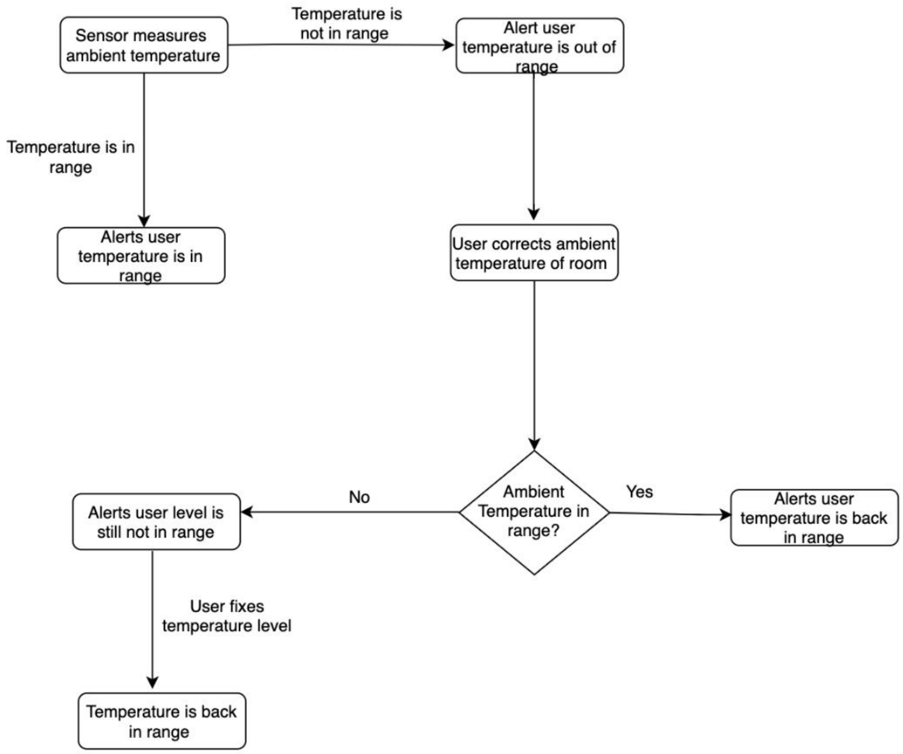

Figure 23: Ambient Temperature Sensor Flow Chart (by Chris Hernandez)

The next step would be to test the temperature sensor that will be submerged in the water. The best way to test the water to get an independent measurement that does not come from the temperature probe, it to use a thermometer. To test this, pour a cup of water and let the thermometer sit in the cup, once a certain amount of time has changed, the user can get an accurate measurement of the temperature. Now the temperature probe can be powered on and be tested. If the temperature probe displays the same measurement as the thermometer than the temperature probe is working. To further test the range of the temperature probe, measuring the two extremes of the range will be beneficial in guaranteeing that the temperature probe is working. Since the herbs will be receiving a water solution in a temperature range from 60 to 70 degrees Fahrenheit, then the user will not need an extreme range sensor. There is still the possibility that the temperature sensor will need to measure temperatures outside this desired range due to there being an abnormality that the user must fix to get the temperature back in range. To test that the temperature sensor should measure water that is colder and hotter than the ideal range for the herbs. By either heating or chilling water, the thermometer will measure both temperatures and it will be recorded. The temperature probe will now measure both in different increments so that the sensor won't be affected by a previous temperature reading. If the temperature probe has the same measurement of the thermometer than the waterproof temperature probe does work correctly. By testing both temperature sensors correctly, this will guarantee that they will provide accurate readings.

Below is the flowchart for the water temperature sensor. The logic design of the programming for the sensor is described. The sensor will measure the temperature of the water once every hour. From there the sensor will let the user know if the temperature is not in the optimum range. The user will then have to see if it is over or under the range. The simplest way to correct this error is to replace the water reservoir with new water in that is in room temperature. The sensor will measure the temperature again and will let the user know if it is in range and if it is, it will not alert the user of an out of range temperature.

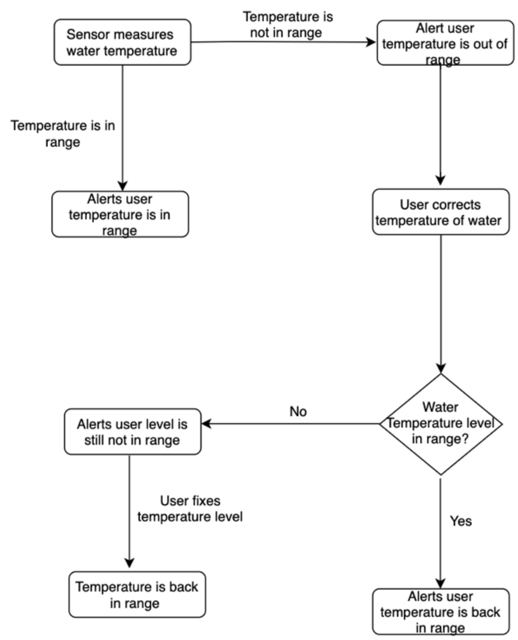

Figure 24: Water Temperature Sensor Flow Chart (by Chris Hernandez)

5.9 Water system Design

The water system design includes the components that help transport the water from the reservoir to the herbs. This includes the water pump, the tubing, the tees, cut off valves and the drip emitters. The various components work together to ensure that the water with the nutrient solution is brought to the herbs. The design of the system starts with the water pump submerged in the reservoir. From there the pump is on and will start taking the water inside the reservoir through the tubes that are initially connected to the pump. The tubes go straight through all the way to the end of the second herb. In between the first end of the tube and the last end, the tubes will separate into secondary pipes. Once the pipe reaches the first herb, there will be a split into the delivery lines. From the mainline, there will be a barbed tee that will be connected to the secondary pipe. From the secondary pipe, the cut off valve will be connected. This is to ensure that the user will have the ability to turn off and on the access to each individual plant if there is a need to. After the valve, there will be more tubing connected and at the end will the emitter where the water will drip onto the herb. The secondary tubes will be connected into the original tube through these three components and help to split off the provided water solution to the herbs. In our design, there will be two drip emitters per herb. Therefore, there should be two secondary delivery lines per herb and each delivery tube will be connected to a drip emitter. Each will be equal distance from each other to ensure that each herb will have the equal amount of water. In order to test this design, the system will need to be completely built. If the reservoir isn't available yet, a bucket of water is fine as long as it contains the same amount of water that the pump will be submerged in in the actual prototype. Once the design is built, the water pump should be turned on. This will cause the pump to start working and you should see movement in the water to indicate that it is working. Next, the user should see that the water is traveling through the pipes. Black tubing will be chosen for this prototype since the color black will help prevent a buildup of algae. The user will should be able to see drops of water falling from the emitter. If the user does not work, then a closer look into dissecting different parts will find a solution. If the emitter is removed, then the delivery line should have a constant flow of water. If it does not, then there is something wrong with the pump in the fact that it cannot deliver the water with a constant flow rate. If there is water flowing through the delivery lines, then the problem would arise with the emitter. If the water system is working correctly, then the testing of the system is finished.

The flowchart below will show the logic design between the soil moisture sensor and the water pump. The soil moisture sensor will measure the soil every hour and will alert the user of any changes. If the soil moisture is too high, then the sensor will recommend to replacing the soil with new one before it affects the herbs. If the soil moisture is in range, then the water pump will not turn on. If the soil moisture sensor reads that the soil moisture level is below the optimal range, then this will alert the water pump to turn on. From there the pump will circulate the water to the herbs that need more water. The sensor will then measure the moisture level again and if it's in the optimal range then the sensor will send a signal to turn off the water pump.

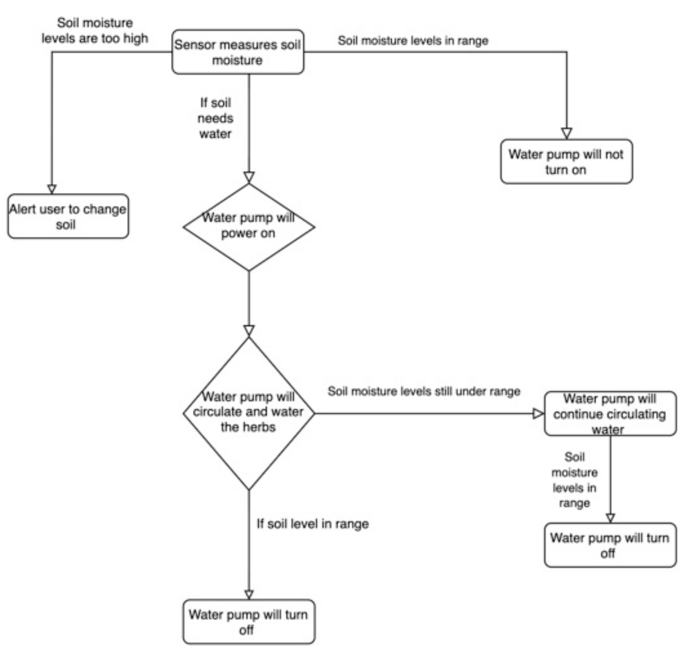

Figure 25: Water Pump Flow Chart (by Chris Hernandez)

5.10 Speaker Design

Speakers will be added to the design of the hydroponics system. It will provide both a functional use for the system as well as entertainment. The functional use comes from the fact that the user will have an alarm system to use when there is an animal trying to bother the hydroponics system. The entertainment use will come from the idea that the speakers will be able to play music from the user's phone as they are connected through Bluetooth. In order to make sure that the speakers will work, the user will need to find the location where the speakers will be placed. It has been agreed that there will be two speakers that will be put in on opposite side of the enclosure. This will maximize the surround sound that the user will hear. The speakers will be placed with the speakers facing outside of the enclosure. There is no need for the speakers to protrude inside towards the herbs. Therefore, there will most likely be a compartment created to put the speakers on or drill a hole with the equal measurement of the diameter of the speaker that will mount it onto the enclosure walls. Now that the decision on where the speakers will be placed, the next thing to decide is figuring out how to test the speakers.

Since the speakers are part of the stretch goals, this aspect of the project has two sections in order to reach that goal. The first part is using a piezo speaker to just implement the alarm sound. In order to test the speaker, it will need to be connected to the microcontroller. Once the microcontroller is connected to the speaker, it must be programmed to work with the speaker and implement an alarm sound to it. Once the programming is done for this, the user should be able to play an alarm sound through the speaker. The use of this alarm is to prevent a pet touching or messing with the system. If there is enough time, then the next upgrade for this system is to implement stronger speakers in order to play music. The testing of this will be more complicated since it will require more components than the piezo speaker. It will also need a longer programming code. Once the initial set up is done, the next part is the actual testing of the speakers. The phone should connect to the blue tooth module and from there the user will be able to pick a song to play on the speakers. The testing will be done before implementing the speakers onto the enclosure since it will be more difficult to constantly removing them when testing them is not finished.

5.11 System Power Design

A power supply circuit has been designed for the entire hydroponic system and will be implemented on the PCB. The way this system will be powered is by first using the voltage supplied by the AC adapter which will connected via a female barrel connector attached to the PCB. The DC 12V delivered to the board will power the water and nutrient pumps along will supply this voltage to the two linear voltage regulators. The 5V regulator will be responsible for a portion of the system and the 3.3V regulator will be responsible for the rest of the electronic components. Below is a schematic showing the power supplying circuits. The circuit in the upper left of the figure shows the DC barrel connector where the 12V will be input into the PCB. From this the 12V branches to the two regulators. Each regulator is equipped with a protection circuit, using a 1N4001 Diode. This diode is in reverse biased as Vin is greater than Vout, in the event that the output voltage becomes higher than the input the diode will forward bias. This protects the regulator by preventing the current flowing into the regulator from its output. The regulator and additionally connected circuitry are protected. The capacitors placed in the circuit function as bypass capacitors which help eliminate AC signals from being introduced to the DC value.

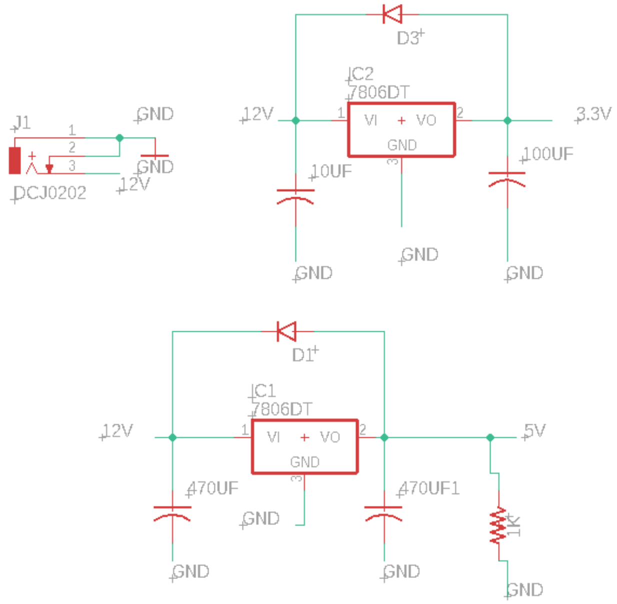

Figure 26: Overall System Power Circuits Designed using EAGLE

5.11.1 Relay Design

Along with the initial power being supplied to the entire system, a way to turn on and off the individual pumps and lights needed to be devised. The first thing to note is the normally closed, common and normally open pins. A connection between the common and one of the other two mentioned will be made depending on the desired mode to use the relay in. The next pins of the relay are the two for the coil which need a voltage to power on the coil which will in turn switch the position of the relays. Across this coil a protection diode is added in parallel. The purpose of this diode is to protect the other components nearby that may be sensitive to the voltage generated in the coil when current flow is interrupted and allows continuous current flow to circulate when the coil is deactivated. When the coil is on no current will pass through this diode. Additionally, a diode may be added to notify when the contacts open and close. This will be useful when testing the induvial relays to show which relay has turn on. An NPN transistor may also be added to the circuit to act as a switch that turns on and off the coil, where the input signal is on the base. The following Figure shows how the relay circuit would look based on the previously described design. This design will be iterated a total of three different times each time for the desired control connection, meaning the nutrient pump, water pump and grow lights.

