EasyHerb (Automatic Hydroponics System)

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***Abstract* — The aim of this project is to create a hydroponic system enclosure that will house herbs for indoor use. The system will be automated and require minimal help from the user which they will be notified of changes that need to be addressed. The automation of most of the system is to appeal to a target audience that has an interest in growing herbs but does not have the time to constantly check their plants. The enclosure will contain various sensors such as water temperature, light intensity sensor, liquid level, humidity/ambient temperature, pH value, soil moisture and nutrient sensors. The system will use data from these sensors to turn on and off water pumps or grow lights and alert the user of any changes to the system. The user will be able to review data on the plant's health on the EasyHerb website**

***Index Terms* — Hydroponics, light intensity sensor, PCB, nutrient pump, water pump, soil moisture sensor, water temperature sensor, power supply, WiFi module, power supply**

I. HYDROPONICS INTRODUCTION

The use of hydroponics has allowed people the ability to grow plants without the use of soil. Plants grown in this method have been shown to grow more efficiently than grown in soil. There are different types of hydroponics methods but for the purpose of this project the drip method was chosen. The drip method involves constantly or periodically dripping a watering solution directly on to the roots of the plants. The plants are then able to absorb any water or nutrient they need from this solution, and the excess flows out of the roots, preventing overwatering. A diagram of the drip hydroponics method is shown in Fig. 1. Since plants growing hydroponically are not able to absorb nutrients from soil, the nutrients are instead added to the water using nutrient solutions, then this water is provided to the plants. Drip hydroponics systems commonly include a tray or reservoir to catch the water that flows out from the roots of the plants, either to reuse this water or just prevent overflow. A medium is also required to stabilize the plants due to the lack of soil. For this system, small rocks are used to secure the roots of the plants in the baskets. These baskets are placed above a reservoir to catch any excess water, and drippers are used at the end of the water pumps to ensure that the plants are receiving the watering solution at a steady rate.

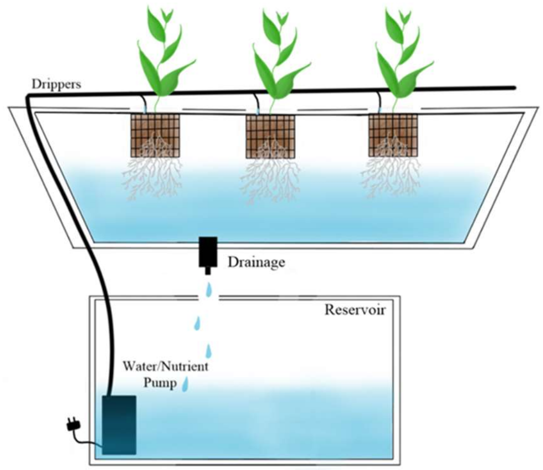

Fig. 1. Diagram demonstrating a drip hydroponics system similar to the one implemented in this project.

II. PROJECT INTRODUCTION

There are many benefits to growing your own herbs in your yard or home, and as such, many people would like to start growing their own herbs. However, many different factors are involved in plant care and growth, which can make this process more complicate for unexperienced gardeners. The goal of EasyHerb is to make the process or caring for and growing herbs easier for the average user. This system is able to monitor and maintain the essential needs for herbs, like watering, lighting, and providing nutrients. EasyHerb uses a variety of sensors to determine what the herbs need and provides it to them without user interaction required. It is also possible for the user to operate the system remotely, so their plants can be maintained from wherever they are. As such, the system is able to automate and simplify the process of plant care, making herb growing more accessible to the average person.

III. SYSTEM DESIGN

Since the system must handle multiple essential aspects of plant care, the overall system is divided into multiple subsystems, each responsible for a specific function. These include the watering system, which is responsible for watering the plants and monitoring the amount of water the system has, the lighting system, which is responsible for determining when the lights should be on and turning them on and off, and the nutrient system, which is responsible for adding the necessary amount of nutrient solution to the water provided to the plants. These systems, while being responsible for their individual functions, also interact with each other in order to fully automate the process or caring for the plants.

