Stem’n’Leaf
Modular Hydroponics

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Abstract - The overall goal of this project is to create a self-monitoring and modular hydroponics system. The system will have hardware and software components that work together to allow for the growth of a plant while being able to check it’s status through the internet on a laptop or other smart device. In order to create and monitor an environment sustaining growth, our hydroponics system will be modular with two main hardware components: a control unit and plant unit. These two components will contain various sensors that communicate data to the software components. The software components that will supplement the hydroponics system that consist of a website, mobile application, database storage, a webserver, and microcontroller processes.

Index terms - Central Unit, Garden Pod, Microcontroller, WiFi Module, Bluetooth Module, Temperature and Humidity Sensor, pH probe, Water Level Sensor, TDS Sensor, Hardware Design, Web Stack, Database

I. INTRODUCTION

In this day and age, We are more aware of our impact on our environment. Sustainability and Conservation has seen a steady rise in popularity. However, despite our technological advancements in sustainability, our agricultural system has been lagging on this front. Indoor Hydroponic agriculture has the potential to revolutionize the farming industry and produce many more times the yield than traditional farming methods. To grow the same amount of vegetation, indoor hydroponic systems;

- Require less water usage
- Use less space
- Do not need pesticides
- Optimize plant nutrition
- Grown in any region

We are still a long way from modernizing this industry. Fortunately, hydroponics is easily scalable and achievable in any home.

II. PROJECT GOALS

Our objective is to design the groundwork for a modular hydroponic system which is fully automated, can fit in any home, and scalable to any size, but most importantly put fresh produce in the hands of any consumer.

Most hydroponic systems on the market are expensive and large scale, and most DIY versions of hydroponic systems require a large sum of installation. What sets our hydroponic system apart from other designs is the modular concept. One of our biggest challenges in creating a compact, modular hydroponic system is balancing size and plant yield. We strived to make our structure small enough to be handled by the average sized person, but also have sufficient space to grow plants and host all the supporting electronics. Another pillar of our design process is making an automated, user-friendly experience that requires little effort or knowledge of gardening. All these factors were considered while considering keeping expenses to a minimum. Through this experience we hope to gain more insight on;

- System level design
- Software integration
- Hardware design
- Engineering team management

- PCB design/ Manufacturing

III. LIFE SUPPORT SYSTEM DESIGN

On the surface, Cultivating plants may seem as simple as giving plants water and light but there are so many more factors at play. To make our system as effective as possible we made sure to consider as many details as possible, when it came to nurture the plants. In light of this, we took extra care in considering our lighting and irrigation options.

A. Hydroponic System design

One of our main goals of this design is efficiency. Given the modular nature of the system and the fact that the growing chamber is partly battery operated, we wanted to ensure our system would draw as little power as possible. Consequently, we choose to adopt the ebb and flow method.

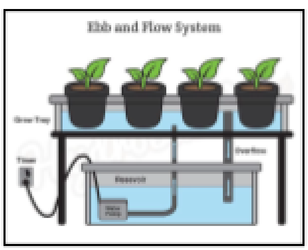


Figure 3-23: Ebb and Flow System

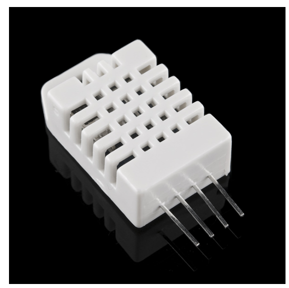
This system utilizes a combination of passive and active watering. The central unit will fill the growth chamber with water until it is full, the roots of the plants are then submerged in standing water. If the water is depleted to a certain level or the water needs rebalancing, the growing chamber can be returned to the central unit for a water exchange. The central unit houses a water reservoir, ph solutions, and nutrient solution, which are mixed together into water which is fed to the plants.

B. Lighting System design

Lighting an indoor garden has little to do with brightness or color, and more to do with light spectrum. To provide the proper PPFD levels appropriate for photosynthesis to occur, we selected an LED array which could emit light in the UV and IR spectrum. The intensity of this LED array will be adjustable to accommodate a wide variety of plants and be controlled by a timer.

C. Temperature and Humidity

The temperature and humidity will be monitored by the same sensor. In this case the temperature and humidity sensor we will be using is the RHT03, also known as the DHT-22.

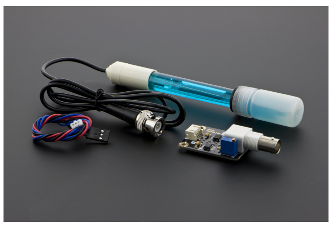


For plants to effectively grow the level of humidity and temperature has to be measured closely in the system. The temperature should be at least 60-70 fahrenheit. To maintain this we will be using combined user knowledge and a fan. To maintain it automatically the fan will do its best to circulate the system and prevent heat buildup. If that is not enough, the user will have access to this sensor data via the application or website. They will be able to move the system to a more apt growing location to better facilitate the health of the plants.

