LetitGrow! An Autonomous Hydroponic Garden

Leandro Alepuz, Danny Nguyen, Edwin Rivera, and Nathan To

DEPT. OF ELECTRICAL AND COMPUTER ENGINEERING, UNIVERSITY OF CENTRAL FLORIDA, ORLANDO, FLORIDA, 32816-2450

***ABSTRACT* — THE RISING POPULARITY OF GROWING YOUR OWN PRODUCE AT HOME HAS COME WITH A MAJOR HURDLE FOR USERS: THE LACK OF TIME AND BOTANICAL KNOWLEDGE. THE PRIMARY GOAL OF THIS PROJECT IS TO FREE THE USER FROM THE DAILY MUNDANE AND REPETITIVE TASKS THAT ARE REQUIRED BY PLANT GROWERS. THIS CAN BE ACHIEVED BY USING A SET OF SENSORS TO MONITOR PH, TDS, WATER LEVEL, AIR/WATER TEMPERATURE, AND HUMIDITY. VARIOUS PUMPS OVERSEE PH STABILIZERS, PLANT NUTRIENTS, AND WATER REFILLING BASED ON THRESHOLDS DETERMINED BY THE USER. ADDITIONALLY, ALL SENSOR READINGS WILL BE AVAILABLE VIA WEB-APP FOR BOTH CURRENT AND HISTORIC DATA.**

***INDEX TERMS* — HYDROPONICS, AUTOMATION, SENSORS, PUMPS, MICROCONTROLLER, WEB APPLICATION.**

I. INTRODUCTION

Plants grown in hydroponic systems are not grown in conventional soil. Instead, water serves as the substitute that will provide not only hydration, but nutrients and oxygen as well. Hydroponic systems can save up to 90% of water compared to traditional methods, while producing high yields with rapid growth. There are a great deal of different methods used for hydroponic systems that have been developed over the years. They all derive from the following basic hydroponic systems:

- Deep water culture systems (DWC)
- Wick systems
- Nutrient film technique systems (NFT)
- Ebb and flow systems
- Drip systems
- Aeroponic systems

Each type has its own set of benefits and drawbacks, but they all have the potential to incorporate some form of automation. We chose the Deep-Water Culture (DWC) technique for this project since its simplicity would be more approachable for the novice home gardener. In DWC systems, the plant's roots are directly submerged in water, which maximizes nutrient absorption. Additionally, an air pump oxygenates the water from the bottom of the reservoir through an air stone or diffuser that provides an even distribution of oxygen throughout the system. A simple representation of a DWC system is shown in Fig. 1. The desired pH and total dissolved solids (TDS) levels are determined based on the type of plants being grown and would require minimal online research to find the appropriate levels for optimal growth.

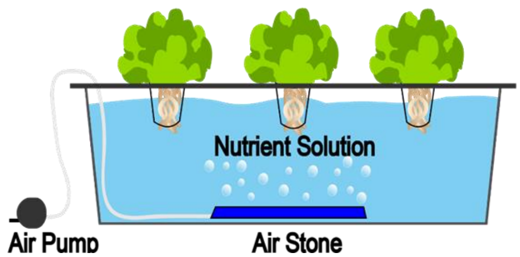

Fig. 1. Deep Water Culture Hydroponic System

II. REQUIREMENTS/SPECIFICATIONS

For our hydroponic system, our team considered the requirements for the overall product as well as the plant's immediate environment. We want to make sure that our system can fit within a typical room and is also transportable. For this reason, the grow tent being used is no larger than 3'x3'x6' and can easily be disassembled. A large variety of produce can be grown within a hydroponic system, but we chose to use romaine lettuce, spinach, cilantro, and basil since their environmental requirements are all within a similar range and are relatively easier to work with. For proof of concept, it was most important that the system can read and maintain the pH, TDS, and water levels indicated within Table 1, as well as sending an alert to the web-app when any of the measurements are not within the recommended range.

TABLE I: SYSTEM REQUIREMENTS

Requirements	Recommended Range
Water Temperature	[65-80]° F
Electrical Conductivity (EC)	[0.5-2] mS/cm
Total Dissolved Solids (TDS)	[600-1000] ppm

Requirements	Recommended Range
Water pH level	[5.0 , 7.0]
Air Quality	[800-1000] ppm of CO_2
Air Temperature	[60-90]° F
Humidity	[50-70]%
Light	HPS lights (14 hrs daily)

III. STRATEGIC COMPONENTS

The ability to monitor all the factors listed in Table 1 requires well calibrated sensors that will work in conjunction with the microcontrollers and pumps to make this project a success. The following components were the most vital in ensuring optimal growth for the plants.

