User and Product Manual

Genius Troop

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Abstract

This document outlines the design and reviews the final prototype. It is intended to allow others to reproduce our hydroponic Vertigo and discusses future development ideas and issues that could be addressed.

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List of Acronyms

Table 1. Acronyms

Term	Acronym	Definition
Nutrient Film Technique	NFT	Hydroponics system that traditionally uses a sloped channel to channel nutrient solution to plants and then drain back into a recirculating nutrient reservoir
Standard Triangle Language	SLT	STL is a file format native to the stereolithography CAD software created by 3D systems.

Introduction

This User and Product Manual (UPM) provides the information necessary for users to effectively use the Vertigro Hydroponics system and for prototype documentation. The Vertigro waterfall hydroponics system is a vertical vegetable growing platform that uses water flowing down its internal sides to supply nutrient solution to nourish the grown produce. This modified NFT system is simple in design and operation, making maintenance minimal and not demanding much theoretical understanding of the system's functions itself. This manual will cover integral aspects regarding project background, system operation, maintenance, troubleshooting, and basic theory. After reading this manual the user will be able to empathize with the project start parameters, understand how to set up the platform, use the system itself, troubleshoot problems, and view the in-depth product part documentation.

Some safety concerns when building the Vertigro Hydroponic would be to ensure to have avoid water in the touch screen wires. Unplug the system and drain when transporting the hydroponic. To do this ensure that a good seal is used on each joint and crack. To ensure no breaking of the structure, remove each unit with two people holding each side.

Overview

The background of this project lies in servicing a non-profit indigenous organization by designing a vegetable-growing platform. The client feeds numerous groups with food being grown at various locations and was looking for a sustainable food-growing product that also provides to educate the indigenous community. This client directive is important as it highlights the issues with food scarcity and the need for development of more space-efficient and effective food-growing methods to meet the demands of larger groups in need of food. The client needs were discussed and empathetically transcribed with the system needing to be scalable, reliable, easy to use, and sufficiently productive in the produce it provides. These needs were translated into problem statements that were addressed during the design process. Those statements were that the system must be low maintenance, utilize minimal space, and be cost-efficient. Our design team brainstormed a variety of prototypes, and eventually landed on the basis which was transformed into our final design the *Vertigro* waterfall hydroponics system.

Figure 1: Final Design

The nutrient solution that is delivered to the plants is held in a reservoir contained in the base of the system, enclosed in a tank lined with insulating foam to prevent waterlogging or damage to the wood frame. A submerged water pump at the center of the reservoir delivers nutrient solution through a single vertical pipe to the top of the tower, where it is then distributed equally to flow down each of the 6 sides, nourishing the exposed plant roots held within each of the plant cups. The cycle ends with the fluid draining to the nutrient reservoir where it can be pumped through again. Nutrient fluid can be dispensed automatically, or manually into the reservoir to maintain appropriate levels, and solenoid valves automatically replace the water inside, ensuring that fresh solution is continually delivered to the plant roots.

A key feature of our product is the use of individual stackable units, with the platform supporting up to 3 units each with 18 cups each unit and a maximum of 54 cups total. These hexagonal units fit on top of the wooden base, and simply stack on top of each other using wood fittings as a guide. This variable unit stacking allows for the height of the system to be adjusted to fit whatever housing it finds itself in. Each individual unit is relatively light, as they are made of a durable foam with simple wood linings on the bottom, making them easy to remove and transport.

The most impressive feature lies in the electronic sensors and touchscreen user interface integrated with the entire system. These sensors monitor all the inner workings of the reservoir, be it measuring pH, nutrient supply, pump activity, and many more. These factors can all be controlled manually using the commands available in the touchscreen interface. Changes can be implemented automatically as well, with the standard being set again from that user interface.

This system differs from the other vertical hydroponics systems on the market in couple of ways. First, the radius of the enclosed delivery tube is much larger. Commercial designs generally implement a much narrower radius and simply pump nutrient solution straight down the entire diameter of the tube. With the design of this system delivering nutrient solution down each individual internal side, a larger diameter was implemented so that there was no crossing of the streams. This prevents any nutrient loss due to the solution being exposed to too many plants, as the flow is diverted equally over each column. The stackable unit feature is also novel when compared to most commercial alternatives. Lastly, it needs to be reiterated that the integrated automatic touchscreen system that controls the distribution of nutrient, test the pH level among other factors is the crowning feature of this system. The whole hydroponics' cost is very impressive as it is difficult to find a vertical hydroponic for 500$ that provides all these features.

Cautions & Warnings

Structural: Ensure that proper gloving is used when spreading the caulking to seal the cupholders. This is because absorption of silicone found in caulking is dangerous and will cause numbness. Avoid water damage by caulking each crevasse noticed. Properly undergo professional training and instruction in using the recommended machine tools (table saw, circular saw, and much more) or get a professional to make these cuts. Always wear safety goggles and proper clothing when in the workplace.

Delivery: When using hot glue, make sure to not touch the nozzle with your bare hands as this can cause burns. When testing the pump and piping, stand clear to avoid having the solution enter the body through any orifice (mouth, nose, eyes, etc.).

Nutrient: Avoid water contact on the electrical features of the system. DO NOT attempt to test this if you have no previous experience with electronics. The voltage being used for these electronics can be fatal if misused or if improper wiring is implemented. DO NOT WORK on the electronics while there is water in the base of the hydroponic!!! Make sure to UNPLUG the electronics from the outlet when reworking on any bugs.

Genius Troop is not responsible for any misusage by the client.

Getting started

Walkthrough of Vertigo Subsystems

Vertigro has three main subsystems; the structural system, delivery system, and nutrient system. This covers the physical structural design of the system itself, the delivery method by which nutrient solution is distributed to each individual plant, and the actual control system by which the nutrient solution is monitored, respectively.

Structural System Final

Figure 2: Structural Proto 3

The overall shape of the hydroponic is hexagonal to maximize space while allowing sunlight to get to each plant. For transportability the structural system can be separated into its separate units (max. 3) and its base nutrient reservoir. Each unit measures 20 inches high with width of 18 inches. The units are stacked upon a base that is 20 inches in height with a width of 32 inches. The platform cannot support more than 3 units as not only would it reach an inconvenient height (7 ft +), but it would also become structurally unbalanced. Each unit has slots for small cup holders for the plants alongside each side of the hexagon unit allowing for 18 plants per unit. The top and bottom serve as connection/linkage points for the delivery system being distributed through each units.

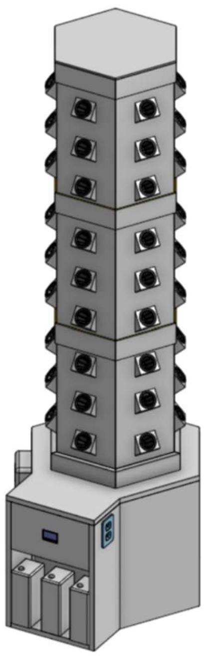


Figure 3 : Structural CAD design

Delivery System Final

The water is distributed from the base to the top of the structure through a continually running submerged pump contained at the bottom of the nutrient reservoir. The top the pipe is open ended, allowing the water to flow out onto a 3D designed water distributor plate that distributes the water equally to flow down the 6 internal sides of each unit. The water falls due to gravity making a waterfall action and sticking to the sides of each unit due to the inherent adhesive properties of water. This water delivery system is thus a modified NFT system in delivery as this system provides plants with a constant flow of oxygenated nutrient solution, just from a vertical point of view in lieu of a more gradual inclined delivery.