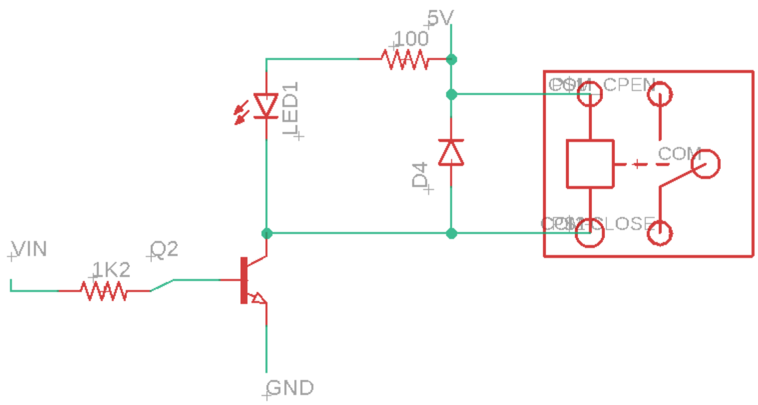

Figure 27: Relay Design for Switching Pumps and Lights on

5.11.2 System Power Final Design

For the final design of the power supplied to the entire hydroponic system, there were a few changes that were made upon implantation of the system to ensure that it worked properly. The first thing is that during our research, there was consideration of if a battery would be used to supply power to certain parts of the system such as the speakers. The use of a rechargeable battery was not implemented in the end. Instead, the original design of supplying the system with an AC to DC wall adapter was used. Additionally, there was consideration to put the relays on the PCB, but instead relay modules were used instead of creating an on-board module. This simplified the design and ensured that the system would function properly as the modules already function as they should and there is no chance that the manufactured module would have a mistake in wiring. In the final design, the power consumption of the system was recalculated. When recalculating the power it was obvious that the originally chosen AC to DC adapter could no longer be used. Instead, the Belker 36 W 12 V AC DC adapter was used instead. This adapter had adjustable voltage which was also useful when testing the various components in the system before the PCB was complete as there was different voltage lines present in our project.

5.12 Supporting Structure Design

All the subsystems will be pieced together to create the overall structure that will house the hydroponic system. In order to describe the way this system will be implemented in a way that is easier to understand, the supporting structure will be described as three different layers. The top layer, middle and bottom. By separating this design into layers, it allows for a closer look to be taken at the way it is constructed to form the final system. The first layer of the system, the upper layer, will house most of the electronics that will be used to control the system. This portion of the system will be made from a lightweight wood. This material needs to be sturdy enough to hold all the electronics that will be inside of its enclosure, although the electronics in the system won't be that heavy. The enclosure should be able to withstand the weight of the PCB board with the microcontroller with all surrounding peripheral circuits, the LCD and speakers are mounted on the outside of it and the grow lights are mounted to the bottom of it so they may hang above the plants. The top portion of the enclosure can be lifted up to show all the components housed inside and will be removable for ease of maintenance if a problem were to occur with any of the electronics. While the remaining sides of the top portion will be solid.

The top layer is supported by PVC pipe in the middle layer. The PVC pipe supports each of the four corners of the top layer. Since PVC pipe is hollow, any wiring that needs to be ran between the each of the three layers will run through the pipes to try to keep all of the wire paths neat and also ease their impact on the overall visual appearance of the system. This means that an open area is created in the four corners of the top layer and bottom layer to allow for these paths to be available. The camera module is mounted in this layer. The intended design for the camera mount is either from the bottom of the top layer looking down onto the plants or mounted to the side of one of the PVC pipes pointed at the system. This placement will depend on the mount created for the camera module and the field of visibility that will be best suited for the camera, which will be determined during testing. The next item that is included in this layer the light sensors that will be placed according to the locations that are determined by testing. The individual plants will be in this layer inside their medium holders, which extend into the bottom layer through holes that snuggly hold the plants in place. Inside the planters for the individual planters will be the moisture sensors. The ambient temperature and humidity sensors will also be located in this layer. All the hosing, including the drippers, that allows for the water nutrient solution to reach the plants will be in this layer. This layer is open on all of the surrounding sides to the external environment around it. The power cord runs from the power circuitry in the top portion of the system through one of the PVC pipes and come out through the bottom just above the final layer to allow for the system to be supplied with power.

The final layer, the bottom layer, houses the majority of the watering system. This section will be essentially split. The upper layer houses the portion of the plant holder that is submerged in the excess run off water. This water will be in the first layer of the water reservoir. The water in this layer will slowly circulate back into the main reservoir which will house the rest of the watering system. This includes the water pump and the nutrient solution subsystem. The nutrient solution subsystem will include the nutrient compartment and nutrient pump. The water level and pH sensor will also be housed in this layer. The water level sensor is mounted directly above the water in the revoir, so there needs to be enough room that when the water is at max capacity it will not flood this sensor. This layer will need to have a way of accessing the water pump for maintenance and also the nutrients, so they may be refilled. Extra care needs to be taken when designing this layer, as the water can be hazardous if it interferes with the power of any of the electronics and the system should not leak. The way this layer is to be designed is double insulated, meaning the external four walls will have a small gap between them and the reservoir that will contain the water. This gapping allows for any external wires to be able to be placed so they are not near the water. Extra care will need to be taken with any wire running though this section and will need to be waterproofed for safety. Having the water reservoir separate will also allow for ease of maintenance. The wood material for this section will need to be durable enough to hold the weight of the entire system built in the layers above as well as the additional weight from the water. This is all shown in **Figure 28**.

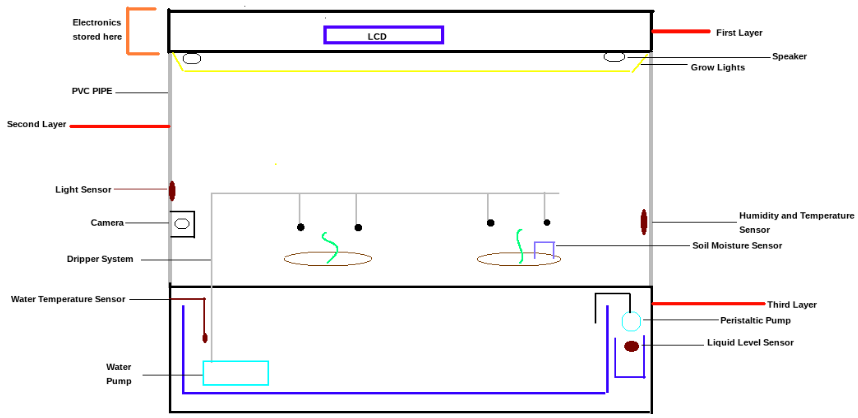

Figure 28: Supporting Structure Design

6.0 Prototyping

The following section discusses how the testing procedure and prototyping that was done for each of the subsystems of the overall hydroponic planter. Along with the methods taken to test each subsystem before placing them all together to create the final product are the results for each of the systems. The section will also discuss when there occurred problems during the testing period and how solutions were found in order to fix the solution. Once all the testing was complete on all the subsystems, the prototype was able to be built.

6.1 Moisture Senor Prototyping

The next item that needs to be tested is the moisture sensing module that will be used to ensure that the drippers in the hydroponic system are functioning properly. Before integrating the moisture sensor into the rest of the hydroponic system, it should be tested to ensure that it is working properly. To understand the results received during the testing of the moisture module, an understanding of how the module works must be gained. The way that the soil moisture sensor works is through the use of the two probes that measure the volumetric content of the soil. When taking a measurement, the two probes deliver a current that is passed through the soil. Once through the soil a resistance value is given to determine the moisture within the soil. This gives the volumetric water content based on the dielectric constant of the soil, which is essentially the ability of the soil to transmit electricity. The resistance value is lower when there is more water in the soil as the soil can conduct the more electricity. Which in turn leads to a higher soil moisture level. On the other side of things, when the soil is drier there will be more resistance. This in turn leads to a lower moisture level. This process is comparable to how a variable resistor would function. On the separate module that connects the sensing probe to the microcontroller there is a potentiometer which allows for the adjustment of the sensitivity and an LM393 high precision comparator to allow for digital outputs. Now that an understanding of the soil moisture is gained, the testing procedure will follow.

The soil moisture sensor has two modes for reading data, it can be done using analog values or digital values. When using the analog mode, the soil moisture sensor will offer a numerical value that gives a more accurate reading of the volumetric content of the medium. When using these values, a range must be determined for the various potential events. For the digital mode the potentiometer on the module will be used to calibrate the digital output. This allows for the threshold to be set and when the threshold value is exceeded the status LED on the module will light up to indicate that the soil is wet. When the soil wet the digital output is set to low. When soil is dry the output is high, indicating that the water pump should turn on. For the application of the hydroponic system, the analog mode is used. This method is chosen because it will allow for a greater control in the soil moisture to determine when the plants should be watered. The digital mode does not provide the exact value which does not provide enough regulation for the system.

The following materials will be used to test the moisture sensor to ensure that is functioning as expected: Arduino Mega2560 development board, parallax soil moisture sensor, connecting jumpers between the sensor and dev board, soil and water. The moisture sensor will be tested using analog outputs. The first thing that should be tested when the code is written is the upper and lower thresholds of the sensor. This allows for the sensor to be properly calibrated to the medium that will be used in the system, to ensure that readings are accurate. The conditions to test this are getting the sensors reading when the sensor is dry for the upper threshold. To get the upper limit the value read by the sensor, it can be placed in water and this value can be used for when the soil has the highest volumetric value.

Upon testing, it is seen that value read by the moisture when it is completely dry and not in soil is zero. When the moisture sensor is inserted into a cup of water a reading around 3900 is found and varies slightly. This is the upper threshold of completely wet without soil. These values will be adjusted when inserted into dry soil and soil that has just been watered. When the water has settled, and the moisture value is found it is about 3600. It should be noted that this sensor takes time to reach a constant value. This is important when calibrating the sensor, but once implemented in the system it shouldn’t change too much. Once implemented the threshold values can be adjusted based on the response to the watering times and the medium used. **Table 27** contains the threshold values below that will be used to determine when to turn on and off the watering pump.

Threshold Value	Meaning	Action
0	Completely dry	Turn on watering pump
3900	Completely wet	Turn off watering pump

Table 27: Threshold Values for Soil Moisture Sensor

Now, that these values have been found they may be used as thresholds to trigger an event. A main event that the moisture sensor will trigger is turning on the watering pump to deliver the water nutrient solution to the plants.

Following the calibration phase will be determining the various ranges that will in turn trigger certain events. The following ranges need to be determined: too wet, target range, and too dry. Once these are determined the proper flags may be added to the code, so that when the measurement is polled it will cause the proper reaction. The pump can be triggered to turn on or off and even remain off when the system is in the target range to prevent over watering the system.

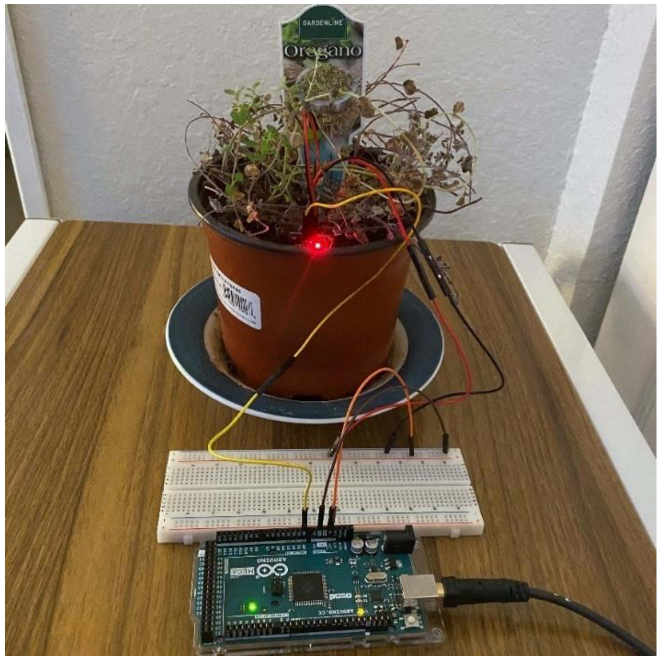

Figure 29: Moisture Sensor Test Setup

Now, that these values have been found they may be used as thresholds to trigger an event. A main event that the moisture sensor will trigger is turning on the watering pump to deliver the water nutrient solution to the plants.