A. pH Sensor

Maintaining the pH levels of a hydroponic system is important because it is what affects the availability of nutrients to the growing plants. Such deficiencies with the intake of nutrients can cause pale and/or yellowing of the leaves as well as burnt leaf tips. As such, choosing the right type of pH sensor that can handle continuous measuring on a long-term basis was required. A pH sensor by Gaohou was selected because of its relatively low cost, moderate reviews, and it already comes with an Arduino for ease of use. The key specifications of this sensor module include:

- Working current: 5-10 mA
- Detectable concentration range: 0-14 pH
- Detection liquid temperature range: 0°C - 80°C
- Working air temperature range: -10°C - 50°C
- Module size: 42mm x 32mm x 20mm

Fig. 2. pH Sensor

B. TDS Sensor

The total dissolved solids (TDS) is a measurement of the amount of nutrients within a solution. This is an important factor because if the TDS values are not within the appropriate threshold for the given plant, the roots will be unable to properly retain water. This is similar to “fertilizer burn” where the water is completely depleted from the plants and causes dehydration as well as leaf burns. A TDS sensor by Pusokei was chosen because of its low cost and reported high level of accuracy. The specifications of the signal adapter board are the following:

- Input voltage: 3.3V – 5.5V
- Output voltage: 0V – 2.3V
- Working current: 3mA – 6mA
- TDS measurement range: 0ppm – 1000ppm
- TDS measurement accuracy: +/- 10%
- Size: Approximately 42mm x 32mm

Fig. 3. TDS Sensor

C. Water Level Sensor

Maintaining an appropriate water level for the reservoir is also vital. In a DWC system, since the roots of the plants are constantly submerged in the nutrient and oxygen-rich solution, the water level will gradually drop over time. The recommended water level is to keep approximately 1.5 inches of the plant roots above the water, allowing the dry parts to absorb oxygen from its surrounding environment more efficiently. A water level sensor by CQRobot was chosen because its waterproof and already comes with an Arduino component for ease of use. The key specifications of the sensor are as follows:

- Power supply voltage: DC 5V
- Output current: 12mA
- Working temperature range: -25°C - 105°C
- Liquid level detection accuracy: +/- 0.5mm
- Approximate lifespan: 50,000 hours

Fig. 4. Water Level Sensor

D. Air Temperature/Humidity Sensor

Another factor that greatly impacts the health and growth rate of plants is the air temperature and humidity. When plants are in the process of germinating and in the beginning stages of growing their roots, a certain level of moisture in the air is required. However, with higher temperatures and humidity comes an increased risk of mold developing. There are many types of temperature/humidity sensors available on the market with varying levels of accuracy, but since our hydroponic system will be within a climate-controlled environment, an expensive sensor with high levels of accuracy is not a high priority. For this reason, the DHT11 air temperature/humidity sensor shown in Fig 5 was chosen. The key specifications of the sensor are as follows:

- Temp/Humidity Resolution: 16-bit
- Repeatability: +/- 1% RH and +/- 0.2°C
- Accuracy at 25°C: +/- 5% RH and +/- 2°C
- Power supply: DC 3.5 ~ 5.5 V
- Supply current: 0.3mA

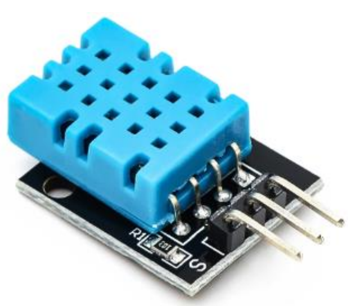

Fig. 5. Air Temperature/Humidity Sensor

E. Water Temperature Sensor

The final sensor that our system requires is a water temperature sensor. This was incorporated into our project because research has shown that maintaining an appropriate water temperature not only ensures a better level of calibration for the pH sensor, but it also allows for more accurate measurement readings of the water's pH level. The sensor by Gaohou was chosen and its key specifications are the following:

- Working voltage: 3.2 ~ 5.25V DC
- Working current: 2mA
- Resolution: 9-12 bit programmable
- Measuring range: -55°C - 110°C
- Measuring accuracy: +/- 0.5°C at -10°C - 80°C

Fig. 6. Water Temperature Sensor

F. Grow Light

A 1000-watt LED grow light made by Aidyu was chosen for our project because of its advanced full spectrum LED grow light. Research has shown that varying spectrums of light are required depending not only on the type of plant being grown, but its stage of growth as well. It also contains two cooling fans and a heat sink to act as its cooling system. This is an important factor since the grow light will be on for twelve hours or more every day.