Figure 4: Delivery system CAD

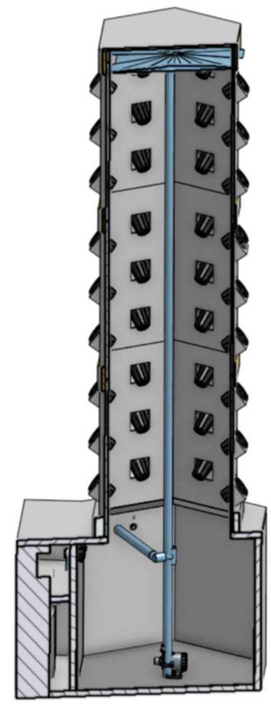


Figure 5: Water distributor CAD

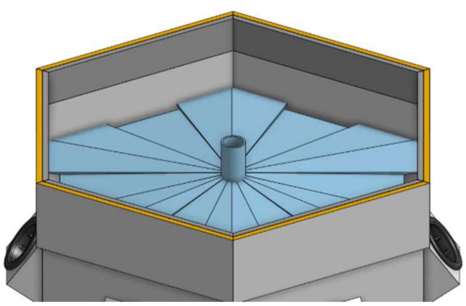


Figure 6: Water distributor Proto 3

Nutrient System Final

The nutrient system is integrated with the installed sensors and electronic components to have the capability to maintain pH levels, control water temperatures, and maintain appropriate nutrient levels. All the electronics are held in a rectangle box located at the front of the system's base. The system includes a pH probe, photosensor, and a water level sensor, all of which are connected to a Mega Arduino that controls and relays information to the touchscreen display. Based on the input of the sensor, the Arduino controls relays connected to the pumps controlling nutrient dispensing, water heating, and solenoid control (for draining and replacing the water in the system). Three containers at the base of the system contain fertiliser, a basic solution, and an acidic solution. The container contents are dispensed using the previous relays to maintain nutrient solution levels, and to control the pH using peristaltic pumps to add the solutions to the nutrient reservoir. A Touch screen located on the top of the box functions as a user interface, by which the user can manually add nutrients or set settings regarding water pH levels and nutrient content.

Figure 7: Nutrient System Home Screen

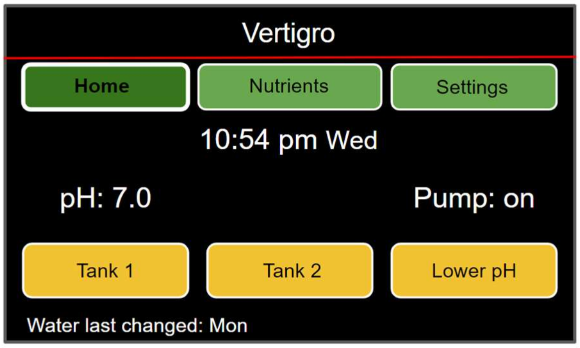


Figure 8: Nutrient System Nutrient Screen

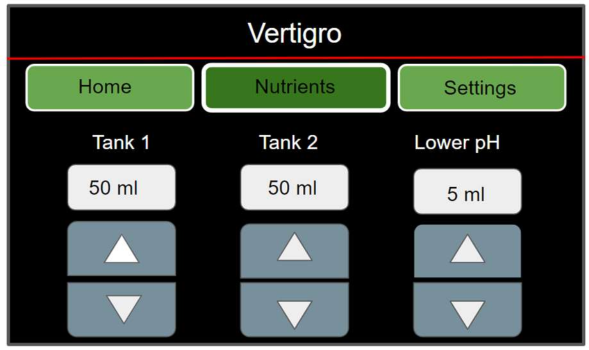


Figure 9: Nutrient System inside view Proto 3

Figure 10: Nutrient System outside view Proto 3

Video 1: Nutrient System (Demo)
Click to follow link: https://youtu.be/MbOxdRYEANE

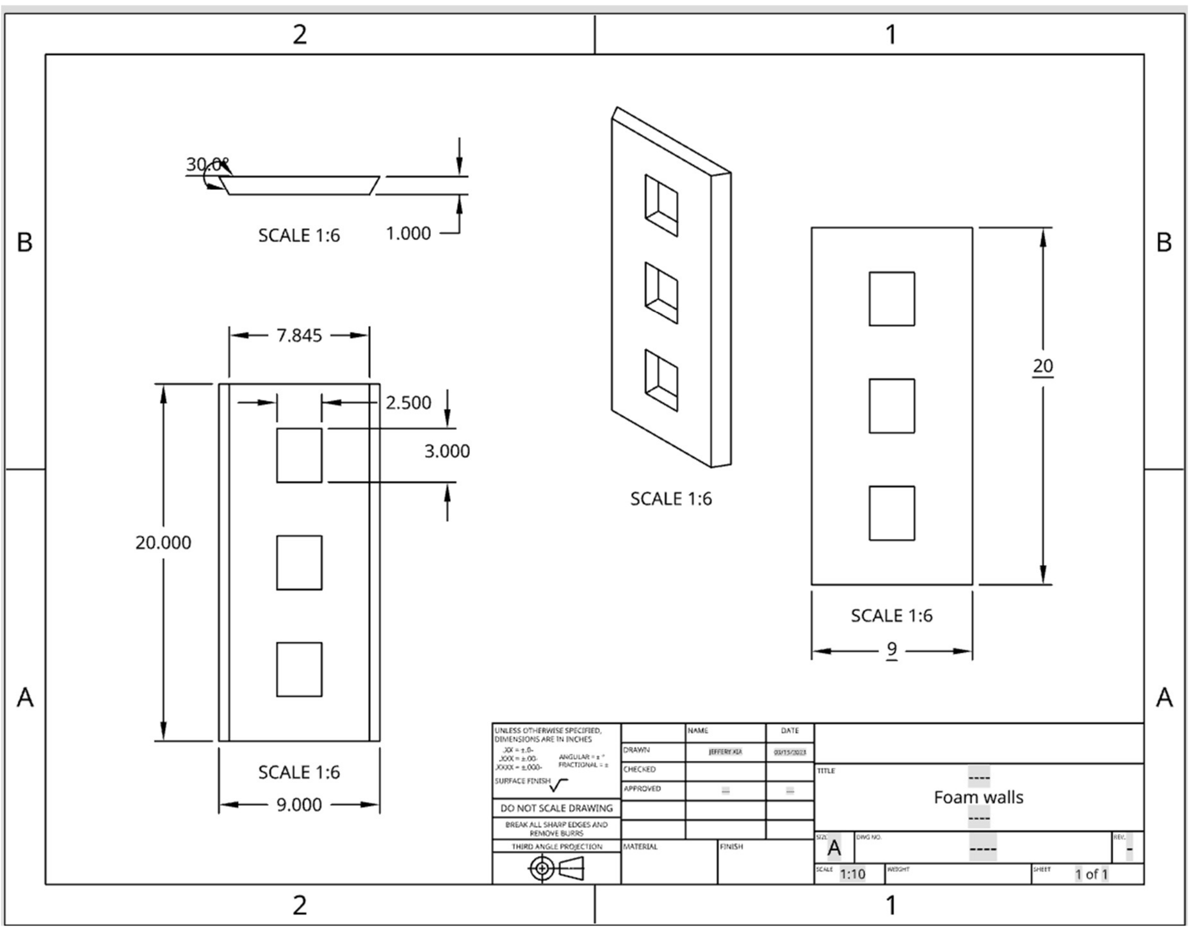
Making the Vertigro

To construct the prototype of our design vertigo we used a variety of tools and construction techniques to build the system.

Building the Structure

Building the structure starts with cutting 1-inch rigid foam into lengths of 20 inches using a table saw. Then, you set the table saw to 30-degree angle and to cut the foam lengths on the table saw and the side that is 20 inches long. Then you set the table saw to 9 inches and you cut the other side of your foam boards ensuring that the angles are both facing inward. See drawing below. Next use a utility knife to cut out the small rectangles in the panel. Next, take one of the 3D printed cup holders and mark the placement of the holes for attaching the cup holders on. Take a drill with a drill bit just slightly larger than the diameter of the cup holder and drill into the foam where you marked the holes. Note: it may be useful to stick a piece of foam behind this foam to prevent dulling your bit. It takes 6 panels to make one unit.

Figure 11: Drawing Unit Panels



After this step, take the 3D printed cup holders and stick them into the foam ensuring that they are all facing the same way and same direction. Make sure that the cup holders are protruding on the wider side of the foam (see figure below). Using a hot glue gun, hot glue the backs of the cup holders to the foam. DO NOT let the glue gun touch the foam otherwise the foam will melt. See image below for example. After letting the glue cool, take a caulking gun and spread caulking on the inside of the cup hold to waterproof the cup holder to the foam. It is easiest to use your finger to spread the caulking on the inside. CAUTION, please use gloves for your safety.