These systems are housed in the enclosure, which is also divided into three main sections. The bottom section holds key components for the watering and nutrient systems, like the water reservoir, nutrient compartment, water and nutrient pumps, and sensors that gather data on the amount of water and nutrient solution and other values. Keeping the water and other heavier elements in the bottom section helps to stabilize the whole system and prevents most electronics from coming into contact with the water. The middle section is open to the environment and contains the plants themselves and any components that come into direct contact with them. These include the drippers on the end of the water pumps and the moisture sensor, as well as any components responsible for monitoring and maintaining the growing environment, like the lights and the ambient temperature sensor. Finally, the top portion of the enclosure houses the main electronic components. Here, all the sensors, pumps, and lights are connected to the custom printed circuit board designed for this project. Also in the top portion are the Bluetooth speakers and LCD screen, which provide additional features and allow the user to interact with the system in more ways.

IV. SYSTEMS SUMMARY

The project consists of multiple subsystems that operate simultaneously and interact to form the overall plant-care system. Each subsystem focuses on a function of the system, including the enclosure, lighting, watering, and power.

A. System Enclosure

The system enclosure is made up of three main sections that allow the hydroponic system to function properly. The upper portion is the main electronics enclosure. This portion houses the PCB which is essential for the control of EasyHerb. A few additional elements are housed in the upper section, such as the LCD and speakers. In the middle of the enclosure there is an open area where the herbs are located. The grow lights, watering tubing with drippers and additional system monitoring sensors are located here. These systems will be described in further detail in the following sections. In the lower portion of the enclosure is the main components for the watering system and for the power supply.

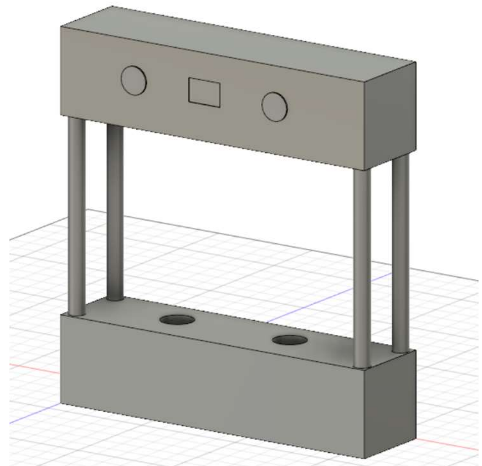

Fig. 2. Model of the system enclosure.

B. Lighting System

One of the major systems in the hydroponic setup is the lighting system. The purpose of the light system is to provide the plants with exposure to grow lights when there is not sufficient natural light present for the herbs. There are photodiode sensors placed around the structure to observe the brightness surrounding the plants. An average of the brightness sensed by the photodiodes is calculated by using the data collected for each individual sensor. If the calculated average returns an analog value of 700, indicating the approximate light intensity of a dimly lit room, then the value will be below the threshold and the lights will turn on and remain on as long as the average is below the threshold. If the calculated average is above this threshold then the lights will turn off. The average brightness is the sum of all the individual sensor measurements divided by the number of sensors used.

LED strips are used to provide this light necessary for plant growth. These lights are attached to the underside of the top portion of the enclosure so the lights shine down on the plants in the middle section. Using LEDs for this purpose makes the lighting system more compact and energy efficient, as well as allowing EasyHerb to be more versatile in the case that the user wishes to grow a different kind of plant than the herbs we are testing. For these herbs, white light is ideal, so the system currently will turn on bright white lighting, however, if a user wished to grow a different plant that may require a different color lighting, like red or blue, this would be possible with these LEDs. These LEDs are digitally controlled allowing for ease of changing the color or brightness needed for the plants a user chooses to grow.

C. Watering System

The watering system is a main component that will allow for the plants to flourish. The watering system will provide the herbs with water and nutrients it will need to survive. A main reservoir will hold six gallons of water. This reservoir has a 12 V DC submersible watering pump which will deliver the water to the herbs via two drippers in each planter. The watering system circulates water in the system automatically on the same constant time interval. This works simultaneously with the soil moisture sensors in the system. When the water pump is not turned on and the sensor senses low levels of moisture in the pot of the plant, it will activate the water pump to cycle water to the herbs.

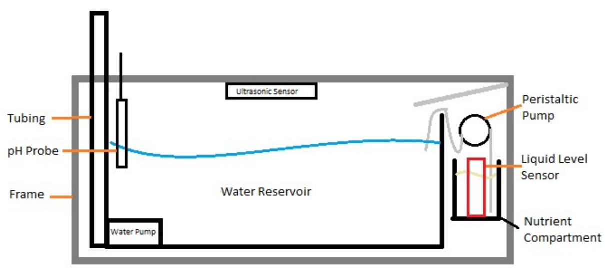

Fig. 3. Diagram showing the bottom section of the enclosure, containing the water reservoir, nutrient compartment, pumps, and sensors.