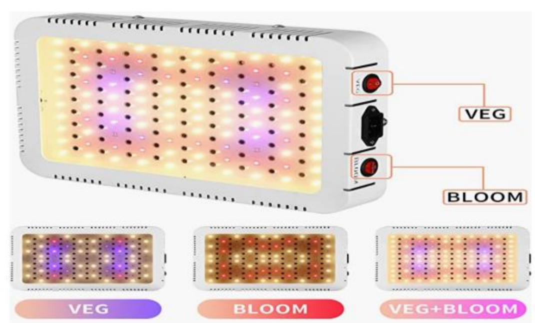

Fig. 7 Grow Light

IV. HARDWARE DESIGN

The power system diagram in Fig. 8 below represents the general idea of how we plan on organizing each of the individual components. A 15V AC to DC converter is first needed before proceeding to either the 12V or 5V DC regulators. The 12V DC regulator is meant to deliver the appropriate power to either the air and/or water pump. The 5V regulator is meant to deliver the appropriate power to the sensors being used to monitor the plant's surrounding environment as well as the nutrient and pH levels of the water solution in the reservoir. Those sensors then send their output signal to an analog to digital converter that in turn sends the final measurement results of the sensors to the microcontroller unit. The hardware diagram in Fig. 9 below represents the remaining "flow" of the other components. Notice that the hardware diagram picks up where the power system diagram left off and shows where the signals from the microcontroller unit are sent to.

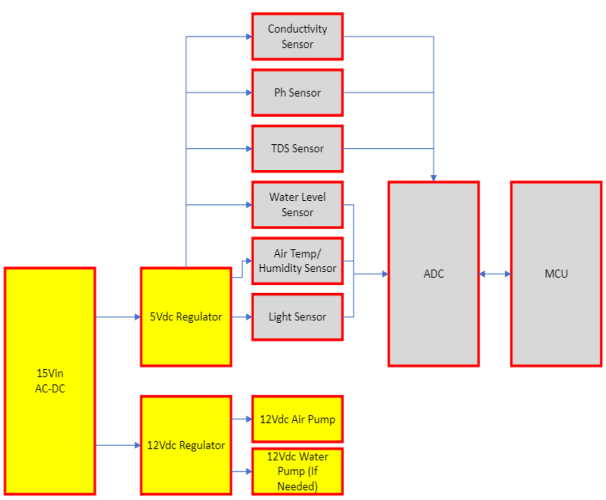

Fig. 8. Power System Diagram

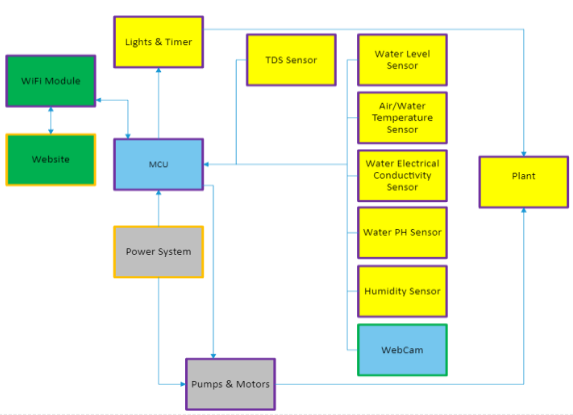

Fig. 9. Hardware Diagram

A. Central Processing Unit

Our board comes equipped with a Quad Core 1.2GHz Broadcom BCM2837 64bit CPU, which is enough to handle the workload. We believe that the most resource intensive task will be the image processing coming from the camera that will be used for detecting any plant discoloration during growth. This processor follows the ARM architecture. Additionally, it allows for core related interrupts, allowing each of the 4 cores to handle interrupts individually, which will be quite useful when trying to lower the power consumption.