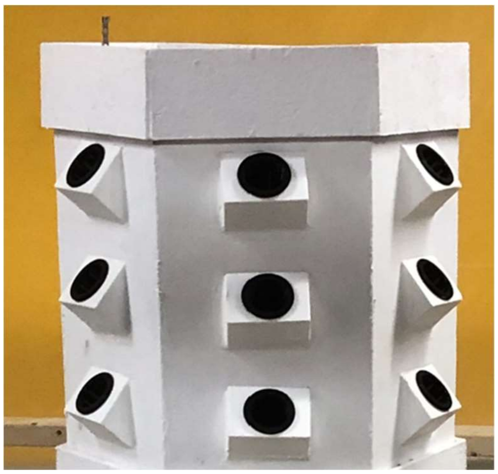
Figure 12: Gluing Cup holders

After doing this for all six sides of the unit you are ready to glue the unit together. Using a foam board adhesive spread a bead of glue on each side of the six panels then stick the sides together using a painter's tape as a clamp. Clean up any excess glue that comes out of the joints. Let the glue dry for 4 to 5 days.

Figure 13: Gluing Sides Together

Finally, take a piece of chip board and cut a strip of wood on the table saw to be 4 inches wide. Then, set your miter saw to a 30-degree angle and cut the wood pieces to a length of 9 inches on the inside angle. The wood should fit on the outside of the hexagon. Once you have six pieces of wood you can glue them onto the top of your unit. Only glue 2 inches of the wood onto the unit since the wood is acting as the joint between units. To hold the wood, use a glue gun and apply a small amount of glue to the top of the unit just to prevent the wood from slipping as the glue dries.

Figure 14: Gluing Wood Joints



Finally, paint the unit with primer then a few coats of regular paint. You may customize your hydroponic by adding any exterior designs using paint. Make sure to add caulking to fill any cracks or any place where water might leak. After this you will have made a unit for the system.

To make the base you will take a sheet of 4 x 8 ft chip board and cut the board into length of 20 inches along the 8 ft side. Then set the table saw to a 30-degree cut angle and cut each the previous board that you have already cut. Then set the guide rail of the table saw to a 30-degree cut that allows for the front side of your board to be 12 inches in width. Repeat this step for all six boards. After completing this take a 2x4 board and set the miter saw to 30-degree angle and cut up the 2x4 so that you have a 2-inch block that has a 30-degree cut. Make 12 of these little blocks.

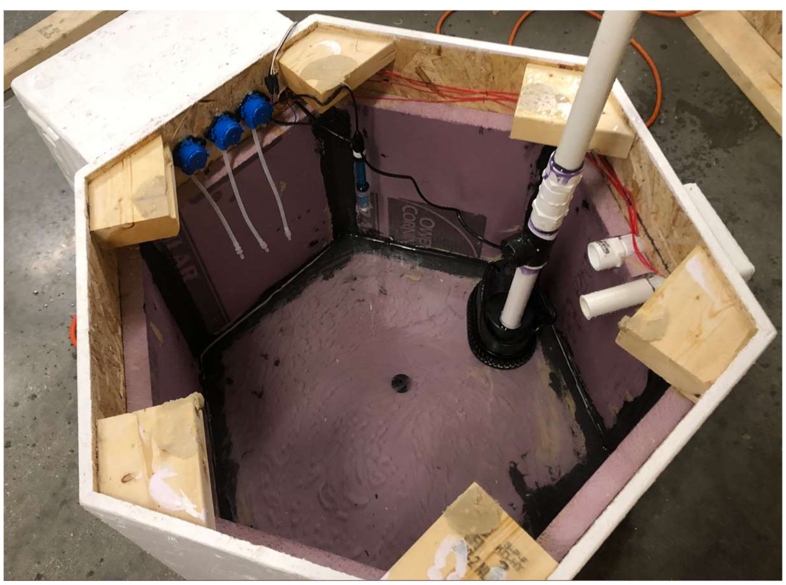
With a companion, get them to hold two of the wood boards together while you screw these boards into the wooden blocks that you make to hold the box together. It is important that the wood blocks are offset by the thickness of the chip board that you are using to allow for a flush appearance of the final product.

To assemble the nutrient box onto the base, set your table saw to a 90-degree cut (right angle) and a width of 7 inches. Then, cut a piece of wood to that thickness. Using a miter saw, cut two lengths of wood approximately 20 inches of chipboard. Then cut four pieces to 11.5 inches. After this, take your 2x4 and cut some small blocks to screw these pieces together or you can use brackets to secure them together. Assemble the pieces and attach them to the base.

Figure 15: Assembled Base

Next you need to take your new foam and cut it into a height of 17 inches. Then make 30-degree angled cuts so that the foam will fit into the wooden base that you previously made. Using the gluing techniques that you used for making the units glue the foam into the base.

Figure 16: Inside View of Base



Finally, you need to cut a piece of wood for the top of your base. Simply set your based on a piece of wood and trace the outside of your base. Then offset your trace by the thickness of your chipboard. Using a circular saw carefully cut out your outline. Next, center one of your units onto the middle of your top pieces and trace the inside of the unit. This will give you the hole dimensions for allowing the water to flow back to the base. Use a vibrating saw to cut out the inside of your top plate.

Finally, paint everything with primer and paint and seal anything that is not watertight. If you base is leaking water, you can apply a flex paste to the leaking point to stop the leak.

Assembling the pump

To assemble the pump, simply place the pump in the middle of the base and find the pump connector that fits the dimension of your pipe. Then using a PVC glue attach the connector to the end of your pipe. Then, simply cut the pipe to your desired height. If you want to get fancy, you can add connectors between each unit to allow changes if you have only one unit or three. Also, you need to add a T connector at the base and run a pipe to the side of the base to allow for the out pump.