The watering system also contains the nutrient tank and the nutrient pump. The nutrient pump will be activated upon request from the user and will turn on the nutrient pump to disperse the nutrient solution from the nutrient tank into the water reservoir. The amount of nutrient solution needed in the reservoir is calculated by the system based on the amount of water currently in the reservoir, and this amount of solution is precisely added to the water by the pump. The level of nutrient solution in the tank is also monitored, and the user is notified to refill the tank when the level gets too low.

D. Power

Considerations for the how the system would be powered were made when designing the entire system. Since the water pump and nutrient pump were both powered with 12 V DC the input voltage of the entire system needed to be 12 V. One of the specifications that our group decided on was to power the system using a wall outlet. Since the system needed to be powered using a wall outlet a AC to DC adapter was necessary. The adapter chosen for the project delivers the 12 V to the PCB via a female DC jack barrel connector that is 5.5 mm x 2.1 mm. The adapter has a 2.5 amp current rating and can supply a 30 watts of power to ensure that the system will function properly. The rest of the components in the system ran at either 5 V or 3.3 V. Since there needed to be a different voltage for the rest of the system the use of a voltage regulator was necessary. For the 5 V bus, a LM7806 voltage regulator is chosen. This regulator has a max input voltage of 25 V so it is suitable to handle a 12 V input. For the ESP8266 WiFi module used in our system a 3.3 V regulator is also necessary. The regulator chosen for that is a LD1117-3.3. 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.

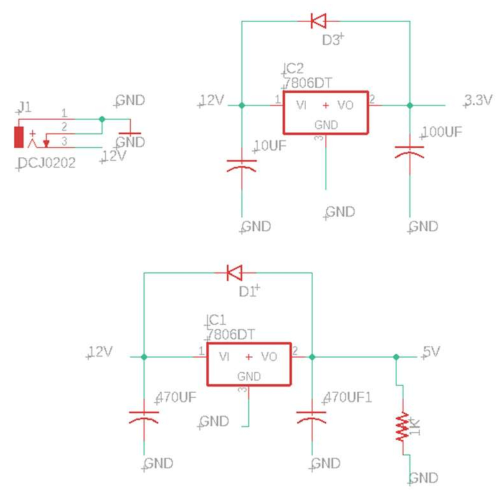

Fig. 4. Overall system power circuit designed using EAGLE.

Another element of the power design is the use of relays modules. The relay module chosen for the hydroponic system is the TONGLING 5V relay module. This relay has a 5 V trigger voltage and can handle a max DC load current of 10 A at 30/28V DC. The relays are used to turn on and off the individual water and nutrient pumps. The relays used in the system were connected using the normally open water and nutrient pumps. The relays used in the system were connected using the normally open position. Fig. 5 below shows the contact position of the relay, along with the electromagnetic coil responsible for opening and closing the contacts. The trigger time for this is 5-10 msec. This means that the when the relay is open the pump is not connected to power. When the digital pin is triggered the relay closes the connection to power allowing the pump to turn on.

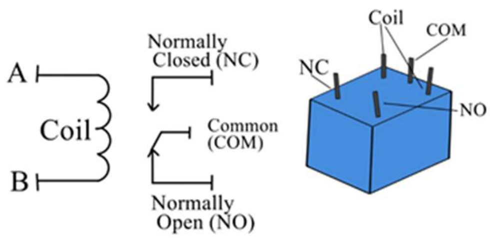

Fig. 5. Relay pin diagram.

IV. COMPONENTS SUMMARY

The hydroponics system contains parts such as sensors and pumps that are needed in order for the whole enclosure to successfully support the growth of the herbs. Below are the main components in our design.

A. Water Temperature sensor

In the watering system, the water reservoir contains a water temperature sensor to monitor any changes in water temperature. The water temperature sensor we used is the DS18B20 sensor. The sensor can measure between a temperature range of -55 degrees Celsius to 125 degrees Celsius. The sensor won't reach the extremes of this range in the water reservoir as it is unlikely the water will vary from the desired temperature range of 15 to 21 degrees Celsius. The water temperature sensor is enclosed in a stainless-steel tube that will protect it from water damage. The sensor comes attached to a plastic sheath that is long enough to place the sensor and wires to the bottom of the reservoir tank. The sensor will measure the water temperature periodically and alert the user if the water is out of the desirable range.