B. Memory

Our microcontroller comes equipped with 1GB of SDRAM that is a low-power double data rate, which consumes less power than DDR memories. This memory will store our code, as well as our collected data before being sent to the web server. We want to ensure complete self-reliance for our system in case the web server fails. To accomplish this, the data will be stored locally inside our memory and work in redundancy with the web server as backup. The ATMEGA328 Nano's key specifications are the following:

- Architecture: AVR
- Flash memory: 32KB (2KB by Bootloader)
- SRAM: 2KB
- EEPROM: 1KB

C. Analog To Digital Converter

An AD converter is used to convert an analog signal to a digital signal so it can be read and processed by a microcontroller. Some MCUs already have built-in AD converters but the Raspberry Pi 4 B that we will be using in conjunction with our custom-made PCB does not. The ATMEGA328 microcontroller has an eight-channel analog-to-digital converter already built in and is capable of converting an analog voltage into a 10-bit number from 0 to 1023. The inputs to the ADC on the microcontroller pins have connections A0 through A7. The ADC can convert signals at an approximate rate of 15 kSPS, and the ATMEGA328 can only convert one channel at a time. The ADC circuit additionally needs to have a clock signal. The clock is generated internally from the same clock that is used to run the microcontroller. The CPU clock is too fast, so the microcontroller includes an adjustable "pre-scaler" to divide the CPU clock down to a more appropriate rate of speed. Interfacing the ADC, the software uses a group of registers.

D. Peristaltic Pump & Sensor Subsystem

The peristaltic pumps and sensors are a crucial subsystem that is meant to periodically test the chemistry of the water solution. If either the pH or total dissolved solid values do not fall within the ranges established by the user, a signal should automatically be sent from the microcontroller to the peristaltic pumps to administer the appropriate type and amount of solution to rebalance the water's chemistry. Maintaining the correct water chemistry entails dispensing minute amounts of acid to lower the pH level, base to raise the pH level, as well as two different nutrient solutions for raising the TDS value of the water. For this reason, a total of four peristaltic pumps will be required to ensure that each of the solutions are added independently from one another. When the chemistry levels are within range, it is only necessary to take a sample reading every hour as the likelihood of a drastic change occurring in less time is remote. However, once it has become necessary to rebalance the water's chemistry by adding the appropriate solution, sampling should occur every few minutes until the readings have returned to their normal levels.

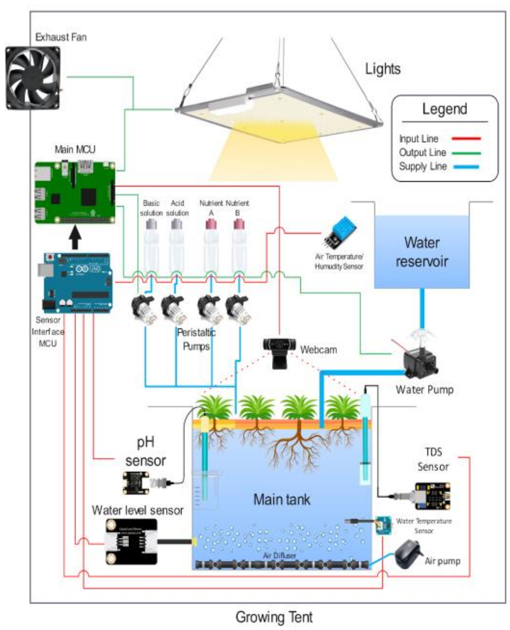

Fig. 10. Overall Hardware Design

V. SOFTWARE DESIGN

For this section, we will split the design of our system by separating it into a web stack, web server, database, UI, and website.

A. Webstack

For our application we want to focus on a dynamic website that can be accessed from both a desktop and mobile phone. The website should be able to modify itself to fit mobile screens. Additionally, each user will be able to create their own account for security reasons, modify threshold levels for the pumps, and access the sensor data as well as its history from the database. Therefore, we will be using the LAMP stack of Linux, Apache, MySQL, and PHP as our web stack. This was chosen since it is very optimal for small projects and has an easy learning curve.