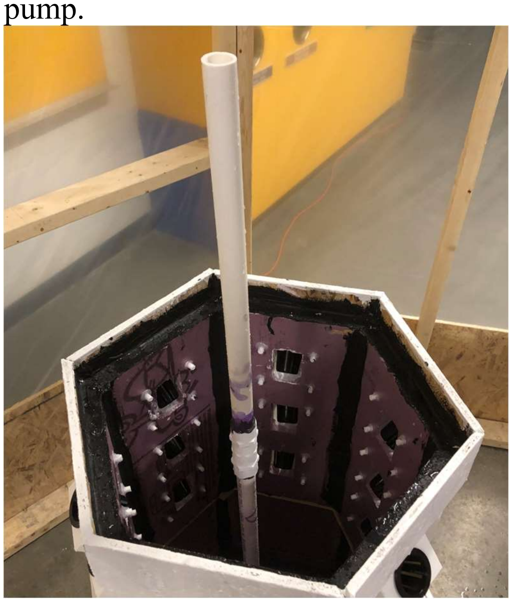


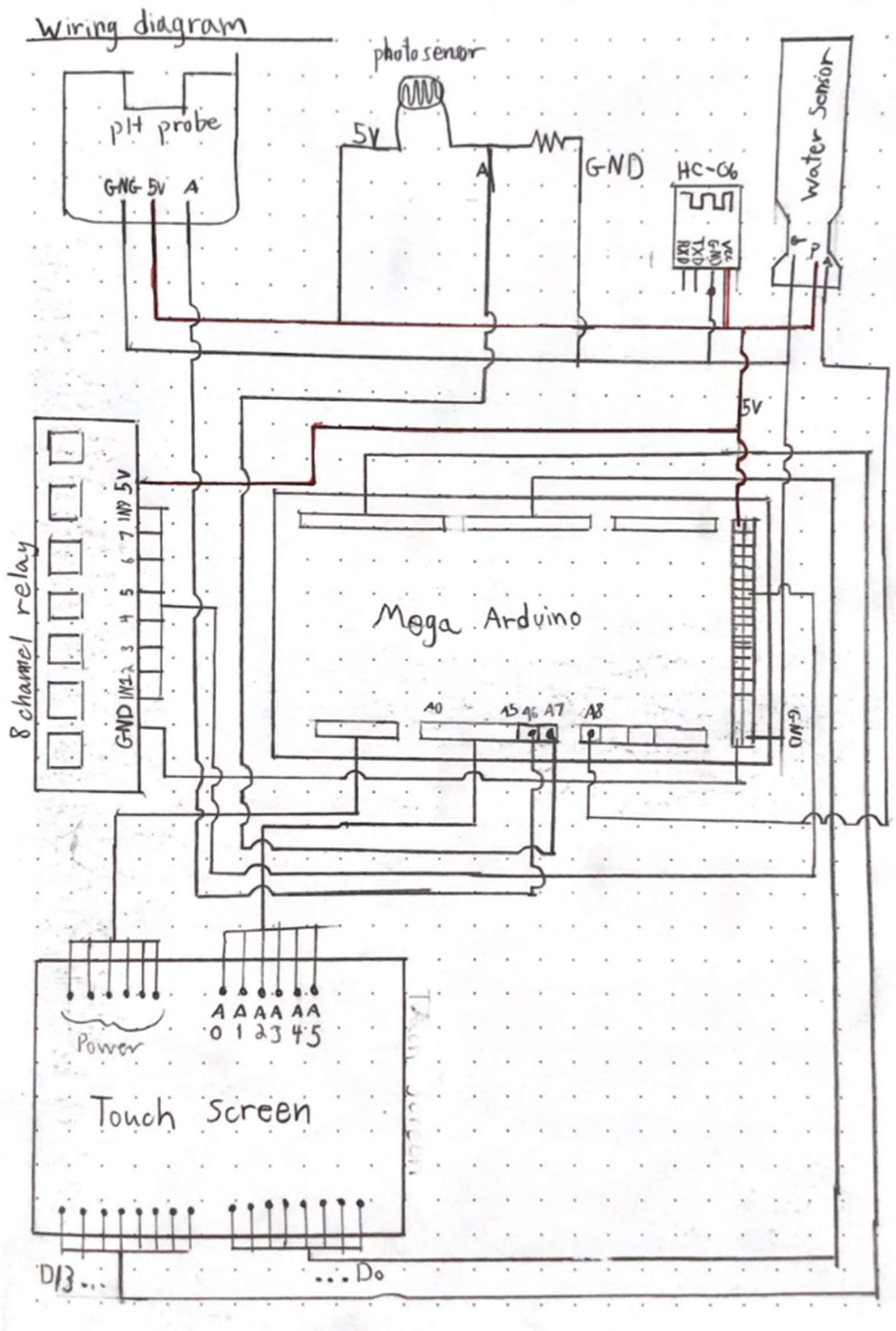
Figure 17: Pump Connected to Pipe

Figure 18: Pipe Extension for Adding Unit

Assembling Electronics

To assemble the electronics, you should first start with the program and wiring of the Arduino. Basic knowledge of working with an Arduino will be required for this part of the design. Start by connecting all the sensors, relay, and touch screen pins to the Arduino by following the wiring diagram below. You will need a breadboard to wire the photosensor and connect all the sensors to power. There is a touchscreen plate that you can 3D print to allow for support of the touch screen while being used.

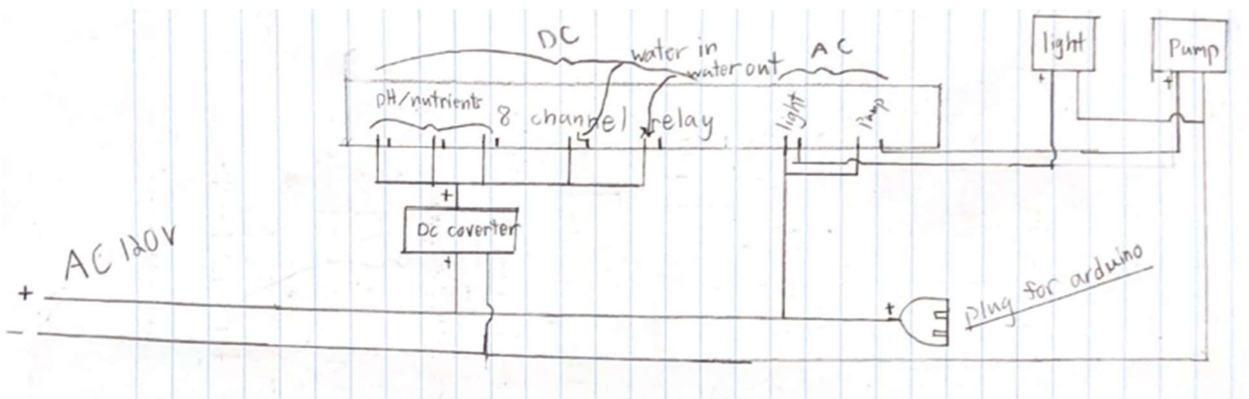
Figure 19: Wiring Diagram Arduino



After the wiring is complete download the Arduino code from the maker repo portfolio and open it on the Arduino IDE. Connect the Arduino to your computer and upload the code. Test the code and fix any bugs or wiring problems if you find any issues with your Arduino.

Next, you wire the AC into the system. Following the diagram below you split the AC power into separate power sources. One for the DC converter another for running the pump and light switch and the final one for powering the Arduino. All connections should be soldered, and this step should be done in the nutrient box since once you have wired everything it will be impossible to put the wires into the box. When doing the wiring make sure that when you cut holes to allow the wires that you do not cut the holes in a place that will allow water to get to the electronics.

Figure 20: Wiring Diagram AC Power



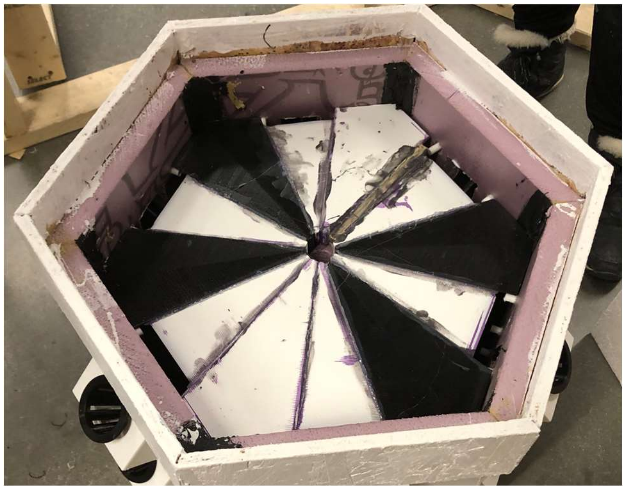
Once all the electronics have been set up, you can test the system by checking if all the relays and electronics are operating properly.

Now that the system is ready, you may close the nutrient box.

Water Distributor Plate

To make the water distributor plate you will need to download the STL files off our maker repo portfolio. You will need 6 pieces of each part to make the water distributor. Using PVC glue, cement the 12 parts together ensuring that the hole in the middle will allow for the PVC pipe to fit through. After letting the parts dry fit the entire plate into the top of the unit. If it doesn't quite fit, trim the edges down to size to that it slips into position on top of the cup holders but make sure each piece is cut equally. Then use hot glue to fix the plate in place.

Figure 21: Distributor Plate



Final Assembly

All you must do now is to fill the base with water, connect the pipe to the pump, and stack the units on top of each other. Then, add the cups to the cup holders and turn on the system. Check for any leaks and if you see any apply some flex paste to the leaks.

Figure 22: Final Assembly

User Access Considerations

As our hydroponic has an advanced touchscreen that monitors and controls multiple different systems, our product would be used more for the newer generation who are constantly surrounded by it. However, this is not an age restriction as the technology is very basic to use and would not be too difficult to learn. Our product is great to educate a wide range of students, as it has a combination of multiple components such as electrical, civil, construction, environment, and many more.

Setting up The System

To set up the system, a user must first set the base on a flat surface with 2 ft worth of space between any wall. Then, a user can fill the base with water using the manual mode or the automated mode. Next, a user should attach the pipe to the pump and then add executions to the pipe depending on how many units they are going to use. Once completed, the units can be stacked on the system and finished by putting the lid on the top. The cups should then be placed in the cup holders and the pump can be turned on.

To complete the process the user should add nutrients, the acid and the base to the containers located at the bottom of the tank. All that's left is programming the touch system. Please see the section "Using the System" for programing instructions.

System Organization & Navigation

The main components of Vertigro are the structure system, the delivery system and the nutrient system. These three systems are separate from each other, yet they are reliant on each other to function properly.

Structural System

The structural system is the physical structure of the hydroponic. The structural system is responsible for supporting the weight of the growing plants and storing the nutrient solution. According to the design criteria this structure must be space efficient, be easy to transport and easy to assemble. This system does not include the structure that houses the nutrient system's electronics, fertilizer, and sensors.