Following the calibration phase will be determining the various ranges that will in turn trigger certain events. The following ranges need to be determined: too wet, target range, and too dry. Once these are determined the proper flags may be added to the code, so that when the measurement is polled it will cause the proper reaction. The pump can be triggered to turn on or off and even remain off when the system is in the target range to prevent over watering the system.

6.2 Light Sensor Prototyping

In order to determine how the light sensor should be implemented into the overall system and how to properly design the structure for the photoelectric sensor, it must first be tested. The resistor will be used to determine the ambient brightness and light intensity of the environment that is surrounding the plants. This sensor will be used to determine if the plants are receiving enough light, if not the sensor should trigger the grow lights to come on. The sensor can also be used as an additional security feature to ensure that the lights are functioning properly.

The light sensing module chosen to be used in the hydroponic system is able to output data to be interpreted by the microcontroller in either digital or analog. When using the digital outputs to read data the potentiometer on the module can be used to adjust the sensitivity which allows there to be a set the brightness threshold value to determined when the module should output a 1 or a 0. When using the digital output, the module also had an LED light that turns on to indicate the ambient light exceeding the threshold value, set by the potentiometer. Using the analog outputs will give values of the light intensity to allow for a more exact measurement of how much light the sensor is receiving. For now, the first thing done to make sure the sensor is working properly for the function intended the following test will be done.

The light sensor will first be used in digital output mode with a simple set up to ensure it is working properly. The light sensor will be connected to the development board along with an LED. The LED should turn on when the light sensor is no longer receiving light and turn off once the light sensor is receiving light once again. Once this is functioning properly, the next thing that must be tested is using this sensor to turn on the grow lights of the hydroponic system. When the grow lights are able to turn on and off at the proper times the system will be modified in an attempt to use multiple light sensors to get an idea of how much lighting the plants are receiving. If they are receiving enough from sunlight or ambient lighting, then the grow lights will remain off. In the event that they are not receiving enough light then the lights should turn on. The amount of sunlight per day that the plants should receive will determine how often the sensor will collect data from the environment. The system will need to have timers to let the sensor know it is nighttime and there for the grow lights should not be on. These can be based off of the real time clock as the microcontroller will be connected to a Wi-Fi module. The programing of timing of turning on the grow lights will require trial and error as the frequency the system is polled will also lead to how this entire subsystem works.

6.3 Camera Prototyping

In order to test that the camera is properly programmed to perform the desired actions. The camera will be meet the following image requirements: color image, daily image save and continuous live feed that can be accessed by the user. The camera will save these picture files in a location that the user may access them to view. The location that has been determined to be is a microSD card that will be connected to the camera. There are a few things that need to be considered when accessing the data from the camera. Since the camera will need to be able to send the saved images and display the live feed, the database will need access to the photos to allow the user to view these at any time. Initial testing for the camera will confirm that a picture can be saved to the microSD and also be accessed.

The camera will need to take a picture and send it the data a location to store all the photos for later. These photos should be opened and looked at to make sure that the quality is adequate. If the resolution is not as desired it may be adjusted. The camera will be adjusted until the camera functions as it should. The location that the pictures are saved should be able to be accessed by the user to allow them to view the time lapse of the plant’s growth progress. Another path should be available that will allow the user to view the live stream plant monitoring.

The camera and SD card reader are connected to the breadboard along with the moisture sensor. When the enclosure for the system is built a proper camera mount will be included to ensure the camera is able to see the plants and allow for stability when taking photos. The setup used for testing can be seen in **Figure 30** and beside it is the images taken by the OV2640 camera module during testing. The images show the camera in different positions and lighting.

Figure 30: Test Setup for OV2640 Camera Module and Pictures in Different Lighting and Position

When implementing the design for the camera, changes to the original design needed to be made. The original plan was to capture an image with the camera and then save this image to an SD card module. Unfortunately, this was not possible due to the cameras use of SPI and I2C communication. This led to the camera having difficulties using SPI bus sharing. The camera and the SD card were both tested in initial testing and both functioned properly on their own. When trying to combine the two is when it was discovered that the camera had difficulties with SPI bus sharing. Using the Digilent Analog Discovery 2, to look at all of the signals that the camera and the SD module had showed that there were difficulties with the SPI bus sharing. After, making this discovery a module was ordered to connect to the camera and allow it to send an image captured over Wi-Fi. This was able to work as expected and gave us the idea to send the image over Wi-Fi to the the database. Unfortunately, this could not be done because the module used was similar to a development board which is not to be used. To ensure that the project met the criteria we attempted to implement this using the components that would be used in the final PCB design. When doing so, the camera was able to capture the image and send the data over wifi. The final issue was that once the data was received it was unable to be decoded to reconstruct the cameras image. By the end we were able to get the camera to function as we intended and showed these results.

6.4 Software Prototyping

Software prototyping follows a different path than typical hardware prototyping. In software, it is very important to prototype sections of code to ensure that testing said section is useful and relevant. Standard Alpha testing uses a prototype of the software to test an algorithm or data modification for intended outcomes (more about software testing in section 8.1). To prototype certain sections of the software, the undeveloped sections will be simulated (e.g. certain parameters or check conditions will be hard coded as inputs) so that the system will operate under expected conditions. This is by no means a finished program. We can hard code inputs and parameters in the prototyping and testing stages of software development, however there are many more factors to consider until testing and prototyping are considered finished. Once the entire program is developed, it is more difficult to recreate specific events. Since all the variables, functions and algorithms are put in place, isolated events are harder to manage. Prototyping allows these events to be simulated in a controlled environment.

The differences between prototyping and testing, in software, are often overlooked which can to some confusion. In our design, software testing is done to ensure correct inputs and outputs are achieved. Software prototyping is done when a significant amount of development has been achieved to create a semi-working device. Every software prototype will be tested but not every test will result in its own prototype. Our team defines a software prototype by the number of tests it has undergone. As we implement more modules and connect different features together, prototypes will need to be made so that testing does not interfere with the progress made. Any stable prototype deemed a success will be built on and referred to in the case of a future implementation failing to go as intended.

6.5 Ambient Temperature and Humidity Prototyping

As part of the sensor system, this sensor must be able to accurately measure the temperature of the enclosure and the environment it is in and the humidity levels. Constant measurement of the ambient temperature and humidity level is critical so that the herbs will not be growing in an environment that is stunting their growth. The user might be able to use a digital thermometer that measures temperature and humidity but by having a sensor that does this, this will allow the user to not have to constantly check on the readings since the sensor will indicate when there are changes that the user has to pay attention to. The sensor will work with the microcontroller and the interface to ensure that the user is receiving alerts to indicate that there have been changes to the environment that the system is in. The testing for the ambient temperature and the humidity level were done together as there is one sensor that measures both readings at the same time.

For the sole purpose of making sure that the sensor works, an Arduino board is used while connected to a laptop. The sensor has 4 pins where the first pin is a VCC pin and is connected to the 5V output pin on the Arduino. The second pin is the data pin, and this is connected to Digital Pin 7 on the Arduino. The third pin is the NC pin, so it does not connect to anything on the pin. The fourth pin is the ground pin and is connected to the ground output pin on the Arduino board. The code for the sensor to connect to the board is then inputted into the Arduino program on the laptop. The code will then be uploaded into the board and will run. The sensor is then functioning and is measuring the temperature and humidity level of the room. The measurements are then shown on the laptop with a new reading being measured every 2 seconds. By testing the sensor in different parts such as outside versus inside it shows that the sensor is working correctly.

The test setup of the temperature and humidity sensor with the Arduino can be seen in the Appendix as **Figure 1A.D**. The set up will be different once the enclosure is built.

6.6 Water Temperature Sensor Prototyping

Another part of the sensor portion of the system is the water temperature sensor. This sensor will constantly measure the temperature of the water. This is one of the most important sensors since this will let the user know of any changes to the temperature of the water reservoir. If the water temperature is not in the optimum range for the herbs, then this will cause stunts in their growth. Therefore, this sensor must work correctly so that the measurements received are right. The decision to choose a sensor over a normal thermometer is so that the user doesn't have to constantly monitor the temperature while making the system as autonomous as possible. The only time the user will have to interact with the sensor is when the user gets an alert that the temperature of the water is out of optimal range of the temperature.

The items to test the sensor include the DS18B20 sensor, wires, 4.7k ohm resistor, Arduino board and a breadboard. The water temperature sensor has three wires. The red one is connected to the 5V pin on the Arduino board with the resistor in between them. The black wire is connected to the ground pin on the Arduino board. The yellow wire is connected to the data pin 2. The resistor is also connected to the data pin as well. Once the connections are all made, the Arduino is set up to the Arduino program on a computer. From there the code to test the functionality of the sensor is uploaded. Once the program runs and is executed, the sensor gave out readings of the temperature of the water in the glass of water. As shown below in **Figure 31** this has the set up of the sensor with the connections.

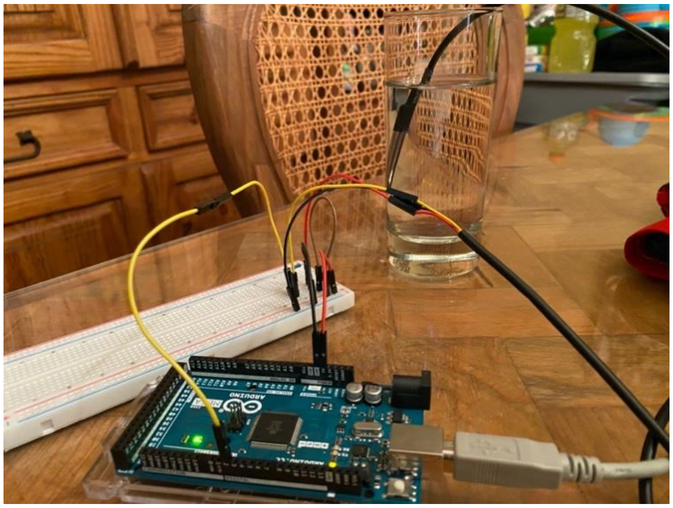

Figure 31: Water Temperature Sensor Prototyping

6.7 Distance Sensor Prototyping

As previously discussed, research was conducted in order to determine how the level of water in the reservoir would be measured, develop a design for this system, and determine what components would be necessary to implement this feature. It is essential that the level of water within the reservoir be measured continuously in order to have an accurate and updated measurement of the amount of water in the reservoir for use in determining how much nutrient solution is needed when the reservoir is refilled and for providing information about the amount of water in the reservoir to the user. Without this measurement, the system would not be able to function properly as intended. While resistive and capacitive sensors were initially considered, it was ultimately decided to use an ultrasonic distance sensor to measure the level of water in the reservoir. This sensor is placed above the surface of the water in the reservoir and continuously measures the distance between the sensor itself and the surface of the water. From this measurement and knowledge of the dimensions of the water reservoir and placement of the sensor, it is possible to determine the volume of water in the reservoir at any time and to easily detect any change in this amount. The possibility that the sensor would be unable to accurately detect the surface of the water was considered when designing this system, in which case an alternate design would be implemented. This alternate design involved including a flat object that would float at the surface of the water and raise and lower along with the water level, acting as a kind of bobber to give a solid object that the sensor would be able to more easily and accurately detect.

After considering a variety of comparable parts for use in this project, the part that was ultimately chosen to be used for sensing the water level in the reservoir is the HC-SR04 Ultrasonic Distance Sensor. This sensor is very affordable and available from many different manufacturers. Specifically, for this project, the HC-SR04 sensor produced by Adafruit was chosen. This part was purchased from the electronics component distributer Mouser Electronics from their website for $3.95. Included with this part were two 10 kohm resistors.