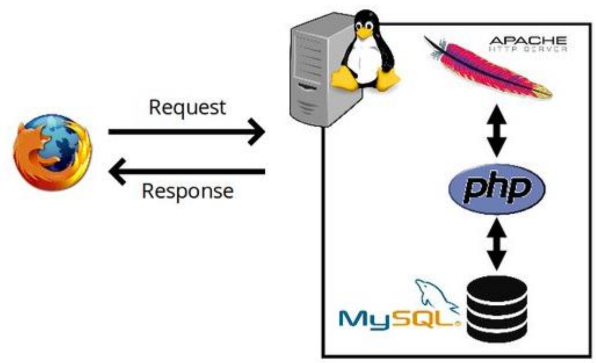

Fig. 11. LAMP Webstack

B. Web Server

Members of our group have experience with both Node.js and Apache HTTP servers, but feel more comfortable with Apache. Even though it does not offer a large amount of scalability in both vertical and horizontal scaling, we plan on having a small scale of users and gardens. This technology is also known for its wide use, having a very large community to look for support if needed. LAMP web technology has been established since the 90's, bringing many updates that have optimized the technology to make it lightweight and efficient. The speed of the code is enhanced even further by the runtime environment because it supports the non-blocking I/O operations. With the runtime environment, LAMP can process several requests concurrently. This system can handle concurrency more efficiently by modifying configuration files in both Apache and MySQL. Any incoming requests are queued up and implemented quickly and systematically.

C. Database

It was decided that our group would use MySQL to serve as our database. It was chosen because we are familiar with it from previous projects so we can quickly and easily set up its API. It's also highly scalable and able to receive a substantial amount of data. Additionally, it's already compatible with Apache servers and can be accessed through PHP functions. Fig. 12 is a simple diagram that can be applied to multiple different plants. We can create different plant profiles and scale to however many plants are required. With MySQL, we should be able to quickly search and query through the table containing all our plant data. As the diagram shows, we will be creating users with different access levels so lower end users cannot do anything that will break the system. The user table will include email, name, and passwords as well as the garden ID associated with the user. The garden ID will be used to find all the sensor data and thresholding for that specific garden. Each time we upload new sensor data, a timestamp will be created, to create a graph in the UI. The timestamps can also be used to determine if the system has lost power or connection to the internet. The user can then be notified if sensor data has not been recorded for a long period of time. A threshold table was also created to store the desired values for pH, TDS, humidity and air temperature for each of our gardens. These values can only be modified by users with admin roles, while guest roles can only see the garden data without modifying it.

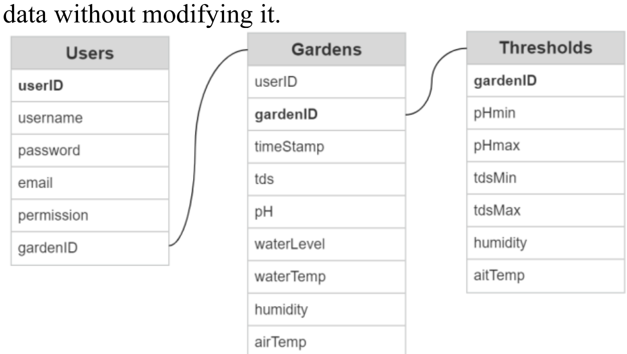

Fig. 12. Database Entity Relationship Diagram

D. Website

The URL of our website is connect-letitgrow.com. It will consist of several different pages such as the login, register, home, sensor data, webcam, profile, and plant settings. There will be a navigation pane across the top of the website with links to all the different pages. The mobile browser and the web browser should be as similar as possible, containing all the same information and access.

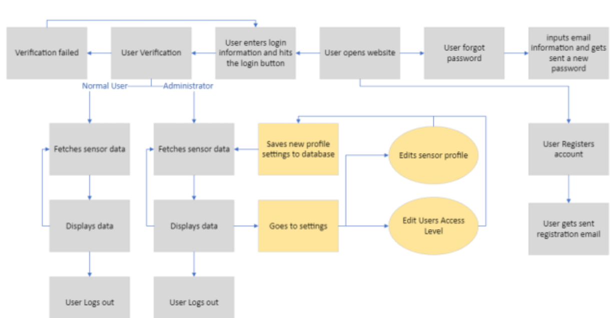

Fig. 13. Webpage Flowchart

E. Websocket

Our system will transmit data on an intermittent basis that will be determined by the circumstances. For instance, if the tank is actively balancing nutrients and pH, we want to capture data from the sensors more frequently than when the pumps are inactive. The user must then be able to look at the fluctuating parameters in the web client. This could be done by multiple requests and responses between server and client; however, this can cause many problems from the backend side. A Websocket would help maintain a constant stream of data to the server client by only having one request (handshake). Once this request is accepted, the client's connection is established. Being a full-duplex persistent connection has many advantages. For instance, after the Client sees the data coming from the sensors, they might want to change the parameters. Thanks to our two-way connection, we could also transmit data in the form of JSON for the microcontroller to pick it up and readjust the pumps.