Delivery System

The delivery system is responsible for transporting the nutrient water solution to the roots of the plants. Thus, this system is responsible for anything to do with the moving or distributing of the nutrient solution to the roots of the plants. Some components of this system would be the pump, piping, nozzles, etc. The delivery system must be easy to set up and must be reliable to avoid the plants in the hydroponic dying.

Nutrient System

The nutrient system is responsible for ensuring that the nutrients solutions maintain optimal nutrient levels for plants. In addition, the nutrient system should have the capability to replace the nutrient solution once a week to ensure maximum efficiency of the hydroponic. The nutrient system should be user friendly and easy to program nutrient levels.

Dissemble the System

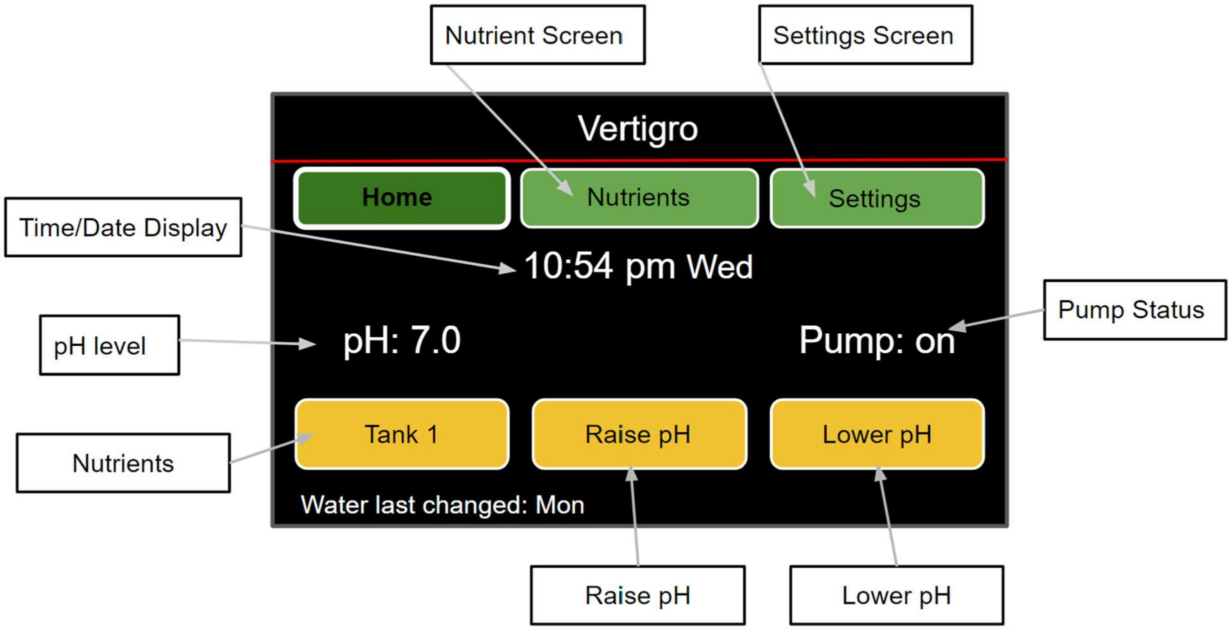
To dissemble Veritgro, the first step would be to shut off the pump to ensure no water spillage. You may unplug Veritgro from the outlet to ensure that the whole nutrient system, pH monitor and so forth are off and no electricity is running through. The second step would be to lift the first stackable unit. To do this lift gently and evenly make sure it is fully removed from the central pipe. Once the first unit is removed, you may twist the central pipe counterclockwise to remove the first unit's piping. Continue this step until all the stackable plant units and pipes are fully removed.

Using the System

To program the system the following instruction lay out how to program the system using the user touch screen.

Video 2: https://youtu.be/MbOxdRYEANE

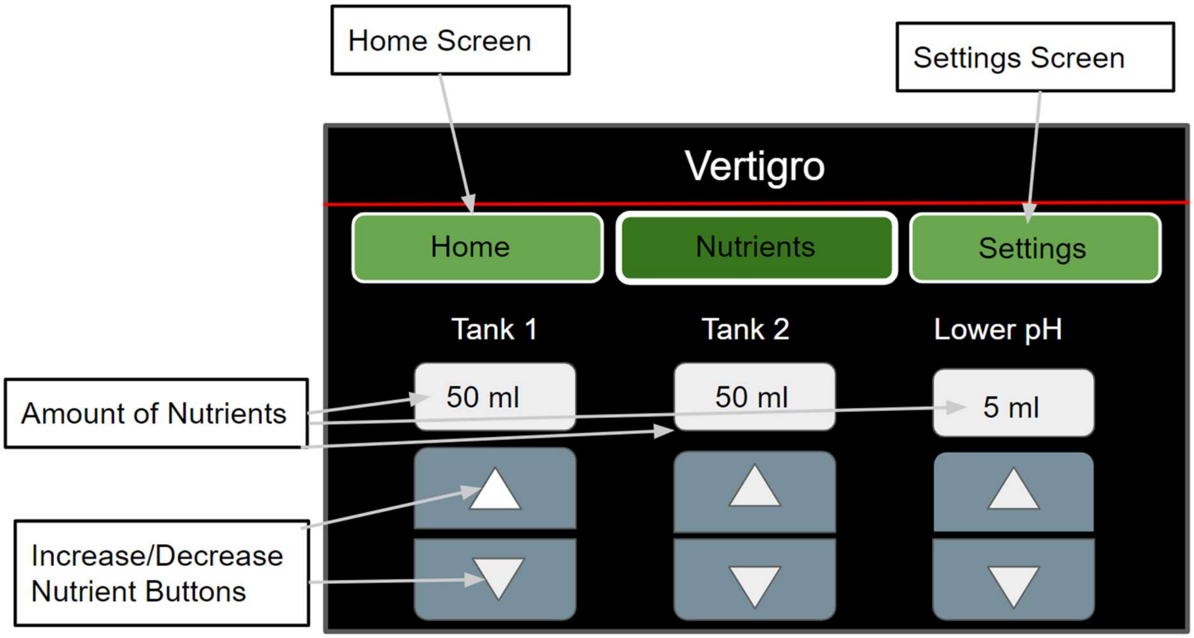
Home Screen



- Nutrient Screen: allows user to go to the nutrient screen
- Setting Screen: allows user to go to the setting screen
- Nutrients: this button adds 5ml of nutrients to the tank when pressed
- Raise pH: this button adds 2ml of a base to the tank when pressed
- Lower pH: this button adds 2ml of a acid to the tank when pressed

- pH level: gives the current pH value of the tank
- Time/Date display: gives the current time and day of week
- Pump Status: indicates if the pump is on