The humidity of the system is monitored by the same sensor and recorded in percentage based on the surrounding air. Depending on the growth stage of the plant the humidity that the plant needs changes. At the seedling stage a plant requires lots of humidity and in pots the top will be sealed to give the plant more humidity. In the hydroponics system these plants are no longer seeds so the humidity they will need is around 50-60 percent. This can be controlled by circulating the air with the fan to decrease the humidity in the system.

D. PH Probe

The pH probe will be located in the reservoir. This proof is necessary to balance the water located in the reservoir. PH of water is important for plants, without the right pH a plant will die in the water very quickly. In this project we decided on using the gravity analog pH sensor from DFRobot.

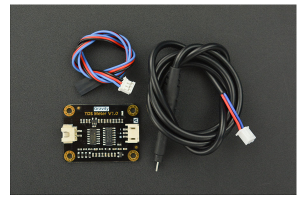


This sensor measures the pH of water that it is in and outputs an analog signal that can be read via the analog pins of the arduino. This pH sensor reads values from 1 to 14, 1 being the most acidic and 14 being the most basic. These measurements are taken to the hundredths degree of precision. Most plants require a pH of water that is slightly acidic, falling into the 4.5-6 range on the pH scale.

The pH of the reservoir as a whole needs to be balanced accurately in order to send water to the pod that is good for the plant. This is done using a set of two pumps and two different solutions. The solutions being ph up and ph down. These solutions are automatically inserted into the water supply when the pH sensor measures that the pH of the water is too low or too high. The user also has access to this information via the application or the website.

E. TDS Sensor

A TDS sensor is a device that measures the total dissolved solids(TDS) in a certain body of water. The sensor works by passing an electrical current through water and measuring the resistance of that water. Using these values we are able to calculate the TDS in parts per million(PPM) of the water. The TDS sensor that we use is called the Gravity: Analog TDS Sensor from DFRobot.



This sensor will accurately and affordably measure the TDS of the water in our reservoir. Measuring the TDS of our water is important in calculating how much nutrients are currently in the water and subsequently how much will need to be added. Nutrients are one of the most important things in a hydroponics system. A plant requires a certain amount of nutrients to be absorbed through the roots in order for it to grow. With hydroponics we are able to accurately pinpoint just how much hydroponics we are giving the plant. Doing this yields a bigger harvest and a healthier plant.

The nutrients of the reservoir will be managed with a pump and a nutrient rich solution. The TDS sensor will measure the TDS of the reservoir's water. An ideal TDS for herbs, which is the main plant we focus on, is around 600-700 PPM. If the TDS is too low a pump will be automatically turned on to increase the nutrients in the water. The user will also be able to see the TDS value on their application or website. When water is added back into the reservoir it will be filtered so the TDS is lower when added back into the water supply. This is to limit unsavory contaminants from entering the reservoirs water supply.

F. Water Level Sensor

The water level sensor is one of the more simple sensors that we use in our project. The water level sensor is pretty self explanatory in the fact that it measures the level of water in the pod. To know how much water is in the pod is important to us since we need to be able to not only accurately fill up the pod with a certain amount of water but also know when the water is below a certain level and when it needs to be replaced or topped off. The water level sensor we are using is the CQRobot Ocean: Water/Liquid Level Sensor.

This sensor works by checking if there is water behind our clear acrylic surface. When the pump fills the pod, it fills it to a certain level, dictated by this sensor. Once the pod is full the sensor remains reading the same level of water until it dips below the water level sensor for a predetermined amount of time. Once this happens the user will be able to see on their application or website that the water is low and will need to be changed.

IV. Hardware Design

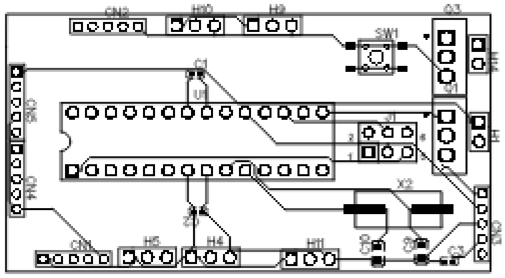
This Hydroponic system is split into two separate compartments; The central unit and garden pod, each with its own microcontroller. The central unit will have an irrigation pump, peristaltic pumps, pH sensor, TDS sensor, wifi module, and bluetooth module. The garden unit will have a temperature/humidity sensor, water level sensor, LED grow light, axial fan, and bluetooth module.