Once this part was received, it was tested to verify functionality and accuracy. It must first be verified that the component functions as it is supposed to. To do this a test program written in Arduino will be executed utilizing the component. For this testing, an Arduino Leonardo development board will be used due to availability. This board includes an ATmega32u4 microcontroller with 20 digital I/O pins and 12 analog input channels. This board can also be connected to a computer via a micro-USB, allowing for easy programming while testing each part separately. The HC-SR04 ultrasonic distance sensor was connected to the Arduino Leonardo through a breadboard. The sensor has four pins, one for Vcc, one for ground, one for the trigger output and one for the echo input. The Vcc pin was connected to the 5V output of the Arduino Leonardo and the ground pin was likewise connected to the ground of the development board. The trig output and echo input pins are both digital and must be connected to digital I/O pins on the development board. For this test, the trig output pin was connected to digital pin 2 on the Leonardo and the echo input pin was connected to digital pin 3. **Figure 32** shows the sensor connected to the development board through the breadboard. A source code for a program to test the functionality of the sensor was obtained from the article “Ultrasonic Sensor HC-SR04 and Arduino Tutorial” written by Dejan Nedelkovski from the How To Mechatronics website. This program sets up the sensor, then reads the duration of time it takes the ultrasonic waves to travel to an object and back. This duration is used to calculate the distance in centimeters, then this distance is printed to the serial monitor. The test code was uploaded to the Arduino Leonardo with the HC-SR04 sensor connected and the program was executed. The distance as measured from the ultrasonic sensor was printed to the serial monitor in centimeters, indicating that the component functions properly. A piece of paper was placed over the sensor and moved up and down above it in order to observe the change in the measurement of the distance between the paper and the sensor. The measurements were inaccurate when the paper was very close to the sensor, with random or extremely high values being printed to the serial monitor. The sensor began to accurately measure the distance once the paper was raised to at least 5 centimeters above the sensor and continued to be accurate as the paper was moved away. After confirming that the sensor functions as intended and provides reliable and accurate measurements of the distance between the sensor and a surface, the sensor must be tested for use with the surface of water. Since this distance sensor will be used to measure the water level in the reservoir, it is essential to know if the sensor is able to reliably detect the surface of water when measuring distance. To test this, the sensor was held above a cup of water and was raised and lowered. The distance displayed on the serial monitor did not reliably change as the distance between the sensor and the surface of the water was changed. As such, the sensor cannot be implemented as intended in the original design, and the alternative 'bobber' design must be used. If a flat object is included on the surface of the water and allowed to raise and lower with the water level, the HC-SR04 will be able to fulfill the necessary requirements for implementing the water level sensor in the reservoir.

Another test was done to determine if the sensor was able to accurately detect the surface of water. This time, the sensor was suspended and kept still over a large tub of water, and the level of water in the tub was changed. This time, the readings from the sensor accurately showed a change in the distance between the sensor and the water's surface as the water level was changed. It was determined that the issues encountered during the previous test were due to the sensor not being held still and the cup of water being too small. In the actual system, the sensor is mounted over a larger reservoir of water, so the second test more accurately represented this. As such, the decision was made to not implement the bobber design, and instead have to ultrasonic sensor detect the water level directly.

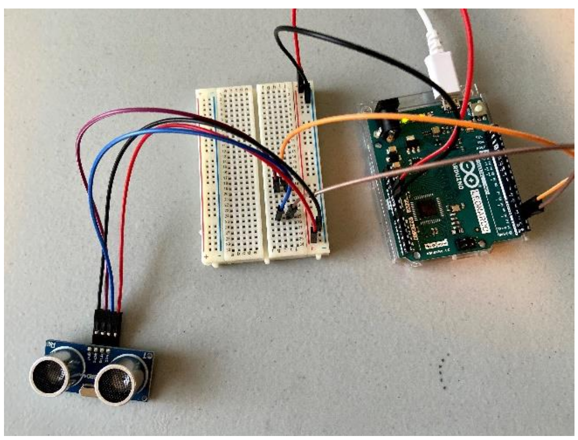

Figure 32: Ultrasonic Distance Sensor Setup and Prototyping

6.8 Liquid Level Sensor Prototyping

As part of the nutrient dispensing system, it is necessary to be able to accurately measure the amount of nutrient solution in the nutrient container at any given time. This number is used to keep track of how full the nutrient compartment is in order to be able to have this information available to the user whenever desired and to be able to notify the user when the amount of nutrient solution drops below a certain level so that the user can refill the compartment with solution. This measurement is also useful for keeping track of how much solution leaves the compartment whenever it is dispensed into the water reservoir. Monitoring how the level of nutrient solution changes when the solution should be dispensed provides a way to check that the correct amount of liquid nutrient solution was dispensed into the water reservoir. This way it is easier to detect if there is an error with the pump dispensing the solution before the system continues for an extended period of time without dispensing the correct amount of solution for the volume of water in the reservoir at the time. Keeping track of the amount of liquid nutrient solution in the compartment is essential to the normal operation of the system.

One of the main design goals of this project is for the completed system to be fairly small, and able to fit on a countertop or in a window. To accomplish this the base of the system, which houses the water reservoir, watering system, and nutrient dispensing system, must be very compact. The compartment that holds the nutrient solution must be small enough to fit either within the reservoir itself or directly next to it. Since the ratio of teaspoons of nutrient solution to gallons of water is also very small it is not necessary to hold a large amount of nutrient solution in the compartment at any given time, so having a smaller compartment is also ideal. Because this compartment is rather small, the sensor within it used to measure the level of liquid nutrient solution within the compartment must also be fairly small.

As discussed earlier in this paper, research was conducted to determine what part would best fulfill these requirements for a sensor used to measure the level of liquid nutrient solution within the nutrient compartment. Due to the small space in which the sensor must be able to operate, as well as the level of accuracy needed, it was determined that it would not be possible to use an ultrasonic distance sensor similar to the one being used to measure the level of water in the water reservoir. Instead, a resistive liquid level sensor is used to measure the level of liquid nutrient solution within the compartment. This type of sensor measures a resistivity value that corresponds to the point at which the surface of the liquid reaches on the device. This information is used alongside knowledge of the dimensions of the nutrient compartment in order to determine the volume of liquid nutrient solution within the compartment at any time. The part that was chosen to be used to fulfill the needs for this sensor is the Water Level Sensor manufactured by SUKRAGRAHA. This component was purchased for Amazon for $5.99.

Once this part was received, it was tested to verify functionality and accuracy. To test that the received component functions as is intended, a test code written in Arduino will be executed utilizing the sensor. Again, an Arduino Leonardo development board was used to test this sensor due to availability. This board includes an ATmega32u4 microcontroller with 20 digital I/O pins and 12 analog input channels. For testing the resistive liquid level sensor, the sensor was connected to the Arduino Leonardo through a breadboard. The sensor has three pins, one for 5 V power, one for ground, and one signal pin for the analog input. The positive power pin was connected to the 5 V output pin from the Arduino board, the ground pin was connected to the ground pin of the board, and the signal pin was connected to the A5 analog input pin on the Leonardo. An Arduino water level sensing code was obtained from the article "Arduino Water Level Sensor Tutorial" by Mike Murray on the website TheGeekPub.com. This code was written for use with a similar but different liquid level sensor manufactured by a different company, so slight modifications had to be made to the code in order to use it for testing the sensor that will be used in this project. When uploaded to the Arduino Leonardo development board with the sensor attached, this program will read the resistivity value measured by the sensor and print this value on the serial monitor. The program was uploaded to the development board and executed. While the program was running, the liquid level sensor was inserted into a cup of tap water. This is shown in **Figure 33.** The sensor was raised and lowered within the water in order to change the point on the sensor where the surface of the water reaches and the measured resistivity value was observed. When the sensor was not in contact with the water at all, a value of 0 was measured. When the sensor was inserted into the water this value grew larger as the sensor was submerged further. With the sensor submerged just barely into the water a value of around 480 was observed. When the sensor was submerged about a quarter of the way into the water a value of around 680 was observed, when it was submerged halfway a value of around, 715 was observed, and when it was submerged about three quarters of the way a value of about 730 was observed. The maximum resistivity value of around 750 was observed when the exposed elements of the sensor used for measuring the resistivity were completely submerged. These measurements are summarized below in **Table 28.** The resistivity value appears to grow exponentially at lower liquid levels but seems to grow more steadily at higher levels. This testing not only confirms that the liquid level sensor functions as intended, but also has collected data necessary for establishing the base values measured by the sensor. The resistivity values measured by the sensor can easily be translated into a percentage of the sensor that is submerged, which can then be used to determine the level of liquid nutrient solution in the compartment as well as the volume of this solution. Since the resistivity value does not grow linearly with the percentage of the sensor that is submerged, it may be more effective to measure the level of liquid nutrient solution in the compartment by comparing the measured resistivity value to certain points at which the percentage of the sensor submerged is known.

Percentage of the Sensor Submerged in Tap Water	**Resistivity Value Measured**
100%	750
75%	730
50%	715
25%	680
10%	480
0%	0

Table 28: Percentage of the liquid level sensor submerged in the water vs the value measured.

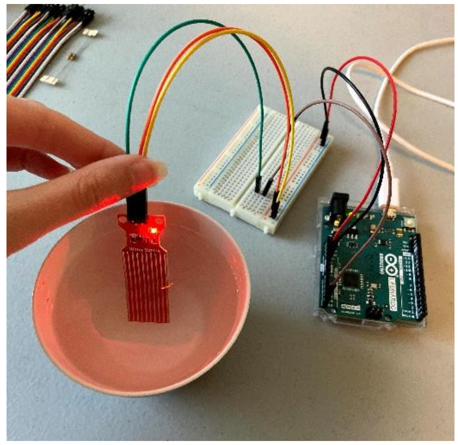

Figure 33: Liquid Level Sensor Setup and Prototyping

6.9 Grow Lights Prototyping

For the system to be able to function properly regardless of where it is located it is necessary to have some kind of grow lights. These lights are able to provide the light needed by the plants even when there is not enough natural sunlight. These lights function along with a light sensor to determine when they need to be turned on. The user can also opt for the lights to be on for the entire duration of time during which the plants need sunlight, and the user is able to turn the lights on and off as desired. Through research discussed earlier in this paper it was determined that, for the specific herbs that this system is being designed to care for, it is ideal to use white lighting. It was also decided that LED lights would be ideal for use in this project. LEDs have a longer lifespan than other types of lighting that were considered for this project. They are also more energy efficient, produce less heat, and use less electricity. It was decided to use WS2812b type LEDs because they are individually addressable and have full color spectrum. This way, the lights can be programmed to emit white light by default, but it is also possible to customize the system to work for other types of plants as well. For instance, a feature could be added to allow the user to choose a different color setting, such as an alternating blue and red pattern that produces more of a purple light. These LEDs are also very easy to control with the microcontroller, which simplifies the operation and design of the system. It is also ideal for the LED strip that is used in this project to be waterproofed. Although the LEDs should not be in direct contact with the water, having the strip be waterproofed prevents the LEDs from getting wet in the event that the system is knocked over or any other sort of accident or error occurs. The part that was chosen to fulfill the needs for the grow lights in this system is the WS2812b LED strip with 30 LEDs/pixels per meter and waterproofing of IP65, manufactured by BTF-LIGHTING. This part was purchased from Amazon for $22.88.

Once this part was received, it was tested to verify functionality. Since this component is not a sensor, it is not necessary to test if it takes accurate measurements. Instead, we are only concerned with verifying if the part functions as intended and will be appropriate for implementation in the project. To test this component a test code written in Arduino was used. This testing was done using an Arduino Leonardo development board due to availability. The Arduino Leonardo development board includes an ATmega32u4 microcontroller with 20 digital I/O pins and 12 analog input channels. The WS2812b LED strip has three pins, one for 5 V DC power, one for ground, and one digital input for control of the LEDs. The LED strip comes on a roll and consists of a series of LEDs connected in parallel. Although they are connected, each LED has its own set of three input pins and three output pins. This design allows the strip to be cut at any of the connections between LEDs and each section is able to operate on its own. This way the entire length of the strip does not have to be used in one application and the LEDs can be split and reconnected depending on the application they are being used for. For this project specifically, the LEDs will be attached to the bottom of the overhead structure of the system and arranged in a series of rows in order to create an array of LEDs and provide light from multiple angles. To do this, the LED strip will need to be cut into smaller strips and each smaller strip will be connected using wire. Since all of the LEDs will still be connected in parallel, they will still only require one set of input pins to provide power and digital control. During testing, the LED strip was connected to the Arduino Leonardo through a breadboard. The 5 V input pin of the LED strip was connected to the 5 V output in of the development board, the ground pins were connected, and the digital input pin on the LED strip was connected to the digital pin 5 on the Arduino board. To program the controls for the LEDs, the FastLED library was installed to the Arduino program. The code that was used to test the LED strip was the ColorPalette.ino example sketch provided in the examples section of the FastLED library. This program cycles the LEDs through various different color palettes and movement patterns. This program was chosen to be used for testing the LED strip for use in this project since it changes the colors, the brightness, and the speed at which these are changed for each LED individually. By running this program, it can be observed whether the LED strip functions as intended or not.

After connecting the LED strip to the Arduino Leonardo, the ColorPalette.ino test program was uploaded to the development board and executed. It was observed that the LEDs changed colors and patterns as expected, moving through various palettes. Each LED operated individually, as is expected of a WS2812b LED strip. The LEDs are shown lit up white in **Figure 2A.D** in the appendix. From this, it can be concluded that the WS2812b LED strip that was purchased for this project functions as intended. This component is able to fulfill the needs of the LED strip to be used as an artificial grow light source within this project. It can easily be programmed to provide white light from each LED that ends up being used on the strips attached to the overhead compartment, and can be programmed to turn on and off based on the time duration, measurements from the light sensor, or on user command.