B. Ambient temperature/humidity sensor

In order to maintain the optimal environment for the herbs, the ambient temperature and humidity need to be measured to ensure the herbs are not experiencing negative effects of its environment. For this reason, sensors need to be used to measure these factors. The DHT22 sensor is used to measure the ambient temperature and the humidity of the enclosure. The sensor can measure temperatures from -40 to 80 degrees Celsius. It has a ± 0.5 degrees Celsius accuracy. The sensor is placed close to the herbs to accurately receive data of the herb's environment. The sensor will alert the user if it measures a temperature or humidity value that is out of the optimal range in order for the user to fix it.

C. pH sensor

As the water solution provides the herbs with nutrients, it is vital that the pH level of the water does not negatively affect the herbs' growth. The pH level affects the status of the nutrients in the water solution, as well as the ability of the plants to absorb the nutrients. If the pH level is outside of the desired range, then the nutrients may solidify and separate from the solution or the plants may not be able to absorb them properly. A pH sensor is used to measure the pH level of the nutrient solution. The sensor that is chosen is the Gaohou E-201-C. The operating temperature is -10 to 50 degrees Celsius. The sensor can measure a full pH range of 0 to 14.

The sensor will be placed in the bottom part of the enclosure and the user will manually measure the pH of the water reservoir. The ideal range for one of the nutrient solutions we will use is 6.2 to 7.0. The ideal pH range for basil, the herb that we are growing to test the project, is 5.5 to 6.5. Therefore, the ideal range to accommodate the type of herb we are growing and nutrient solution we are using is 6.2-6.5.

D. Lights

For the grow lights themselves, strips of LEDs are used. LEDs are energy efficient, long lasting, and readily available, making them the ideal choice for this project. The LEDs used are of the type WS2812b with waterproof level IP65, so each LED is individually addressable and the lights are well protected again any water they might come into contact with if there is an issue in the system. For herbs like the basil being grown as a part of this project, white grow lights provide the ideal crop, so the LEDs will all turn on a bright white light when indicated to by the automatic sensors or the user. [1]

E. Light sensor

The LM393 light sensing module was chosen as the light sensor to be used with our LED grow lights. This module uses a photodiode that senses the light intensity in the surrounding environment. The LM393 sensor has an operating voltage of 3.3 – 5 V. The module has the ability to deliver data using an analog or digital pin. For the system we chose to read analog values from the sensor as this would allow for a threshold to be set. To get the best idea of the light intensity of the surrounding environment we chose to have a total of three light sensors on attached to the surface near the plants. Using these three sensors the data is collected and averaged. The average is then used to determine when to turn the lights on or off.

F. Water Level Sensor

As part of both the watering subsystem and the nutrient subsystem, a sensor is used to measure the amount of water in the reservoir. To measure the larger amounts of water an ultrasonic distance sensor is used. This sensor is placed above the water reservoir and measures the distance from the sensor itself to the surface of the water. This measurement, along with the known dimensions of the reservoir, is used to calculate the volume of the water in the reservoir. The volume of water is used to properly calculate how much nutrient solution needs to be added to the water. The information regarding how full the reservoir is is available to the user, and if the water level drops below 25% the user is notified that the reservoir needs to be refilled.

G. Liquid level sensor

In the nutrient solution subsystem, a liquid level sensor is used to monitor the level of nutrient solution in its reservoir. The Sukraghara liquid level sensor is used to monitor the nutrient solution. This is a resistive sensor, so it measures the level of water by measuring the resistivity between the exposed metal bars on the sensor. By doing this, it can tell where the sensor is submerged in liquid and where it is open to the air. The sensor measures liquid level with a height of up to 2 inches, and since only a small amount of solution is needed per gallon of water the nutrient reservoir is less than 2 inches tall so the sensor is sufficient.

The liquid level sensor will measure the height of the nutrient solution periodically to ensure the nutrient solution reservoir will never be empty. If the solution level is below a designated threshold of about 25% maximum capacity, the user will be notified that the compartment must be refilled. This prevents the system from running for an extended period of time without the proper nutrients in the water, which could lead to the plants wilting or dying.