Nutrient Screen

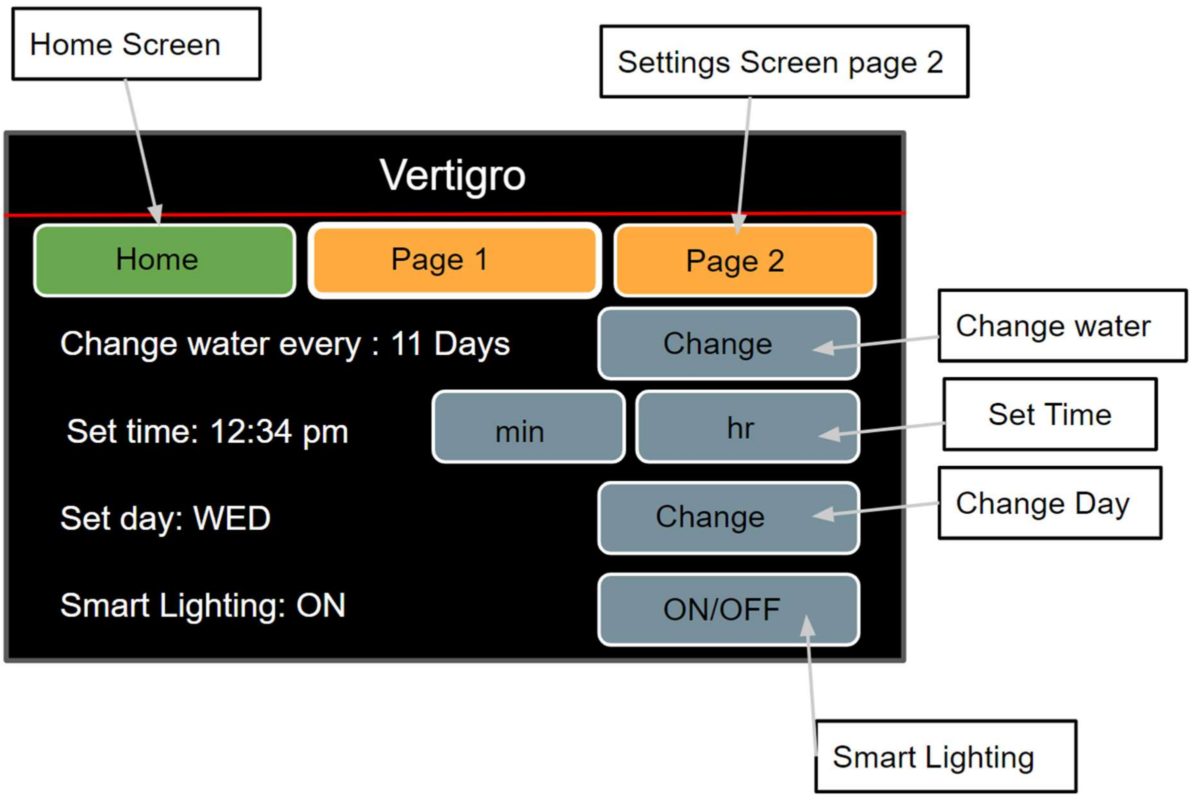


- Home Screen: allows user to go to the home screen
- Setting Screen: allows user to go to the setting screen
- Increase: this button increases the nutrients level by 1ml
- Decrease: this button increases the nutrients level by 1ml

❖ Amount of Nutrients: indicates the amount of nutrients/or pH solution will be added each time the tank changes its water.

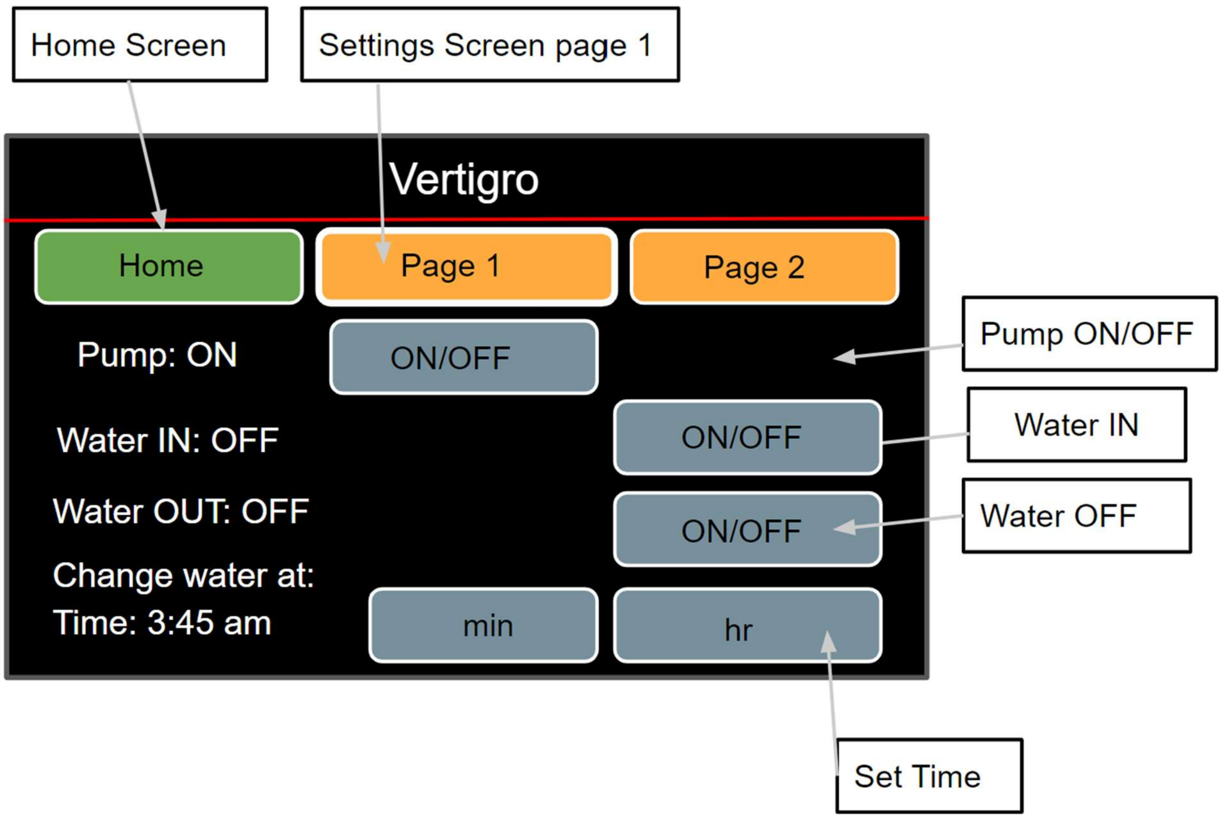
Settings Screen

Page 1



- Home Screen: allows user to go to the home screen
- Settings Screen page 2: allows user to go to the second page of settings
- Change Water: this button increases the number of days between when the water is changed. You can set max number of days to be 14 or set it to never change the water.
- Set Time: these buttons are used to set the current time
- Change Day: used to set the day of week
- Smart Lighting: When the smart lighting is on the plug on the outside of the system will only turn on when it is dark outside. However, if you want to it to always be on simply turn the smart lighting OFF.

Page 2



- Home Screen: allows user to go to the home screen
- Settings Screen page 1: allows user to go to the first page of settings
- Pump ON/OFF: this button increases turns the pump off and on
- Water IN: when on water will enter the tank
- Water OUT: when on water will be pumped out of the tank
- Set time: set the time for when you want the water to change at

Troubleshooting & Support

- Red Screen Display for Nutrient System

If the touchscreen is displaying a red background rather than a black, this means your pH level has exceeded the recommended pH value. The touchscreen is designed to turn red if the pH level becomes dangerous for your plants. Generally, the system will be able to handle pH levels. However, if for some reason such as the system runs out of a base and the system can no longer control the pH level the screen will turn red to alert the user of a problem. If this problem occurs check the pH solutions at the base of the hydroponic to see if they are empty, if not manually empty and refill the tank. This should reset the pH and the screen should change back to a black background. Continue to monitor the system for a few days to ensure that the system is able to maintain the pH levels.

- No water reaching the top of the hydroponic

If water is getting to the top of the hydroponic, first ensure that the pump is fully submerged in water. Then, go to the bottom of the pump itself as there is a power setting switch. Increase the power setting until you see water come to the top of the hydroponic. You can also decrease this setting if the water pressure is too high.

- Maintenance

To ensure that the system runs properly, each month check on the solution levels for the nutrient system. Each growing season clean the hydroponic with soap and water which will kill any bacterial which could cause root rot. Store in a dry place and preferably off the ground. The units are made from foam so a mouse could chew through the units. Thus, it is best if the units are sorted on top of the wooden base.

- Support

If you should be running into issues that are not addressed in this document, feel free to contact us for advice or questions regarding the design or troubleshooting.

Steven Dunbar

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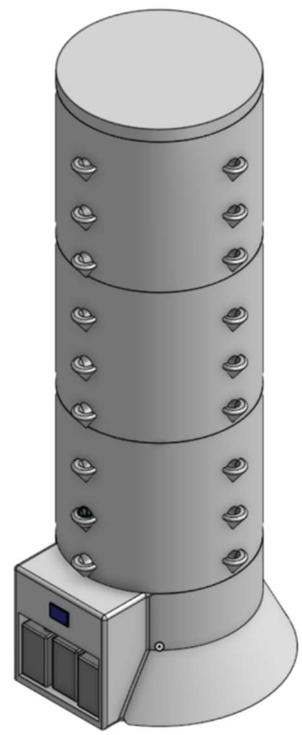
Product Documentation

Materials for Structural

There were a variety of materials that were in the decision for our hydroponic that were not chosen. Each material provided huge problems that would not be ideal in the long run. Recycled plastic has poor resistance to ultraviolet radiation. Steel sheets would need a metal welding lathe which is not provided in the manufacturing shop, and they have the potential to rust poisoning. Multiple materials were discarded due to the high expenses: ABS plastic sheeting, carbon fiber, and epoxy resin. Our final decision was to have the base constructed out of plywood which was later changed to chipboard as the professor only bought these. Originally, we planned that the stackable units would be made from durable acrylic plastic sheets that are ¼ inches thick. As it is UV resistant with as little as 3% degradation outdoors over a 10-year period and easily heated up to be malleable. We have originally concluded that if the whole structure were made from acrylic plastic, it would go way over our original budget of 700$ therefore, using plywood as the base leaves us under the budget amount. However, this was all cut because of our budget change from 700$ to 500$. We changed using acrylic plastic to rigid foam as it is light, durable, thermal insulator, waterproof and most importantly in our budget. Rigid foam is long lasting with a lifetime that can reach 100 years if maintained well. Our solution to make the rigid foam aesthetically prettier than the original pink foam was to paint white over it. This was a great solution to solve our material issue.