6.10 Peristaltic Pump Prototyping

As part of the nutrient management system included in the project, the system must be able to dispense the necessary amount of liquid nutrient solution into the reservoir. The solution is added to the reservoir whenever the reservoir is refilled with water, or whenever the user chooses for it to be dispensed. The amount of nutrient solution to be added is determined based on the ratio of teaspoons of the specific nutrient solution being used to gallons of water and the measurement of the volume of water currently in the reservoir as determined by the system. This amount of nutrient solution must them be dispensed from the compartment holding the solution into the reservoir. Since the amount of solution to be dispensed will be on a small scale, the pump being used to dispense it must be quite accurate. The liquid nutrient solution that is used in hydroponic systems like the one being implemented in this project consists of small amounts of concentrated nutrients that are necessary for plant growth dissolved into water. This solution must then be added to even more water. The water with the added nutrients is then used to water the plants. This way, plants that are being grown hydroponically are still able to get the essential nutrients they would usually get from soil and fertilizer without needing to be planted in soil or fertilizer. Since this solution does contain dissolved nutrients, it could present a problem if the nutrients separate from the liquid and clog the pump. Due to these requires, it was decided to use a peristaltic pump to dispense the nutrient solution from the compartment into the water reservoir. This type of pump provides more accuracy and does not come into direct contact with the liquid. The part that was chosen to fulfill the needs of the nutrient dispenser is the 1150 Peristaltic Liquid Pump manufactured by Adafruit. This part was purchased from Digi-Key Electronics for $24.95 and included the necessary silicon tubing.

The part was received and tested for functionality and accuracy. It is essential to test that component functions as intended. This component was tested by using it to pump water from one cup into another. One end of the silicon tubing was submerged into a container filled with tap water, while the other was placed in an empty cup. The cup of water was used as a source while the empty cup was be the destination. The motor attached to the pump was then connected to a power source. For this part, a 12 V power source was used. The direction in which the pump will move the liquid depends on which pin of the motor is connected to the positive voltage of the power source and which pin is connected to the ground. This connection was setup as needed for this test. The pump was then run and observed to confirm that it is working properly. No errors occurred, so it was concluded that the part functions properly.

To determine the flowrate of the pump, measured amounts of water were pumped from one cup to another and the duration of time needed to pump each amount of water was recorded. The amount of water pumped was then divided by the time taken to pump it to determine the flowrate for each test. This test was repeated seven times, and the average of the results was taken. From this is was determined that the flowrate of the peristaltic pump is 1.34 mL/s. This flowrate is then used when operating the system in order to program the pump to release the necessary amount of nutrient solution by using the flowrate to determine how long the pump must be allowed to run for based on the amount of nutrient solution needed.

6.11 pH Sensor Prototyping

Although it is not necessarily essential to the regular operation of the system, being able to measure the pH level of the water in the reservoir helps optimize the system and allows it to function more without user interaction. The pH level of the water can affect the ability of the nutrient compounds within the nutrient solution to stay dissolved in the liquid, as well as the ability of the plants to absorb these nutrients from the water. If the pH raises or falls outside of the ideal range for the nutrient solution being used, the nutrients may begin to precipitate into solids within the watering solution, which may cause problems in system operations if the pump gets clogged for instance. And if the pH falls outside of the ideal range for the plants, they will not be able to absorb the nutrients they need from the watering solution. The user may be able to measure this pH value occasionally themselves with basic pH testing strips or a separate pH meter, but having a pH sensor built into the system allows it to function for longer periods of time without user interaction, and can help to catch possible issues in the system before it is unable to function properly. It was decided to include a pH sensor module and probe in the system to detect the pH level of the water when needed. The part that was selected for use in this project is the E-201-C pH Sensor Module and pH electrode probe manufactured by GAOHOU. This part was purchased from Amazon for $33.99.

Once this part was received, it was tested for functionality, accuracy, and reliability. The Arduino Leonardo development board was used to test this part due to availability. The electrode probe is the component that actually makes contact with the liquid being measured, and the pH sensing module utilizes this probe to measure the pH value from the probe. The probe connects to the module using a BNC cable. The sensing module is also compatible with a temperature sensor, and includes pins for this application, however for this project we only use this part to measure the pH level. The pins on the module that are used are the 5 V DC input pin, a ground pin, and the pH output pin. For this test, the probe was connected via the BNC cable to the module, and the module was connected to the Arduino Leonardo through a breadboard. The 5 V DC input pin on the module was connected to the 5 V DC output pin of the Arduino, the ground pins were connected, and the pH output pin of the module was connected to an analog input pin on the Arduino board. The datasheet for the E-201-C module includes a test code written in Arduino that was used to test this part. This code records the voltage measured by the sensor and prints this data out to the serial monitor. This voltage corresponds directly to the pH value measured by the sensor. This code was uploaded to the development board and executed. The probe was inserted into various liquids of which the pH values are known, such as distilled water, vinegar, and milk. The voltage output recorded by the sensor for each of these substances was converted into the measured pH values, and these measured pH values were compared with the expected values for each substance. This test confirmed that the pH sensor operates as intended and is relatively accurate.

7.0 PCB Design

Now, that the initial prototyping of the system on the breadboards has been complete, the printed circuit board will need to be designed. The PCB design is an integral part of the hydroponics system as it will house the power and control of the overall system. Since the Arduino Mega2560 Development board was used during testing, it has been decided that the microcontroller used for the hydroponic system will be the ATmega2560. When designing the PCB layout, the pin layout, located in the appendix **Figure 1A.B**, is heavily referenced. Switching to a PCB as opposed to a breadboard has many benefits. The PCB will have permanent connections and a greater current carrying capacity as opposed to the breadboard. By designing a printed circuit board for this project rather than using a preexisting development board, we can customize the printed circuit board to more specifically fit the needs of this project. This will also make the system more compact by removing any unnecessary components that are included with the development board that are not required for implementing the system in this project. A few different considerations need to be made when designing a PCB such as the software that is chosen, the layout of the board, the company that will print the PCB and the mounting of the components. These topics will be discussed in this section.

7.1 Software

Before looking for a company to print the PCB, a design of the PCB will need to be created first in a PCB design software. The PCB is created by having the user first create a schematic diagram of the device and using this to produce the PCB layout. There are multiple software programs that must be bought and others that are free that can be used to create the desired PCB.

KiCad

The KiCad software is an open source software that is free that provides PCB layout designs. It can do up to 32 layers of PCB layouts and is able to implement a 3D view of the PCB design while also having the ability to rotate and look at the design from all angles.

EAGLE

Eagle is another software program that features PCB layout and schematic capture. This program is one of the most popular PCB programs to use and is free to use. This software allows for libraries that include the symbol and footprint to be added aside from the ones included which lets the user have a greater access when including certain parts or modules. A 3D model can also be created.

DesignSpark PCB

DesignSpark PCB is like the other two software programs that are mentioned. The software is able to create a PCB layout of an electronic circuit design. It also has a 3D option where the user can see the PCB layout in a physical view. The software is easy to use and is also free.

The PCB design software chosen for the hydroponic system is Autodesk EAGLE. The first step to creating the PCB is to create the schematic of the overall system. The planned connections have been previously mentioned in the design chapters and have been explained in detail. The following section will discuss considerations that were made when designing the PCB.

7.2 Design Considerations

Now that the PCB software has been chosen, the previously discussed designs must be implemented. The schematics used in the PCB are shown in depth in the design chapter as well as this chapter. When designing a PCB, it is important to note the number of layers that will be implemented. For the purpose of the hydroponic system board, there only needs to be two layers. The upper layer will include the various voltage planes and the second layer will be the ground plane, made up of copper foil. When creating a board with more layers it leads to a larger cost, therefore the designer should be mindful of this. The size of the board is also important when considering cost, as the size of the PCB should be as small as possible minimizing the amount of unused space without reducing the integrity of the intended design. A larger board leads to an increased cost, so maximize a small area is important. When implementing a PCB design, it is also desired that the majority of the components are surface mounted to reduce the cost in fabrication due to the drilling for through hole components.

7.2.1 Microcontroller Connections

The schematic in **Figure 34** shows the pin layout for the Atmega2560 and the currently planned connections to the rest of the system. These connections may change as additional sensors needed in the system will be added. Another item that is not included is the teams stretch goal of the speakers, which will be connected upon implementation. The Atmega2560 was chosen due to several factors. One that is highlighted here is the number of I/O pins. This controller has 16 input analog pins and has 54 input digital pins, which is important for the number of sensors that the system has. Additionally, having available pins is necessary if there is a desire to expand the system. This current layout is likely to change as the system continues to develop.

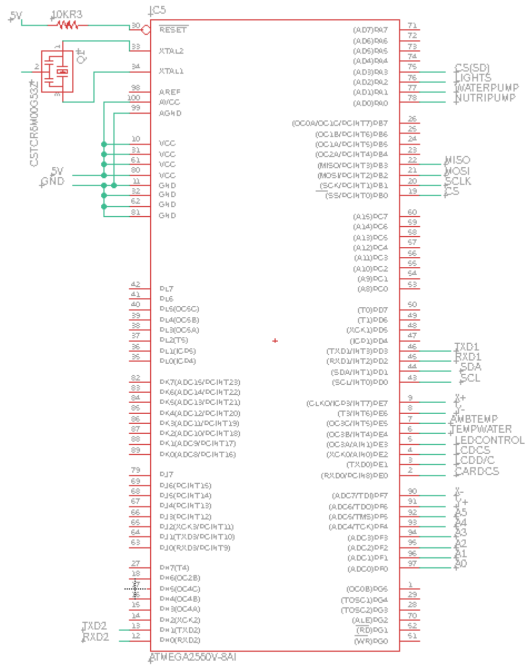

Figure 34: Atmega2560 Connection Schematic

7.2.2 Sensor Connections

Due to the nature of this project the system can be implemented using a single circuit board. The board will include the microcontroller, Wi-Fi module, Bluetooth module, pin headers for the sensors and the system power. Due to the locations of the various sensors in the system, it is not practical for them to have connections straight to the PCB. Instead, the various sensors will connect via individual pin headers allowing for their locations in the system to be flexible. The **Figure 3A.D** in the appendix includes the current layout for the pin headers and their connections to the power and microcontroller. Any additional circuitry needed for any of the sensors is included here as well.

7.3 PCB Layout

When producing the first iteration of the PCB the board is initially laid out in an unpractical way. The wires are not initially routed when switching from the design schematics to the board layout. EAGLE has an autoroute tool as an option, which is an effective starting place. It can give some initial guidance on how to route the board. It should be noted that this can still lead to long traces, which may need to be adjusted by the designer to ensure that the best possible layout has been achieved. Shorter traces are desired to reduce the about of electromagnetic interference (EMI). Another reason shorter traces are desired is that increased cost of longer traces as it will take up more space on the board. **Figure 35** shows the PCB design upon the creation of the PCB layout, without any of the traces routed.

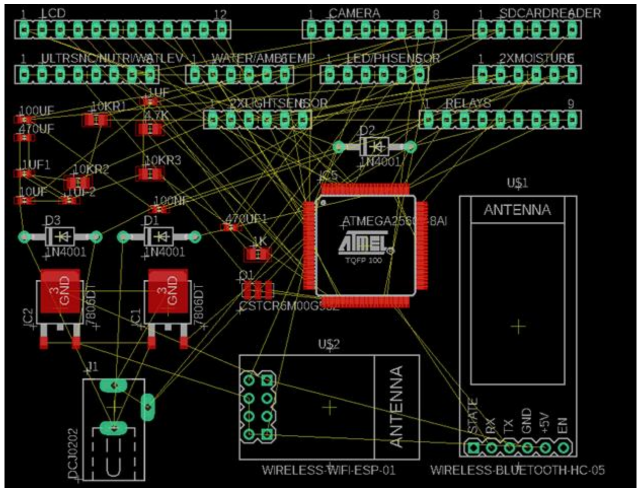

Figure 35: Hydroponic System PCB Displaying Airwires

At the time of this layout, the board layout is subject to change to allow for the most efficient use of space. Additionally, mounting hole are desired in the four corners of the board, so that it may be placed in the system securely. The system is also at a point of expansion where the stretch goal of the speaker system has not yet been implemented, along with a potential implementation of a battery and charging circuit.

Now, the considerations previously mentioned for routing have been implemented, which can be seen in **Figure 36.** The first layer of the board can be seen by the red traces, while the second layer can be seen by the blue traces made on the board. The positions of the sensor headers may be rearranged to allow for a more compact PCB design and leader shorter wires being used in the overall system assembly. It can be seen that an effort has been made to place all the power components on one portion of the board. Organization of the PCB is important allowing for the shortest traces possible and maximizing the space available on the board.