H. Water pump

The water pump serves as one of the most important components in the water system. This helps provide the herbs with nutrient-rich water. The water pump chosen for the project is Mountain Ark 12V Submersible water pump. This pump has a flow rate of 63 gallons per hour and runs on 12 volts. The water pump is submersed at all times where one end is connected to the tubing that will reach the herbs. The pump works alongside the soil moisture sensor to provide water to the plants when it is needed. This pump is controller using a relay to connect the power to a 12V input. The water pump pulls watering solution from the water reservoir, then pump the solution up to the middle portion of the enclosure through a series of clear tubes. At the end of these tubes are four drippers, which keep the water from flowing out all at once and instead regulate the flow to drip on the roots of the plants slowly. This way, the plants are not given too much more water than they need and can absorb, which prevents overwatering.

I. Nutrient pump

The nutrient pump transfers the necessary amount of nutrient solution from the nutrient compartment to the water reservoir. The peristaltic liquid pump 1150 is used for this purpose since it is ideal for precisely pumping small amounts of liquid. This level of precision is necessary for this application, since only about ¼ teaspoon of nutrient solution should be added per gallon of water in the reservoir. The system takes information measured by the water lever sensor to determine how much water is currently in the reservoir, then dispenses the required amount of nutrient solution. This pump was tested to determine the flow rate, which is about 1.34 mL/s. This information is used by the system to determine how long the pump must be on in order to dispense the necessary amount of nutrient solution as calculated using information from the water level sensor. The pump is connected to a long section of silicon tubing. One end of this tubing is placed into the nutrient compartment, while the other end is placed into the water reservoir. The peristaltic pump allows the solution to be moved accurately between the two containers without the pump actually coming into contact with the solution. This helps to prevent and possible issues that might occur if the nutrient solution were to clog up a submersible pump.

J. LCD

The Kuman TFT LCD was chosen based on the size and cost. It has a screen resolution of 480x320. The LCD provides a way for the device to communicate the state changes to the user. The screen size was big enough to provide a way to display information without compromising our budget. We modelled the setup to resemble the small screens that are seen on printers. This screen is supported by the Adafruit_GFX library and can respond to a touch input. Testing different graphic displays on the screen showed the limitations of the refresh rate when undergoing numerous state changes.

K. WiFi module

The Wi-Fi module enables the microcontroller to communicate with the user beyond the limits of their residence. The microcontroller connects to a predefined network on startup and begins the routine. The device is then able to receive requests from the web server to change the state of the device on demand. This is achieved by having the Wi-Fi module send a request to the web server across the network for any changes that need to be made. The Node MCU 12-E was used for testing based on the availability and functionality. The system itself uses the ESP8266 Wi-Fi module controlled by the microcontroller. This module features integrated TCP/IP protocol stack and extensive libraries. Upon testing, some limitations of the module were shown. Certain libraries interfered with the module connecting to a network. After adjusting some libraries and functions, the module was able to connect to a local network and the non-local web server. The remote access state change was tested when both the device and server were in the same residence as well as in two different locations with two different networks. We achieved a state change response time under 3 seconds during testing.

L. Speakers and amplifier board

Our system includes speakers to enhance the user experience and function as entertainment for the user as they care for their plants. The speakers chosen to be used in the system are manufactured by Visaton. These speakers are max rated for 5 Watts of power. They are also 4 ohm speakers. Since the speakers do not function on their own an amplifier board is needed for them to function properly. The amplifier receives the signal from the user's phone via the on board Bluetooth module and then amplifies the signal where the speakers will output the music the user is playing. The amplifier board chosen is the Icstation module which has a maximum transmission distance of 15 meters. This module uses a supply voltage of 3.7- 5V and has a power rating of 5 watts per speaker which makes it a great fit for the speakers chosen.

M. Camera

The camera module chosen for the system is the Arducam 2MP OV2640 Mini. This camera is chosen because it offers color image and is allows for video to be seen. The camera has a lower resolution but it does not affect the visibility of the images that the user sees of the plants. Another benefit of this camera is its use of SPI and I2C communications in order to function. This camera's IO ports are 5V/3.3V tolerant which is desired for the system being created. This camera was also chosen as it had an affordable price which was a major deciding factor in this project as it is self funded by the group members.