There will be two microcontrollers used to operate the system. These two separate microcontrollers will communicate wirelessly over bluetooth, while the central unit will have wifi capabilities and transfer data to a web application. For this system, we will use one Raspberry Pi and an Atmega382P-PU.

A. Control System

The central unit of the tank will need a relatively strong controller. The easiest answer to this problem is a small computer. Since we will need Bluetooth components, Wi-Fi components, and logic it makes sense to have a small computer inside the central unit. The most common and easily accessible controller we can use is a raspberry pi. A raspberry pi is a small computer that runs its own version of Linux. There are many benefits to using a raspberry pi in the central unit which will be covered in this section. The raspberry pi features a 4× ARM Cortex-A53 CPU. This is not the most powerful CPU in the world but it is good for use in our project. It has 1 GB of DDR2 RAM that runs at 900MHz. The newer versions of the raspberry pi have onboard Bluetooth and 802.11n wireless internet.

For the Garden pod, we will be incorporating the Atmega382P-PU in our PCB design. The Atmega382P-PU is easier to incorporate into a board and while it is not as powerful as the Raspberry Pi, The Atmega382P-PU has 32KB of In-System Self-Programmable Flash program memory and 23 Programmable I/O Lines, which will be able to support the subsystems of the PCB. The package type of the microcontroller is through-hole. To make testing more convenient and flexible, the PCB design features an IC socket so the chip can be easily transferred between the PCB and development board. Since we choose to exclude a usb-interface the microcontroller will initially be programmed on the elegoo development board.

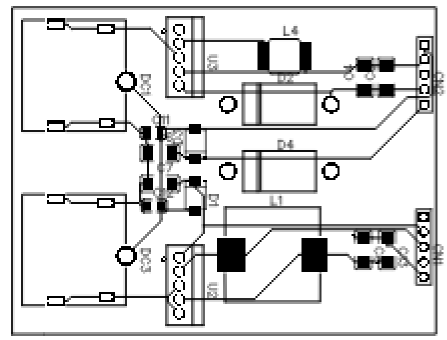


The PCB will function as break out board for the microcontroller. There will be two IRF520 mosfets which will allow us to adjust the intensity of the LED array and Axial Fan.

B. Power Supply circuit

It was essential that our system support 12V and 5V devices, The life support system runs exclusively on 12V and the monitoring system, including the microcontroller is rated at 5V. To allow our system to run at peak performance, we decided to use a 12V AC/DC converter with a maximum current of 6 amperes. Using the LM2576 as a buck converter, The 12V DC input voltage is converted to a 5V source rated at a maximum of 3 ampere. The LM2576 is more efficient voltage regulation compared to the more popular three-terminal linear regulators and provides very consistent line and load regulation while requiring few external components. The voltage regulator is equipped with a rectifier diode, at its input, to protect it from overcurrent. To stabilize the regulator, capacitors and inductors will be at the output voltage.

In the original design, we intended, but due to part selection error, we ended up with two 5V regulators. Fortunately, there was not much need for a 3.3 voltage source so we decided to exclude it.



V. Software System

This section will cover the overall software design of the system by splitting the software into the following sections: webstack, web server, website design, mobile design, and database. All of the sections will have a more detailed plan, considerations, and designs to give a better overview for the software aspect of our project. The overall software design is for the physical hydroponics system to communicate and connect with the website using the WiFi module. Then the database will be updated with any recent sensor information from the garden pod.

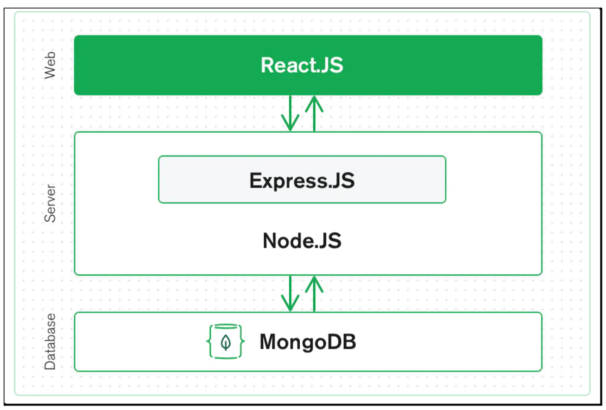
Authentication features including login and registration were included to provide a track record of the users accessing the page.

A recipe functionality was also included to allow more versatility with the software applications. The goal was to have future planning and use of the grown plant within the same application. This recipe search function utilizes the EDAMAM recipe search api [1] that allows the user to access 2.3 million recipes.