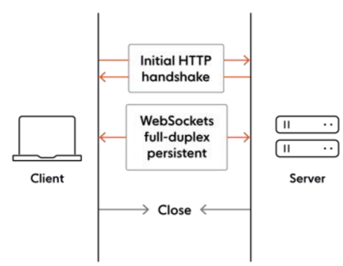

Fig. 14. Websocket

F. Printed Circuit Board

For our automated hydroponic system there will be a lot of complex subsystems that will take a lot of code. We will need to control all the hardware and transmit information in between each of them. We will need many contingencies to be able to react to as many different situations as possible. We will have many sensors and pumps we will need to control, so in order to control all these systems we will split the code into three main parts. The first will control the ATMEGA328 microcontroller that's mounted on our custom PCB, that has all the pumps and sensors connected to it. The second part will control the Raspberry Pi that will receive the data from the PCB and transmit it. The last part of the code receives data from the Raspberry Pi and moves it to the website and database backend.

VII. CONCLUSION

Our automated hydroponic system, LetitGrow, has been an enjoyable project that has taught us all how valuable it is to have a strong team of individuals to come together and see a project through from beginning to end. Throughout the entirety of the project, our technical and problem-solving skills were tested as we worked together to formulate an idea for a project and make a plan on how to execute that idea. We put our plan into action and held ourselves accountable to abiding by our own deadlines and times to meet as a team. Ultimately, the goals and objectives we set for our project were a success.

GROUP MEMBER BIOGRAPHIES

Leandro Alepuz is a Computer Engineering student graduating in Fall 2022. Born in Cuba and coming to the US at the age of 17, Leandro will be a first generation graduate. He is passionate about computer hardware, and hopes to work in embedded systems.

Danny Nguyen is an Electrical Engineer student who will be graduating in the Fall of 2022. He was born in Saigon Vietnam, he and his family escaped Vietnam when he was 5 years old on a tiny boat. It was a very dangerous journey on the Pacific Ocean. Danny will be the 1st person in his family to graduate college. Currently he works as a Senior Engineer Technician at DRS. He will be working as an Electrical Engineer at DRS after graduation. After high school, Danny Nguyen attended East Coast Aero Tech and graduated with an Airframe and Powerplant certificate.

Edwin Rivera is an electrical engineering student graduating from the University of Central Florida in the Fall semester of 2022 and was born in Bridgeport, Connecticut. His passion for electrical systems was the inspiration to join the power and renewable energy track at UCF. He hopes to work for a power company as a protection and control distribution engineer.

Nathan To is a student currently pursuing a computer engineering degree to graduate in Fall 2022 and born in Pembroke Pines Florida. He has a great love for traveling around the world, learning new things, and reading. He is skilled in programming and hopes to find a profession in software engineering in the future.

ACKNOWLEDGEMENT

The authors wish to acknowledge the assistance of the sales representatives with Advanced Circuits in Aurora, Colorado with the manufacturing of our printed circuit board. We would also like to extend our thanks to Dr. Richie, Dr. Wei, and Dr. Kar for all their assistance and guidance throughout our senior design.

REFERENCES

[1] Helmer, J. How the Coronavirus Pandemic Has Led to a Boom in Crisis Gardening. HuffPost Canada. 3 April 2020. Available Online: https://www.huffpost.com/entry/seeds-crisis-gardening-coronavirus-food_n_5e85eca0c5b6f55ebf492212 (Accessed on 20 June 2022).

[2] Brewster, M. Canadians are Being Asked to Stop Panic-Shopping. Are They Listening? CBC News. 19 March 2020. Available online: https://www.cbc.ca/news/politics/covid-19-pandemic-coronavirus-border-panic-1.5502058. (Accessed on 20 June 2022).

[3] Helmore, E. Americans Turn to Home-Farming as They Fear for Their Food Supply. The Guardian. 6 June 2020. Available online: https://www.theguardian.com/world/2020/jun/06/food-insecure-americans-are-home-farming-as-covid-wreakshavoc-on-agricultural-chain

[4] Small Scale Gardner, Deep Water Culture (DWC) Ultimate Guide: Date of Publication is not shown. Available Online: https://smallscalegardener.com/hydroponics-farming-guide/hydroponic-growing-systems/deep-water-culture-hydroponic-system/