N. PCB

In order to control the system a printed circuit board (PCB) was designed. The PCB includes the Atmega2560 microcontroller, a voltage regulating circuit, indication LEDs and the pin headers to attach all of the system components. The PCB was designed using EAGLE and was manufactured by JLCPCB. The footprint of the PCB is 100 mm x 100 mm. It is a two layer board with a 12 V input that is used to power the pumps that is then regulated to 5 V to power the rest of the board and system. A layout of the PCB can be seeing in Fig. 6. The first layer of the board can be seen by the red traces, while the second layer can be seen by the blue traces on the board. The positions of the sensor headers may be rearranged to allow for a more compact PCB design and shorter wires being used in the overall system assembly. An effort was made to minimize the length of the traces by arranging the components closely whenever possible. By having shorter traces this helps to reduce 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.

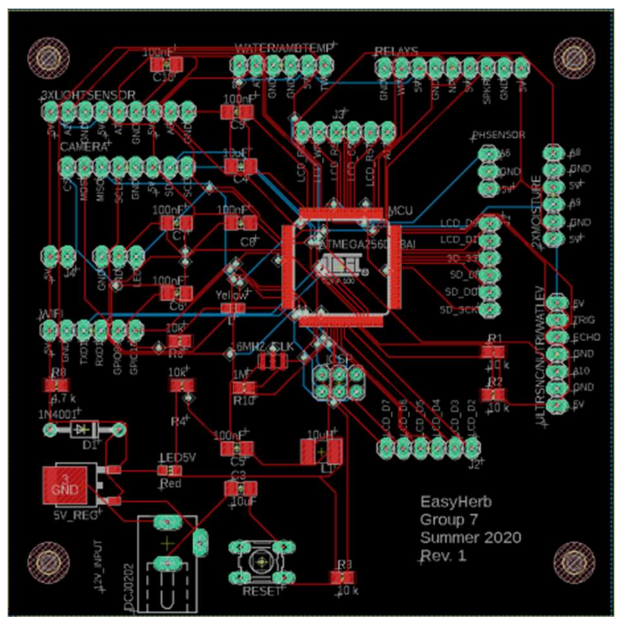

Fig. 6. Project PCB layout.

O. Microcontroller

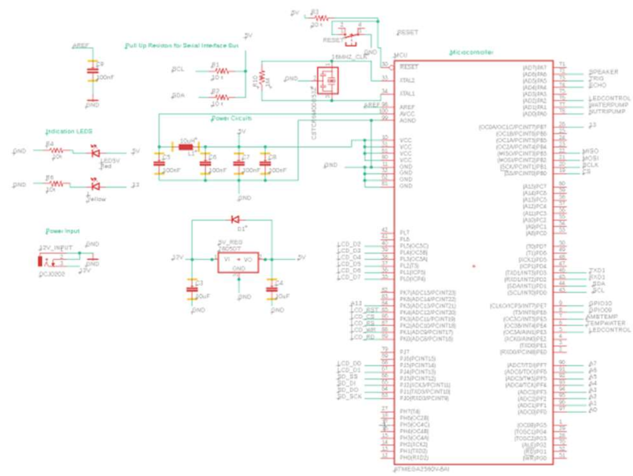

Fig. 7. Microcontroller pinouts.

The microcontroller that was chosen 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. Fig 7. Shows the microcontroller connections that were used to connect the sensors used in the system. 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.

P. Moisture Sensor

A moisture sensor was used to determine when the plants have enough water and when they are in need of watering. The moisture sensor chosen for the system is manufactured by Parallax. This moisture sensor has an operating voltage of 2V- 5V and can output analog values. This moisture sensor has a small footprint of 20.0mm x51.0mm that allows for it to fit inside the planter. When testing this soil sensor it reads a value of zero when it is completely dry and when the sensor is completely wet it reads a value of 3900.

V. SOFTWARE INTERFACE

A. Webserver

In order to achieve remote access for the device, a web server was created for EasyHerb. This web server holds the state of the system as well as sensor measurements. A user can access this web server and change the state of certain subsystems. When a user inputs a state change for their device, the web server updates that change accordingly. The device can then initiate that change upon receiving the state data across the network. Running the system as well as the web server on the same device does not accurately reflect how a consumer remote access device operates. Moving the device to a different Wi-Fi network would require the user to go into their ISP settings to port forward the server. For this project, a web server was created, and hosted on a separate wi-fi module setup by a group member. This web server runs the JavaScript and html code. Since only the web server is port forwarded, the EasyHerb device can be connected to any network and connect to the server with no additional port forwarding required by the user.