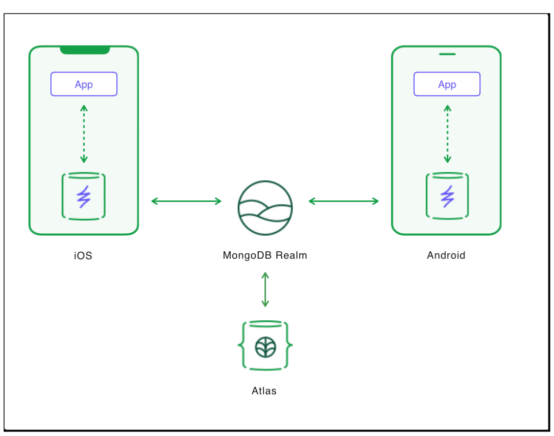
A. Web Stack

In creating dynamic software applications we had design considerations on the frontend and backend technologies. The mobile app and website were both developed with ease of compatibility in mind so the implementation of the MERN stack was utilized to provide full stack functionality. Our frontend, being the view that the user views, was built with React.js for the website and React Native for the mobile app. Node.js and Express.js created the web framework and javascript web server that powered our website.

The picture below demonstrates how each technology of our webstack interacts to realize our software designs.

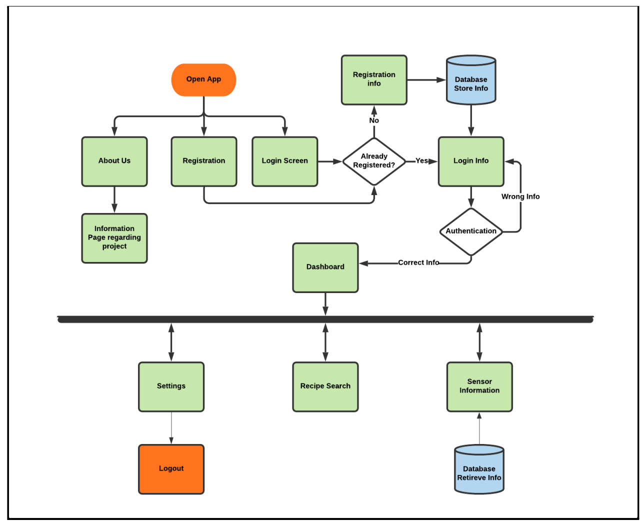


Our mobile app was built using a serverless application within MongoDB Realm that provides the same functionality as a server based website. The picture below demonstrates how each technology of our webstack for our mobile app interacts to realize our software designs.We built the app with Android in mind due to familiarity of implementation.



B. Website Design

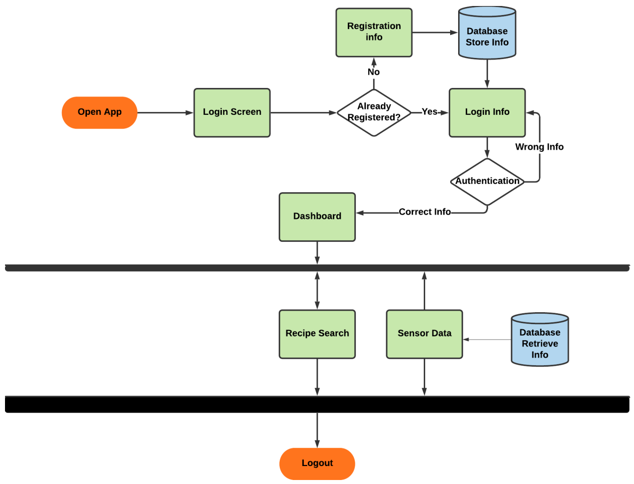
The first step in designing the website was creating a flowchart for how the user interacts and uses the application. The picture below demonstrates the flowchart logic of a user interacting with the website named Hydroponics Guider.



The web pages allow the user to interact with settings for their account, a recipe search api page, and a pod sensor data page. The page is set up so that only authorized logins are allowed and users can only sensor data. The user either creates an account or provides already established login credentials to enter the website. From there the user will be created with a welcome screen and basic information on how to use the website. Navigating to other pages within the app requires interaction with the sidebar menu on the top right that will allow page navigation to any pages desired.

C. Mobile Design

The picture below demonstrates the flowchart logic of a user interacting with the Mobile App called Hydroponics Helper.



The user either creates an account or provides already established login credentials to enter the mobile app. From there the user will be created with a welcome screen and basic information on how to use the app. Navigation is the same as the website except logout functionality is available throughout the entire app and allows for unique touch swipe functionality to change screens.