Structural Subsystem Final Prototype

Figure 23: Original Design



For our structural final design, we have designed hexagonal shape structure. The reasoning for this would be that it provides a flat surface to secure the flat back of the cupholders. The second reasoning is that compared to our original idea, which is a cylinder, a hexagon would be easier to build with rigid foam. With each plant having its own side, this makes it so the plants don't have to compete for space, nor sunlight. Lastly, our construction team was planning on making a greenhouse that is hexagonal, so for aesthetic reasoning, we wanted to match.

Original idea:

Our original idea of material was to use acrylic sheets. Our main issue with using this material was that it was overly expensive and hard to cut. Our budget was originally 700$ which was later cut to 500$ which meant we had to find ways to reduce or change our materials. The rigid foam was a great solution to our problems as it is durable, waterproof, thermal insulation, and overall, a cheaper option.

Delivery Subsystem Final Prototype

Our original idea was to use a drip system to distribute the nutrient solution. After discussing it as a group, we found that this method of having a distributor plate full of holes was not the most efficient. The middle part with holes provides no purpose as it won't reach any plants. We have chosen to use a modified nutrient film technique because the nutrient solution will have a constant flow downward insuring it will reach each plant root. Our nutrient film technique design forces the solution to be directed into these six gaps.

Figure 24: Original Water Distributor

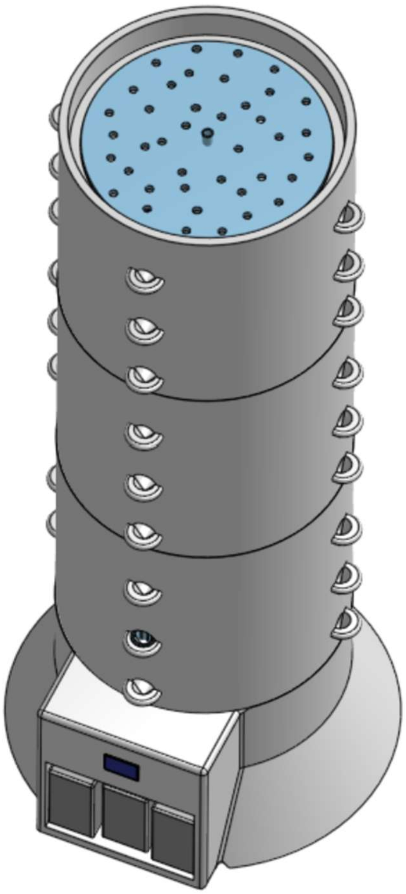
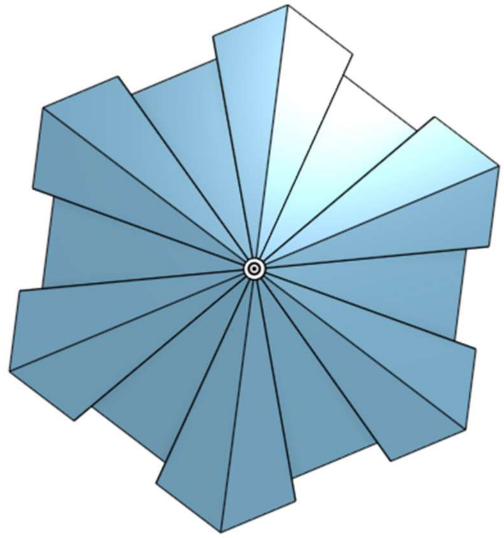


Figure 25: Final Water Distributor



Power efficiency

The following is the calculations for the water delivery system on the work that the pump would have to introduce into the system to lift the water to the top of the system. We found that because of our one pipe design the energy required to move the water through the system was significantly less than other designs.

Pump:

<u>Assumptions for calculations</u>:

- Steady-state flow
- Incompressible, Newtonian fluid
- No change in velocity ($V_f = V_i$)
- Pump introduces no additional friction loss
- Flow is unidirectional, upwards (no angles)

Given:

- Maximum volumetric flow Q_{max} = 3000 L/h
- Volumetric flow used Q = 2000 L/h
- Maximum power output of pump W_{max} = 24 W
- Diameter of PVC pipe D_{pipe} = 0.5 in = 0.01295 m
- Pressure at top of pipe $P_2 = P_{atm}$ = 101325 Pa
- Height of piping h = 2 m
- Dynamic viscosity of water μ = 0.001 Pa.s
- Density of water = 1000 kg/m^3
- ε = 0.000001524 m

Calculations:

- Apply Bernouilli's equation:

$$\frac{dW_{n1}F_1}{dm} = \frac{P_2 - P_1}{\rho} + g(h) + \frac{v_2^2 - v_1^2}{2} + F$$

$$\frac{dW_{n1}F_1}{dm} = \frac{P_{atm} - P_{atm} + \rho g h}{\rho} + g(h) + 0 + F$$

$$\frac{dW_{n1}F_1}{dm} = F$$

- Reynolds number calculation to determine type of flow:

$$Re = \frac{vD\rho}{\mu} = 55\ 697 > 4000\ \left(turbulent\ flow\right)$$

- Friction factor calculation:

[Equation]

- Friction calculation:

$$F = \frac{2fv^2h}{D} = 31.57\ N$$

- Work (power) calculation:

$$W = \rho Q F = 17.54\ W < 24\ W\ (\mathrm{max})$$

II. pH:

Assumptions for calculations:

- Diprotic acid behaves as monoprotic acid
- Initial pH = 7

Given:

- Acid constant of phosphoric acid K_{a1} = 7.2E-3
- Acid constant of dihydrogen phosphate K_{a2} = 6.3E-8
- Volume solution = 25 L
- Concentration buffer = 0.01 M

Calculations:

- Apply Henderson-Hasselbalch equation (initial):

$$pH = pKa + \log\left(\frac{[A^-]}{[HA]}\right)$$

$$6.50 = 2.15 + \log\left(\frac{[A^-]}{[HA]}\right)$$

$$\frac{10^{-6.5} - 10^{-7}}{F - 10^{-6.5} - 10^{-7}} = 10^{6.50-2.15}$$

$$F = 2.16 \times 10^{-7} M$$

Volume of buffer to be added (initial):

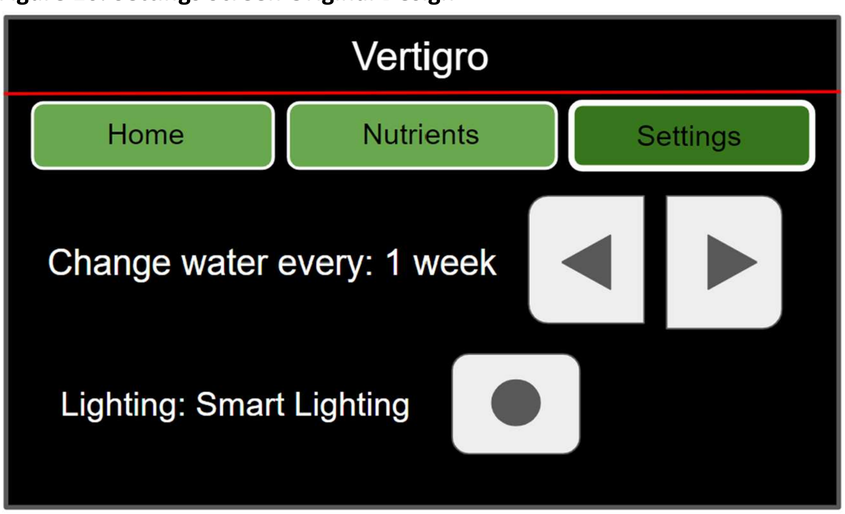
$$C_{sol}V_{sol} = C_{buffer}V_{buffer}$$

$$V_{buffer} = 5.40 \times 10^{-4}\ L$$

Nutrient Subsystem Final Prototype

In our team, we had students who are in the electrical engineer majors and thought it would be a great learning experience to challenge our ability to program multiple functional systems. We could have gone with the easier route of having buttons which provides no electronics; however, we wanted our product to be advance and involve the growing modern interest of technology. Also, we realized that the buttons had a higher chance of becoming clogged with dirt so we decided that a touch screen would be the best solution. Before starting the coding, the team did an outline for the code. In addition, prototypes of the screen display were created using Google slides.