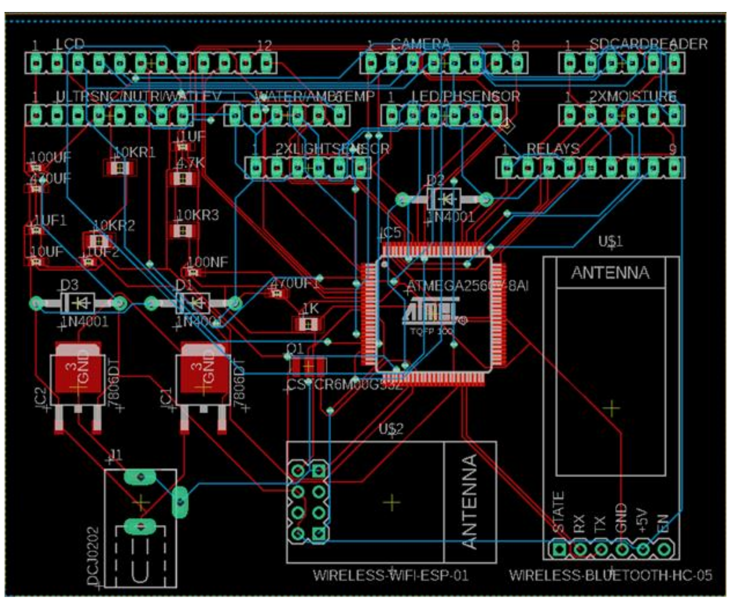

Figure 36: Hydroponic System Wire Routing First Iteration

Since a two-layer PCB design has been implemented the bottom layer of the PCB is the ground plane. Creating a ground plane is done by using the polygon tool in EAGLE. When creating the ground plane, the polygon should be created to cover almost the entirety of the board. Once this has been completed, this layer may be renamed as the ground (GND) to ensure that all of the associated pins are able to connect. The following, **Figure 37**, shows the PCB layout when the ground plane is highlighted after using the polygon tool and ratsnest tool. As this is the first iteration of the PCB design, testing must be done to ensure that the PCB has been designed correctly and functions as expected, it is likely that multiple iterations will need to be made in order to get the best possible design that also performs the intended actions of the system.

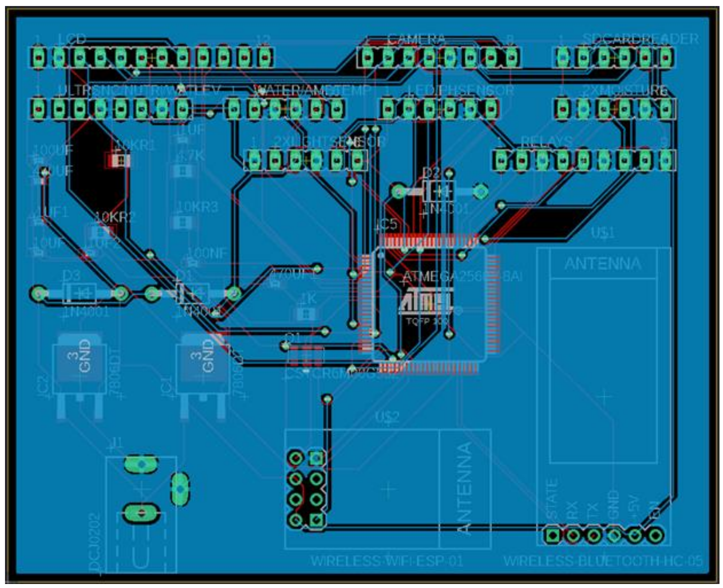

Figure 37: PCB Layout Showing Ground Plane

7.4 PCB Companies

Once the PCB layout is finished on the PCB design software, the next step is to pick a PCB vendor that will bring the digital design of the PCB into a physical PCB design. Due to the current situation, it will be best to pick a company in the United States that can ship it in a reasonable time for the lowest possible cost. Given that the main constraints when choosing a manufacturing company are cost and delivery time, it is crucial that the company chosen gives the best outcome for both. The reliability of the board cannot be sacrificed for a lower cost, so in some cases a tradeoff may be necessary. Additional research and the final decision of the company that prints the PCB will be determined at the time that the initial iteration of the PCB has been checked and ready to be tested. This will also depend on the situation at that time.

The company that was chosen to print the printed circuit boards that were designed was JLCPCB. This company was chosen due to the low cost that came with printing multiple PCBs. Ordering multiple PCBs was beneficial to ensure that there were backups in the event of any issues while soldering. This company also offered a relatively fast shipping time which was crucial to keeping the project on time.

7.5 PCB Final Design

The first iteration of the PCB included four drill holes that could be used for mounting the PCB to the inside of the top enclosure of our system. These were added in case the PCB needed to be secured in place to make moving the enclosure easier. The final dimensions of the PCB were 90 mm x 90 mm.

The original connections have been updated to solve some of the issues that arose in the first iteration of the PCB. When fixing the connections, some other connections were placed incorrectly limiting the functionality of some features. Unfortunately, due to COVID restrictions and delays a third iteration of the board was not able to be completed, but if there had been all wiring issues could have been resolved. Overall, the microcontroller connections were correct enough for the entire system to have proper functionality with minor adjustments. The microcontroller connections for the second iteration of the board can be seen in **Figure 38**.

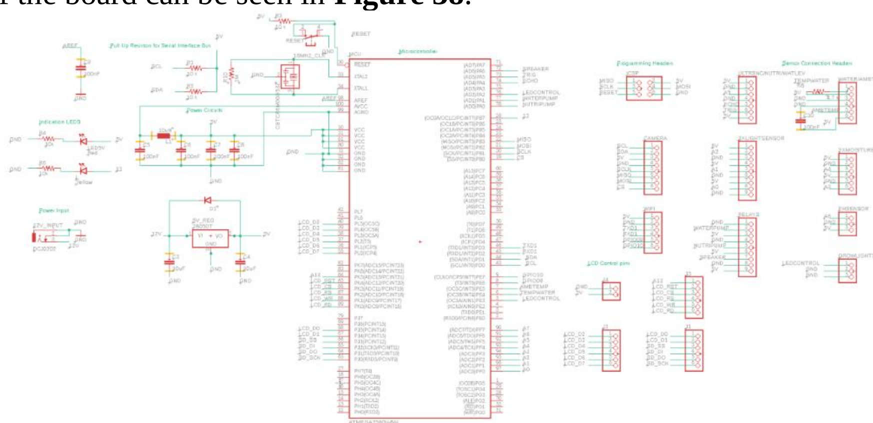

Figure 38: Final Microcontroller Connections for PCB

Once the proper connections were made, then the layout for the board was created. The board layout can be seen in **Figure 39**.

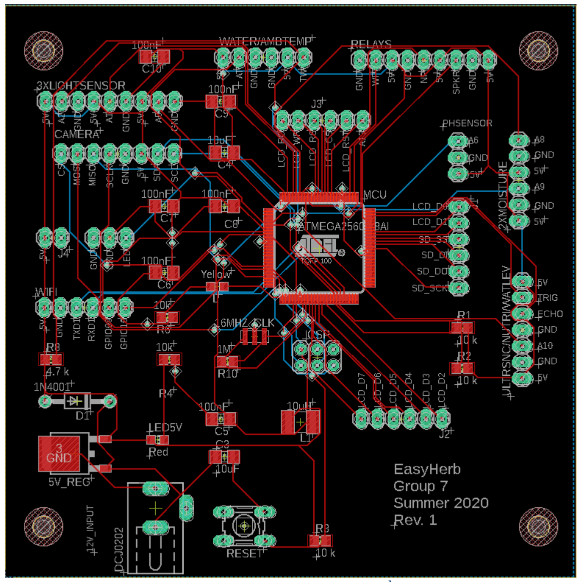

Figure 39: PCB layout for 2nd Iteration

After receiving the first iteration of the PCB, some design decisions were made that would alter the connections and layout of the second iteration. Since a decision was made to use the NodeMCU ESP8266 the WiFi module was removed in the second iteration. Upon testing, the team decided that the NodeMCU should not be used because it is like a development board, which is not allowed. Since that was decided, the ESP8266 was used instead stand alone to ensure that the requirements were met. Unfortunately, the second PCB had already been ordered, so there was no longer an on board 3.3 V regulator. The ESP8266 needs a 3.3 V regulator because it does not have its own. Using the originally researched 3.3 V regulator that had been ordered for the first iteration of the PCB, it was attached to an extra PCB that had been ordered and then used the 5V bus from the completed PCB as the input. This new 3.3 V bus was used to power the ESP8266 that was controlled by the main PCB. In a third iteration this would be corrected, to allow for the use of one singular PCB. Overall, the second iteration was able to allow for the system to function as expected and meet the determined engineering specifications.

Once the printed board arrived from JLCPCB, the components that were ordered from Mouser were able to be assembled onto the board. This was done using the following tools: soldering iron, heat gun, soldering wire, and solder paste. The picture in **Figure 40** shows the final PCB one all the components were soldered on and the PCB was ready to be tested.

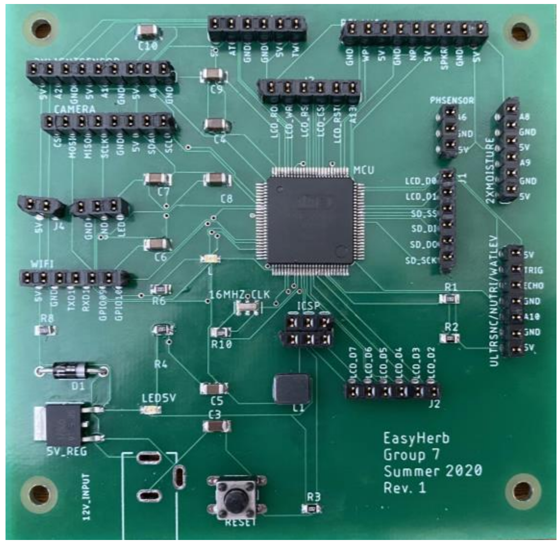

Figure 40: Final Assembly of the PCB

To ensure that the PCB was functioning properly before attempting to upload code, a multimeter was used to test that the on-board voltage regulator was functioning properly. It was seen that the voltage regulator read 12.06 volts on the input pin and on the regulated output pin the voltage was 5.08 V. This proves that the 5 V regulator was functioning properly and the 5V red LED was on indicating this was the correct voltage being received as well.

The next step was to burn the bootloader, this was done by connecting an Arduino UNO to the ICSP headers of the PCB. The UNO was used as the programmer for the PCB and was used to upload a simple test code that blinked another LED on the PCB. Once this test was successful, it proved that the PCB functioned as expected. Since this was the case the final code that would be used to control the entire hydroponic system was able to be uploaded and the PCB is able be connected to the rest of the system, to control the various sensors and components.

8.0 Testing

Testing is crucial to the successful operation of a system. Issues can arise at any point during development. The earlier we can identify those issues through testing, the faster we can fix those issues. Since each smaller system that comprises the overall system is different, a different testing method must be developed and used for each system specifically. Components used in the system were tested on their own before they were added to the prototype to make sure they function properly and to determine exactly how they should be implemented in the overall system. As the separate parts were added to the overall system, the individual subsystems needed to be tested to identify any possible issues. Then, when all of the subsystems were combined into the overall system, extended testing on the prototype was conducted to ensure that the system would function properly and dependably. Any issues that were identified during this testing were addressed and solved as early as possible in order to avoid losing time by having to disassemble the entire system to identify and address a problem if it is not necessary.

8.1 Software Testing

After developing the software far enough to achieve a Minimum Viable Product, testing began to ensure that the system ran as intended. There are many different structures and procedures that can be applied to our design to test the system appropriately. Before diving into the overall structure of our system tests, some key terms need to be addressed.

8.1.1 Test/Edge Cases

To successfully test programs, an empirical system must be put into place to compare results, measurements and any useful data collected during the testing phase. Test cases are specifically designed to traverse the many different program paths and occurrences that can happen during the usage of the program. They can be simple such as having the system print a message to the console or complicated such as tracing the direct path and latency of data collection.

Another term used when testing the software is “Edge Cases.” Edge cases are a type of test case whose primary goal is to push the system to its boundaries to ensure that the program is still operating as intended. This is very important so that the team can understand the limitations of the software. Understanding program limitations allows the developers to either push the boundaries of the program or put a “cushion” in place so that users are not able to break the program by reaching an unintended boundary.

8.1.2 Bugs

Do not be alarmed, this is not a section on entomology. Software bugs are failures, mistakes or unintended consequences that a computer program achieves. Bugs can range from small faults such as typos in the display all the way to data corruption and program unresponsiveness. Test and edge cases are great at understanding the overall structure of the program and ensuring operation. However, bugs arise when the variables and operations create so many program paths that the testing structure is not able to handle them all. At this point in the testing, developers have a decision to make; dedicate more time to restructure testing and fix any bugs or move forward to publishing the program and fixing bugs after release.

While bugs are typically found in most programs, it is important to address them as early as possible so that other parts of the program are not affected. Bug fixing post-release carries some unintended consequences. Certain parts of the program may be taken advantage of using the bug as an entry point. This is where users with malicious intent can access structures and data that the developers do not want released.

There are many reasons that a software bug can arise. Communication plays a big part in development teams. As more than one person works on a piece of the program, miscommunication can cause an unintended program path. When a bug fix is being implemented, the fix itself can cause another component of the software to reach an unintended program path. Other reasons include fundamental programming errors, redesigns and many more. To prevent bugs from arising, it is important to identify weak points early on and safeguard the program from reaching those paths.

8.1.3 Black/White Box Testing

Black and white box testing are terms used to describe the virtual environment that the tester will be in. Black box testing analyzes the functionality of the program without being able to view the structure or algorithms put in place by the developers. On the flipside, white box testing is analyzing the functionality of the program while being able to trace its functionality through the software development program.

8.1.4 Alpha/Beta Testing (Software)

Alpha and Beta testing are terms used to describe the type of environment and person that will test the program. Once the requirements, test cases and MVP are established, we can transition into Alpha testing. Alpha testing is a type of in-house testing. It is done by the software developers to test the software in the virtual environment. Since the testing is done in-house, the developers can test the system through black and white box testing.