D. Database

A crucial component in storing sensor and user data is with a well structured database. The NoSQL Mongo database is what makes this system accessible for the website and mobile application. The current database uses several different tables to store user and sensor data. This design lets the database to be extremely robust and scalable.

The database for this system was built with NoSQL in Mongodb and Mongodb Realm. The database is designed to be simple in its design and the group will try to remove any third-party processes that may be needed to maintain data verification. MongoDB stores and authenticates users in the same service. Below demonstrates the basic database entity relation diagram;

User	
Data	Page Key
Name	
Email	
Password	

Sensors	
Data	Page key
pH	
tds	
temperature	
light_level	
water_level	
humidity	

VI. Cost Analysis

Item	Supplier	Price/Unit		Units	Total Cost	
Axial Fan	Amazon	$	12.99	1	$	12.99
Water Level Sensor	CQ-Robot	$	21.99	1	$	21.99
Temperature/Humidity Sensor	Amazon	$	6.49	1	$	6.49
UV LED Grow Light Strip	Amazon	$	19.99	1	$	19.99
HC-05 Bluetooth Transceiver	HiLetgo	$	7.99	2	$	15.98
pH Sensor	DF-Robot	$	56.90	1	$	56.90
ATMEGA382P-PU	Amazon	$	3.30	1	$	3.30
IRF520 Mosfet	Amazon	$	1.36	4	$	5.44
TDS Sensor	CQ-Robot	$	13.99	1	$	13.99
Perstaltic Pump	Gikfun	$	10.43	3	$	31.29
Subermersible Fountain Pump	Amazon	$	10.29	1	$	10.29
Raspberry Pi	Amazon	$	59.99	1	$	59.99
12V 6800 mAH Li-ion Battery	Amazon	$	38.99	1	$	38.99
Nutrients	Amazon	$	41.28	1	$	41.28
Building Materials	-	$	165.60	1	$	165.60
PCB Assembly	JLC		$100	1	$	100.00
Sum					**$**	**604.51**

VII. Conclusion

Our modular hydroponics project has come a long way since the first discussions with many skills and knowledge built from the classes at ucf being used to implement the software and hardware. Our technical and problem solving skills were refined and expanded upon when tackling the challenges of this project. We used good communication and flexibility through the two semesters of Senior Design I and II to create the Stem'n'Leaf.

VIII. ACKNOWLEDGMENTS

Our group holds in high regard and greatly appreciates the faculty and the professors at UCF for their expertise and support through COVID and all years studying engineering.

IX. REFERENCES

[1] Edamam, “Try Edamam's new diet filter focused on COVID-19. It leverages scientific publications about nutrients and foods to promote immunity support and coping with viral infections.,” *Recipe Database, Nutrition Analysis and Food Database APIs by Edamam*. [Online]. Available: https://developer.edamam.com/?gclid=Cj0KCQjw6NmHBhD2ARIsAI3hrM2ZF7gPdzusH_j8BlObVUVQsV4LjIZj0GW1frF1IdCbYw6tT-UPvrAaAhmFEALw_wcB. [Accessed: 20-Jul-2021].

X. GROUP MEMBER BIOGRAPHIES

Adam Loree

Adam Loree is currently a senior at the University of Central Florida who is majoring in Computer Engineering with a minor in bioengineering. After college Adam hopes to go to medical school and become a doctor.

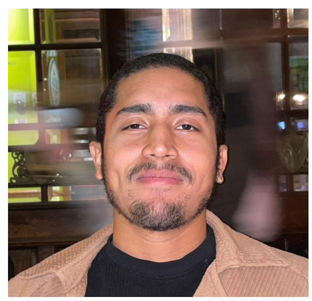
Brandon Mitchell

Brandon Mitchell is currently a senior at the University of Central Florida majoring in Computer Engineering with a minor in Aerospace studies. After graduating with a BSCpE, Brandon plans to commission as a 2nd Lieutenant in the United States Air Force.

Don Ellington

Don Ellington is currently a Senior at the University of Central Florida with plans to graduate in the Summer of 2021 with a Bachelor of Science in Computer Engineering and minor in Aerospace Studies. Don Ellington is a United States Air Force Reserve Officer Training Corps cadet and is a part of the Detachment 159 Cadet Wing at UCF. Upon completion of his degree and graduation he will gain his commission to become a 2nd Lieutenant in the United States Air Force.

Jon Rodriguez



Jon E. Rodriguez is a senior at the University of Central Florida, currently working for the L3Harris internship program in the Digital Circuit Card Assembly Department. In August of 2021, He plans on graduating with a BSEE and moving into a full-time engineering position.