B. Data Storage

The device keeps the recorded sensor values of the device and sends them to the web server. That data can then be displayed on the web server or phone app. The web server displays some statistics of the device as a graph so that users can understand the data from a different perspective.

C. App

An iOS app was created to enhance user experience and usability. This app utilizes the EasyHerb web server backend to achieve the same functionality in a well-known wrapper. The user can change the state of the device as well as view the current statistics remotely. If the user does not have access to the app, a web browser may be used. The app was created using XCode and loaded on a group member's iPhone X for testing. The state change initiated by the app reflected the same response time of less than 3 seconds on the device.

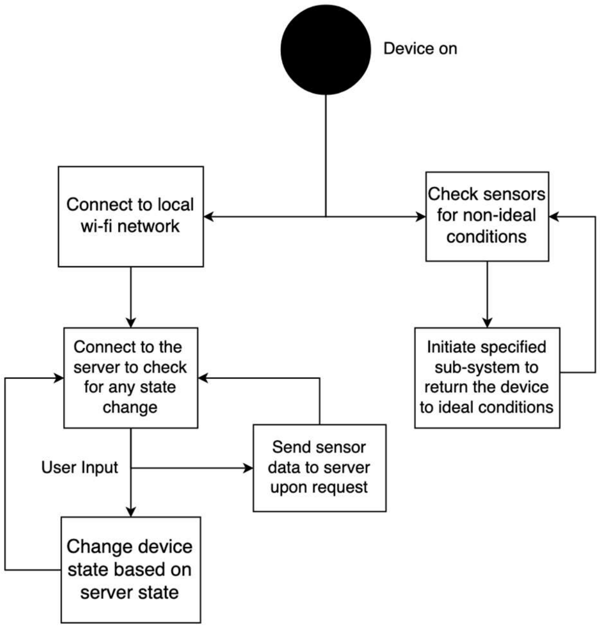

Fig. 8. Software flowchart.

VI. Conclusion

This project has been great experience for us. Having a long-term goal and seeing our project grow from inception to completion due to our hard work has been very rewarding. This two-semester project displayed a lot of real-world factors and challenges that we may face in the workforce. Each stage of Senior Design taught many lessons about the changes that a system undergoes. The initial design of our system went through modifications and adjustments to fulfill the engineering requirements for the device. The Covid-19 pandemic caused a lot of additional challenges that our group, as well as many others, faced. Despite these challenges, our group managed to adapt to the changing environments and restrictions put forth.

VII. Acknowledgements

Our group would like to acknowledge all of our professors, mentors, and peers who have taught us so much and helped us to reach this level in our education. We are thankful for everything we have learned from you for enabling us to do this project, and for all the guidance we have received over the course of this project.

IX. Engineers

Luna Vazquez is a baccalaureate student in Electrical Engineering at the University of Central Florida. Her interests include power distribution and embedded systems. Upon graduation she plans to pursue a career as an electrical engineer in protection and control at Black and Veatch.

Lindsey Feldman is a baccalaureate student in Electrical Engineering at the University of Central Florida. She is interested in power and renewable energy. Upon graduating, she will begin her career as an electrical engineer in power distribution with Black and Veatch.

Chris Hernandez is a baccalaureate student in Electrical Engineering at the University of Central Florida. He is passionate about power distribution and nuclear energy. After graduation, he will become a systems engineer at Exelon Generation in Illinois at one of their nuclear power plants.

Kyle Patrick Magboo is a baccalaureate student in Computer Engineering at the University of Central Florida. He currently works as a Software Engineer for nScrypt, an industrial micro dispensing and Direct digital manufacturing tech company. After graduation, he plans to continue working at nScrypt as a full-time Software Engineer.

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[1] Loughrin, John H., and Michael J. Kasperbauer. "Light Reflected from Colored Mulches Affects Aroma and Phenol Content of Sweet Basil (Ocimum BasilicumL.) Leaves." Journal of Agricultural and Food Chemistry, vol. 49, no. 3, 2001, pp. 1331–1335., doi:10.1021/jf0012648.