Beta testing is done by users that are typically customers. It is usually performed in the real environment and usually lasts over a longer period than Alpha testing. Beta testing is especially important for programs that have numerous variables that Alpha testing cannot cover in a given time interval. It is also useful for the developers so that they can see how a new user interacts with the system without having seen it previously. Beta testers can run the program from a fresh perspective and give feedback about the real-time operation of the software. For programs that communicate with different hardware components, Beta testing provides real-world interactions outside of a closed system. Software development tools and simulations are great at providing computer generated data. However, Beta testing exposes the program to variables that are less than ideal. Alpha testing is almost always used due to its efficiency and availability of testers. The development team can test the program routinely throughout the development process. Beta testing is primarily seen in video games due to the availability of users that can test the system thoroughly.

8.1.5 Software Testing Considerations

There were numerous considerations to make when testing the software. As the development team progressed through the test cases and edge cases, some key attributes of the program were analyzed.

Code quality is one of the most important attributes of a program. A simple program may be able to be developed without code quality in mind and still fulfill the software requirements. However, as programs evolve into complex applications that utilize high level data structures and algorithms, code quality becomes a defining factor in the overall efficiency of the system. Understanding this concept allows programmers to transform a brute force code into a program with lightning fast runtime.

Integration testing involves the combination of different parts of code and how they interact with each other. After an MVP is developed, features are then worked on to build off the core program. Bugs can arise when features conflict with one another. Certain variables or functions may cause the program to reach unintended events. To counter any conflicts, specific testing should be done to protect the core program from being faulted by a feature.

Performance testing was done when the program operates as intended. Certain aspects of the actual program execution can be analyzed. Typically, performance tests are done to keep track of the program runtimes. Some functions and routines require more computation than others. These need to be tracked so that fixes can be made if the runtime is not acceptable. Long runtimes can lead to bottlenecking and program inefficiency.

Throughout the software development phase, it was extremely important that these testing considerations were brought into play. Future implementations and designs that were based off this architecture thrived the most when given a solid foundation. The quality of code, how it integrates its different parts and its performance all contributed to a successful and efficient program.

8.1.6 Software Testing Structure

After careful planning and analysis of our current resources and environment, a testing structure was designed to fit the needs of, not only our system, but our team. Our system operates on a cycle/interval routine check structure. This made testing the different inputs, outputs and routines straightforward. For each variable that was associated with a sensor or timer, a flag was raised. To test each variable, every flag was outputted in some way so that the team was able to see when each change was made. As we progressed through the numerous cases and tests, a checklist was updated to ensure that tests were not unnecessarily repeated. The team decided that traditional Alpha testing was put in place. As we developed the software, tests and edge cases were created and implemented so that we could ensure that the program was operating as intended during the development process. Given our current circumstances, we were not able to utilize traditional Beta testing. Our program was tested rigorously by users that have not been exposed to the code previously. Real-world integration testing with hardware implementation was done in-house by the team. Performance tests were ran to confirm that the system operates within reasonable time frames. Networking tests were implemented once the system operated locally as intended. The primary focus of the testing phase was to safeguard our MVP functionality and confirm that the software fulfills the system requirements. An optional secondary focus was the accessibility and latency of the program.

Each sensor and check condition had their own unit test to ensure desired operation. Edge cases based on the specific range conditions were developed and implemented so that boundaries are set. Network setup and connection were considered “Software Testing Phase 2.”

8.1.7 Software Error Handling

It is beneficial to the developers as well as the users for a program to have sufficient error handling. As different faults and unintended consequences arise, developers can prevent some faults from causing a program crash or even a data corruption. This is done by implementing error conditions for known boundaries. If a user is attempting to access a condition range that is outside the acceptable boundaries of the device, the software may attempt to pass these unacceptable ranges to the appropriate function. This could cause the system to fault and possibly require recalibration of certain components. The software can instead check for the conditions that the user is trying to modify and if it does not meet the set conditions, then the software will output an error message to notify the user that the modification they are trying to make is not allowed. This was a small but very effective prevention method. Since the input that could potentially force the software to enter an unintended state is now directed towards an error message, it safely redirected the program path to a known safe state.

There are many different types of error handling procedures that developers can implement. Many require a console or display window to output the error code and message. This also helps during the prototyping and testing phase of development due to its traceability and debugging capability.

8.1.8 Calibration

When working with many different hardware components, the software that controls them may need to have some initial boundaries. These boundaries are also known as “calibration.” Using a specific point in sensor readings as reference, the system can understand how to calculate deviations from the calibrated reference. For instance, a water level sensor may need to be adjusted so that when a certain reading is found, the exact amount of water is sent. However, there are other factors that may cause the initial calibration to be inaccurate. Environmental factors such as humidity, evaporation, etc. can affect the points at which sensors read the data. Certain checks conditions can have a function to adjust the initial calibration of the hardware to fit the specific needs of the user. A light sensor can be calibrated so that the ambient light of the device is set. Environmental conditions range widely so calibration is necessary to set the “normal” conditions of the device. Presets will be available at startup. These are predetermined minimal conditions that are used to ensure that the environmental conditions are at least the bare minimum to facilitate plant growth. Calibration is also important to help the user understand how the system works during initial setup.

The final design had preset values that were pre-calibrated for demo purposes.

8.1.9 Software Unit Testing

As stated before, the software was tested throughout the development process. To create clarity among each hardware component, the software had separate tests to ensure that the input and output of the device was functioning as intended. This was achieved by assigning boundaries to each sensor. When a sensor was read, that value changed the variable assigned to it. The boundaries of the variable were between 0 and 100. A function was called to calibrate the sensor at the start to ensure that accurate readings are taken. The hardware devices were tested to output different readings and the corresponding variable were checked so that the intended value was read.

Unit tests were created to create baselines for each sensor. These baselines assisted in creating the default threshold values for the system. Unit tests were comprised of a function that tested for the minimum and maximum values for the sensor.

8.2 Hardware Testing

It was essential that the physical hardware components of the project are tested. Due to the circumstances surrounding the design and construction of this project, each part was tested separately before it was added to the combined system. A testing procedure was designed and executed specifically based on each component that was being tested.

8.2.1 LCD Testing

The LCD screen used in our system must be tested so that the intended output is displayed on the screen. This required testing. A typical test for the LCD was displaying an image on the screen that was sent to it through the microcontroller. To implement this test, the LCD screen was connected to the microcontroller and a function was called that instantiated the LCD screen. This was done to confirm the dimensions of the display as well as its resolution. Each pixel on the display can be modified so another function was called to change every pixel on the screen to white. This serves as a functionality test and a test for any dead pixels. The initial tests proved the intended functionality of the LCD screen. The LCD module test was considered a success.

8.2.2 Wi-Fi/Bluetooth module Testing

Both the Wi-Fi and Bluetooth modules allow the device to communicate to other devices wirelessly. These modules require individual testing to ensure that connection and communication are stable and accurate. Both modules were connected to the microcontroller and each were tested separately. The Wi-Fi module was set up so that a connection could be searched for and connected to. A home Wi-Fi network was used as a test network due to the limited conditions of the build environment. A network was able to be found and the device was able to connect to the network. The Bluetooth module operated similarly but instead of connecting to a network, an audio device was used. The module was connected to the microcontroller and a smartphone with Bluetooth capability was sued to connect to the device. The microcontroller was able to be found by the smartphone and the audio source was ready to be outputted. The Wi-Fi and Bluetooth module testing were considered a success. Another test implementing the speaker will need to be done so that the audio test will be considered successful.

9.0 Results

The completed project functions as intended and successfully meets our defined engineering specifications.

The first engineering specification that was demonstrated is that the time between when an event trigger occurs, and the system executes a change is within 5 seconds. This is demonstrated in the lighting system specifically by measuring the time it takes for the system to turn on or off the lights based on a change measured by the light sensors. For this test, the lights were initially on in a dark room. A flashlight was shined on the light sensors to simulate a bright light source, causing the lights to turn off. The time from when the flashlight was turned on and the LEDs on the system turned off was recorded. When the flashlight was turned off, there was no longer sufficient light being measured by the light sensors, so the LEDs would turn back on. This response time was recorded as well, as the time from when the flashlight was turned off and the LEDs turned back on. In each of these tests, the response time measured did not exceed 5 seconds. In fact, the average response time observed was actually around 2.59 seconds, as shown in **Table 29**. This demonstrates that the project successfully meets the engineering specification of having an automatic response time to event triggers of less than 5 seconds.

Desired time to change after an event triggers	Computed average from tests
Within 5 seconds	2.59 Seconds

Table 29: Data for the engineering specification regarding the time it takes the lights to change after an event trigger.

The next engineering specification that was tested and demonstrated is that the system measures the amount of water in the reservoir within 0.1 gallons. For this test, a function that measures the distance from the ultrasonic distance sensor to the surface of the water, uses this to calculate the volume of water in the reservoir in gallons, and prints this value to the user was used. Water was added to the reservoir in cups of 0.25 gallons at a time, and the volume measured by the system was recorded. This was repeated from 0 to 1 gallon and the amounts recorded are shown in **Table 30**. In each test, the error between the measurement and the actual amount was less than 0.1 gallons, so the engineering specification was met.

Test #	Actual amount of water added tank	Sensor recorded amount of water	Error
1	0.25 gallons	0.24 gallons	0.01
2	0.5 gallons	0.48 gallons	0.02
3	0.75 gallons	0.72 gallons	0.03
4	1 gallon	0.95 gallons	0.05

Table 30: Data for the engineering specification regarding the accuracy in measurements of water volume.

The last engineering specification that was tested and demonstrated is that changes to the system can be made using remote access within 3 seconds. This was specifically demonstrated using the companion app to turn the LEDs on and off. With the LEDs off, the button on the companion app was pressed to turn the lights on and the time between when the button was pressed and the lights came on was recorded. The button to turn the lights off on the companion app then pressed, and the time until the LEDs turned off was recorded. This test was repeated both on the same Wi-Fi network as the system and off of the network. The response times measured in these tests are shown in **Table 31**. In each test the response time was less than 3 seconds, so the engineering specification has been met.

Test #	Actual response time
1	1.72 seconds
2	0.87 seconds
3	1.34 seconds
4	0.9 seconds

Table 31: Data for the engineering specification regarding the remote access response time.

10.0 Administrative Content

When researching, designing, prototyping and implementing the hydroponic system it is important that the group members keep track tasks that need to be completed as well as other administrative responsibilities. The first item that is addressed is a schedule for the project. By setting project milestones it is ensured that each major section of the project is completed in a timely manner and that the overall system is broken down into smaller tasks that can allow for the continuous progression of the project. The next section discusses the overall budget and includes an itemized materials list. Keeping track of this information is crucial as this project is self-funded by the members of the group and it also ensures that the implementation of the system is one that is financially feasible.

10.1 Project Milestones

The project is broken up into smaller sections that are to be completed across the next two semesters. The different sections have been divided amongst the group, not only to evenly distribute the workload, but to ensure that all areas of the project are covered. **Figure 41** below shows the milestones for this project. The tasks are split, so there are at least two members working on a given portion of the project. This method allows for the group members to assist each other in trouble shooting and to allow for multiple tasks to occur at once.

Senior Design I (EEL 4914)														
Project Task	Name		Weeks											
			1	2	3	4	5	6	7	8	9	10	11	12
Planning/Research	Everyone													
Documentation	Everyone													
Ordering/Testing	Everyone													
Prototyping	Everyone													
Senior Design II (EEL 4915)														
Hardware	Everyone													
Senor Programming	Everyone													
MCU/I/O	Luna	Kyle												
Nutrient System	Lindsey	Chris												
Water System	Chris	Lindsey												
Lighting System	Lindsey	Luna												
Power	Luna	Chris												
PCB	Luna	Chris												
Communications	Kyle	Lindsey												
Software	Kyle	Luna												
System Enclosure	Chris	Lindsey												
Testing	Everyone													
Final Documentation	Everyone													

Figure 41:Milestones

10.2 Project Budget

After research and planning, the following is the final costs of materials for the hydroponic system, shown in **Table 32**. The budget in the table below includes the costs of the major components of the project.

Component	Cost
ATmega2560	$11.85
Water Level Sensor	$3.95
Photoelectric Sensor	$5.99
Peristaltic Liquid Pump	$24.95
PH Sensor	$33.99
WS2812b LED Strip	$22.88
Water Temperature Sensor	$2.60
Temperature/Humidity Sensor	$10
Moisture Sensor	$4.99
Water Pump	$10
Camera	$30.99
LCD Screen	$17.80
Wi-Fi Module	$6.49
Speakers	$20
PCB	$ 30
Construction Materials	$110
Relays	$10
Relays	$10
Total	$356.48

Table 32: Itemized Project Budget

11.0 Appendices

11.1 Appendix A: Copyright Permissions

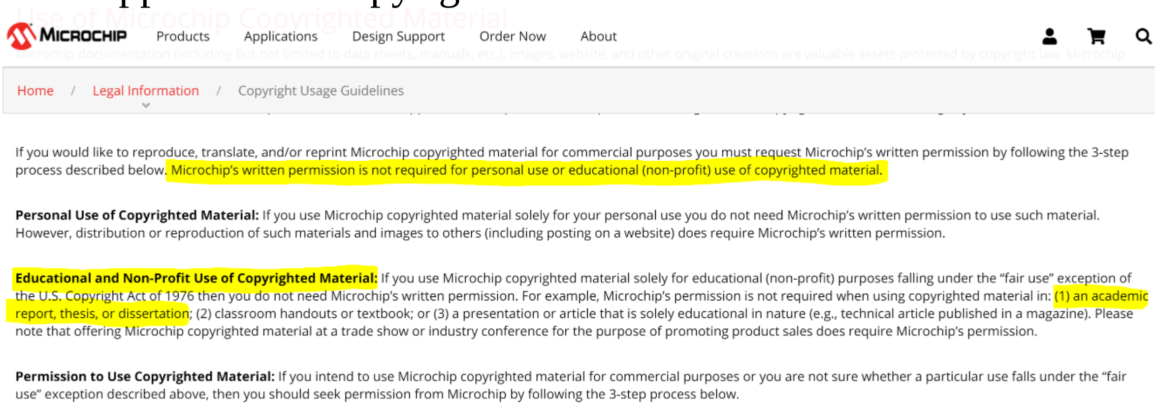
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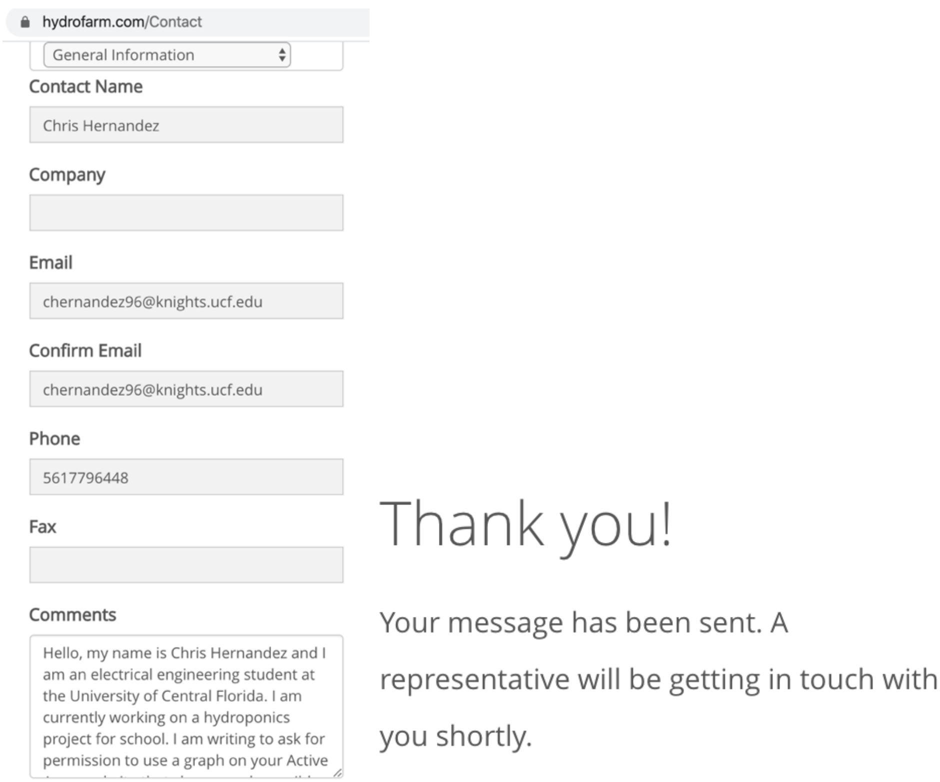
Figure 1A.A: Copy Right Permissions for Atmega2560 Pin Layout


hydrofarm.com/Contact

General Information

Contact Name

Chris Hernandez

Company

Email

chernandez96@knights.ucf.edu

Confirm Email

chernandez96@knights.ucf.edu

Phone

5617796448

Fax

Comments

Hello, my name is Chris Hernandez and I am an electrical engineering student at the University of Central Florida. I am currently working on a hydroponics project for school. I am writing to ask for permission to use a graph on your Active

Thank you!

Your message has been sent. A representative will be getting in touch with you shortly.

Figure 2A.A: Copy Right Permission for Pump Graph

11.2 Appendix B: Datasheets

1. Pin Configurations

Figure 1-1. TQFP-pinout ATmega640/1280/2560

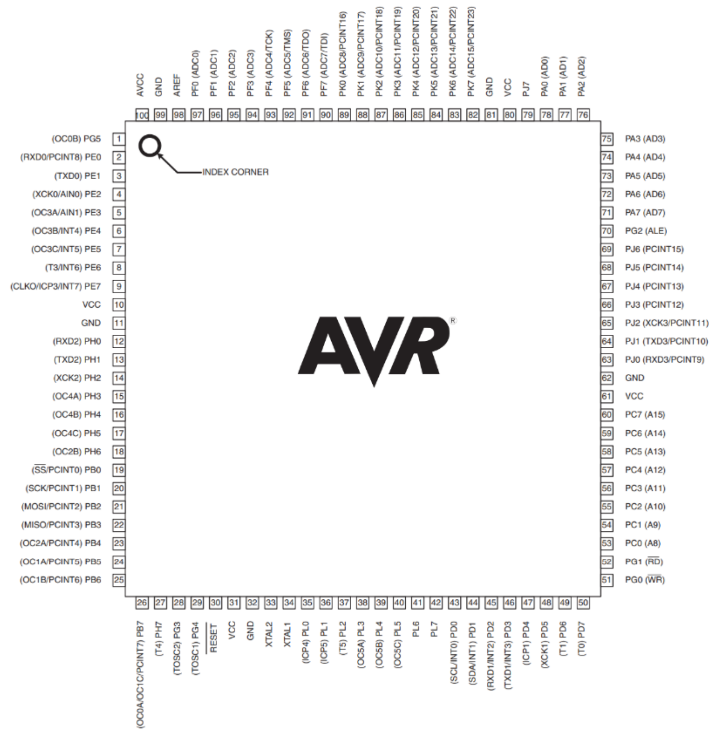


Figure 1A.B: ATmega 2560 Pinout from Atmel Datasheet (Reprinted with permission Microchip Technology)

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11.4 Appendix D: Additional Images Mentioned

Figure 1A.D: Humidity and Temperature Sensor

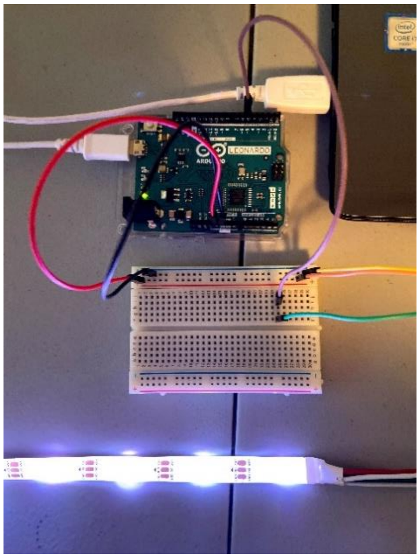

Figure 2AD: LED Grow Lights Setup and Prototyping

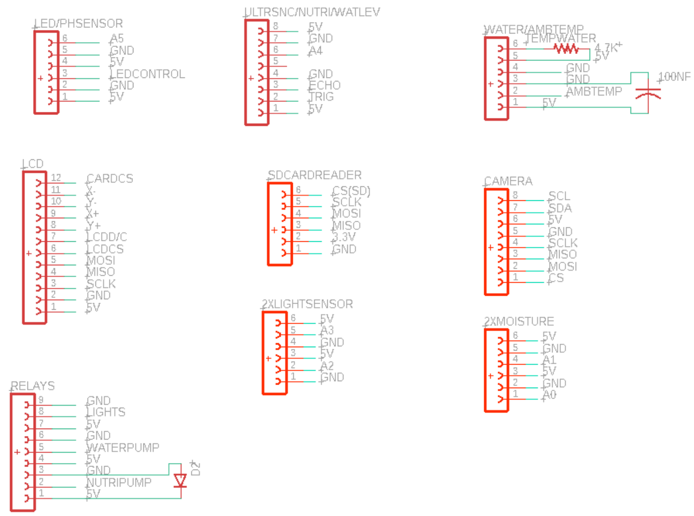

Figure 3A.D: Sensor Connections Via Pin Headers

11.5 Appendix E: Shipment Info

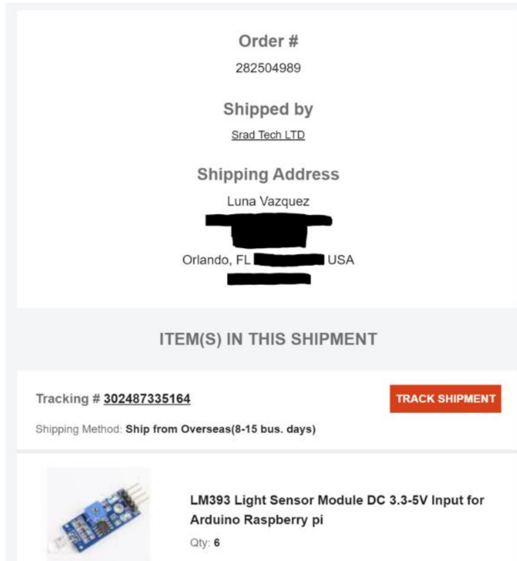

Figure 1A.E: LM393 Shipping Information

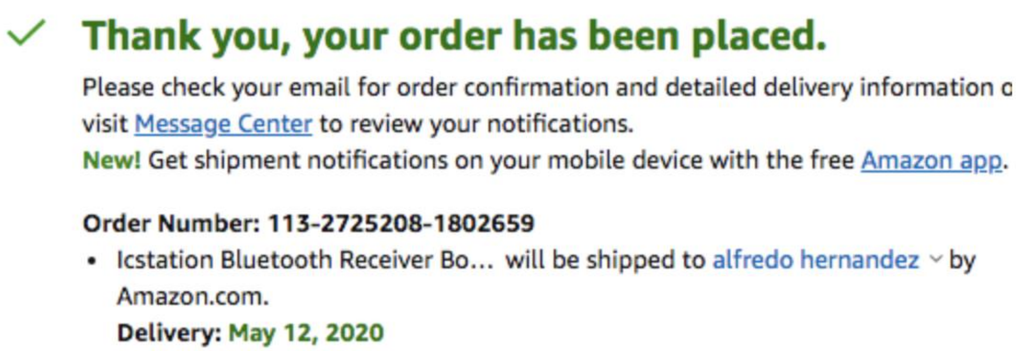

Figure 2A.E: Amplifier board Shipping Information

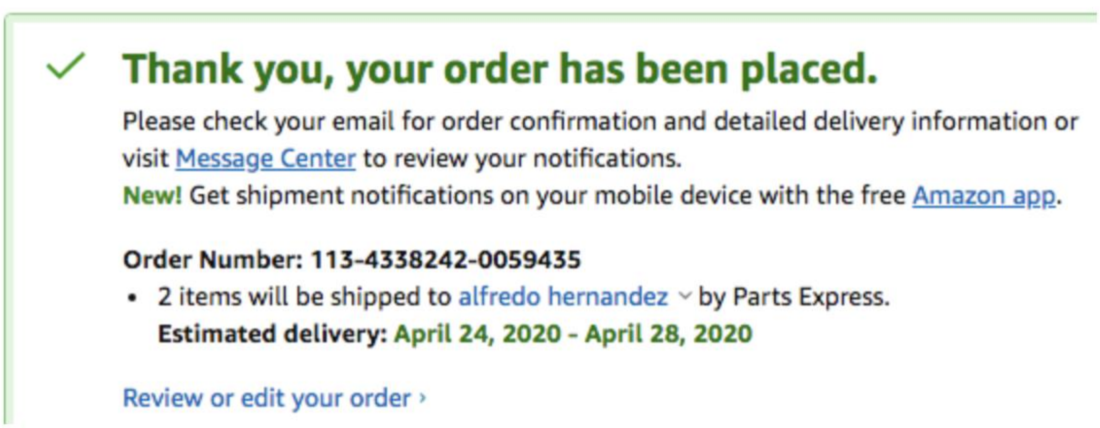

Figure 3A.E: Speakers Shipping Information

Order #

304359059

Shipped by

1Panda Tech LTD

Shipping Address

Chris Hernandez

Tracking # **302500117386** TRACK SHIPMENT

Shipping Method: **Ship from Overseas(8-15 bus. days)**

1 Channel 5V Relay Module Shield Low Level Trigger for Arduino UNO 1280 2560 ARM PIC AVR DSP

Qty: **3**

Figure 4A.E: Relay Module Shipping Information

Order # 111-8253541-2397807

Order total $33.99 (1 item)

Shipment details

Standard Shipping

Shipped

Apr 29, 2020 - May 20, 2020

GAOHOU PH0-14 Value Detect Sensor Module + PH Electrode Probe BNC For... $33.99

Qty: 1

Sold By: Eastowest Direct

Contact Seller

Figure 5A.E: pH Sensor Module Shipping Information.