Figure 26: Settings Screen Original Design



BOM (Bill of Materials)

	COMPONENTS	QUANTITY	COST	SOLD	ACQUIRED	TOTAL $
PUMP	*PUMP*	1	$ 36.00	HERE	☐	$ 36.00
	PVC TEE 1/2 INCH	1	$ 1.00	HERE	☐	$ 1.00
	PVC 1/2 INCH x 10 FT	1	$ 12.00	HERE	☐	$ 12.00
	FEMALE ADAPTER PVC 1/2 INCH	4	$ 2.00	HERE	☐	$ 8.00
	MALE ADAPTER PVC 1/2 INCH	3	$ 1.00	HERE	☐	$ 3.00
	PVC GLUE	1	$ -	AVAILABLE	☐	$ -
					TOTAL $	$ 60.00

	COMPONENTS	QUANTITY	COST	SOLD	ACQUIRED	TOTAL $
NUTRIENT	*MEGA ARDUINO*	1	$ 30.00	HERE	☐	$ 30.00
	RELAY 8 CHANNEL BOARD	1	$ 11.00	HERE	☐	$ 11.00
	PERISTALTIC PUMP	3	$ 12.00	HERE	☐	$ 36.00
	SOLENOID 1/2 INCH	2	$ 15.00	HERE	☐	$ 30.00
	PH PROBE	1	$ 39.00	HERE	☐	$ 39.00
	BREAD BOARDS/CABLES	1	$ 14.00	HERE	☐	$ 14.00
	WATER LEVEL SENSOR LIQUID	1	$ 14.00	HERE	☐	$ 14.00
	3.2 INCH TFT TOUCHSCREEN	1	$ 15.00	HERE	☐	$ 15.00
	PHOTORESISTOR	1		UNKNOWN	☐	$ -
	POWER TOOL CORD, 6', 14, AWG, 15A/125V AC	1	$ 12.00	HERE	☐	$ 12.00
	POWER CONVERTER: AC TO 5V DC	1		UNKNOWN	☐	$ -
	POWER CONVERTER: AC TO 12V DC	1	$ 19.00	HERE	☐	$ 19.00
	GFCI OUTLET	1	$ 16.00	HERE	☐	$ 16.00
	SILICON TUBE	1	$ 11.00	HERE	☐	$ 11.00
					TOTAL $	$ 247.00

	COMPONENTS	QUANTITY	COST	SOLD	ACQUIRED	TOTAL $
STRUCTURAL	*220-in x 48-in x 96-in Clear Acrylic Sheet*	1	$ 349.00	Here		$ 349.00
	3/4 inch 4 ftx8 ft Standard Spruce Plywood	1	$ 67.00	Here		$ 67.00
	8ft X 4ft PETG Sheet	1	$ 68.00	Here		$ 68.00
					TOTAL $	$ 484.00

	TOTAL COST	TOTAL COST PER SYSTEM			ADDITIONAL COSTS
		NUTRIENT	PUMP	STRUCTURAL	
LOW EST	$ 592.00	$ 208.00	$ 74.00	$ 310.00	
HIGH EST	$ 623.00	$ 219.00	$ 78.00	$ 326.00	
APPROX	$ 608.00	$ 214.00	$ 76.00	$ 318.00	

Equipment list

The following is a list of equipment needed for the construction of the Vertigro:

Structural Equipment list:

- Table saw
- Mitre saw
- Vertical panel
- 3D printers
- Drill

Electronic Equipment list:

- Computer
- Arduino IDE
- Soldering iron

Prototype Tests

The following test were preformed to test our most critical systems. The nutrient system and the water delivery to each plant.

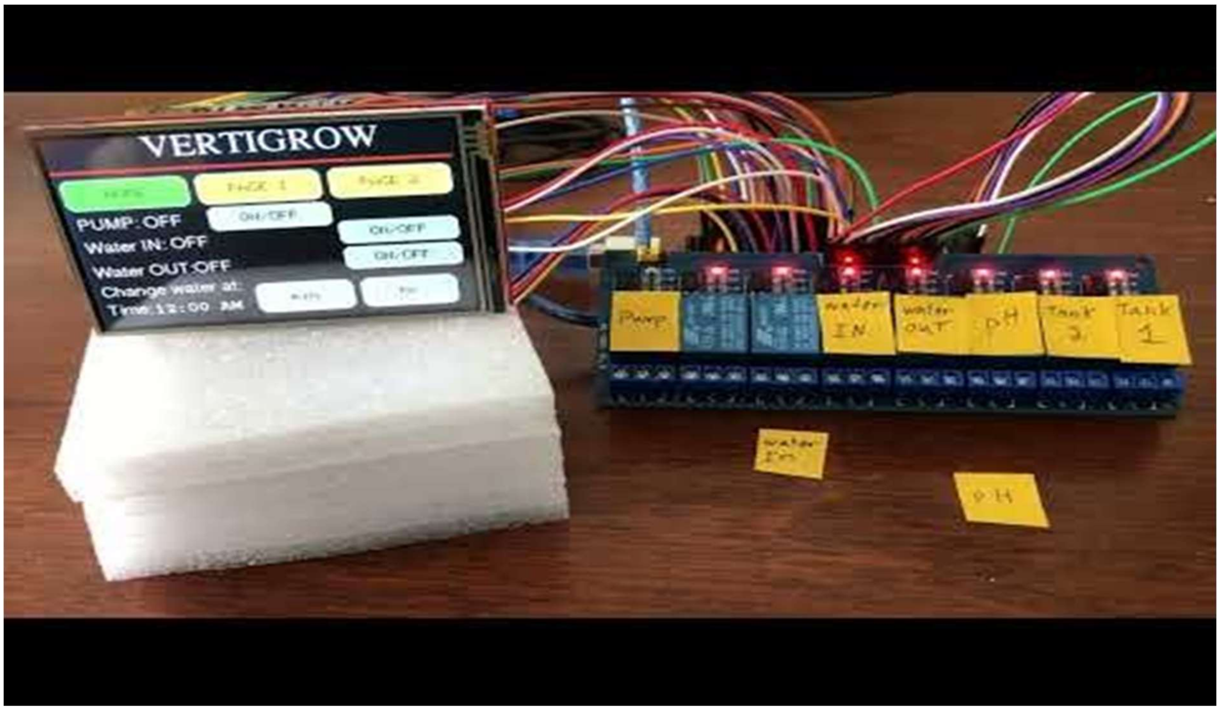
Nutrient System Test

We wired the mega arduino to the 8-channel relay and 3.5 TFT touch screen. For the code the mcufreind, Adafruit, and TouchScreen libraries from arduino's public domain were used. Upon running the trial code, the results were promising. The touch screen responded appropriately to the user's touch and the display was relatively clear.

The clock function for the code was tested by running the electronic system overnight. After debugging the code, the clock keeps perfect time for 24 hours and it was successful at changing the day of the week.

Next, all off and on buttons were tested to see if the screen changed and the relay would respond appropriately. Also, for important buttons such as turning the pump on and off a warning screen was to be displayed to avoid users accidentally turning off the pump. After testing, all the buttons responded appropriately changing the screen and relay.

Then, we tested the system's ability to empty and fill the tank based on the clock-timer. We did this by modifying the pre-set settings of the system to trick it into thinking it was time to change the water. Then we observed if the appropriate relays were tripped, and all the delays worked. After completing the test 3 times we concluded the changing water sequence was activated according to the pre-set time. Note: this test is not included in the video.



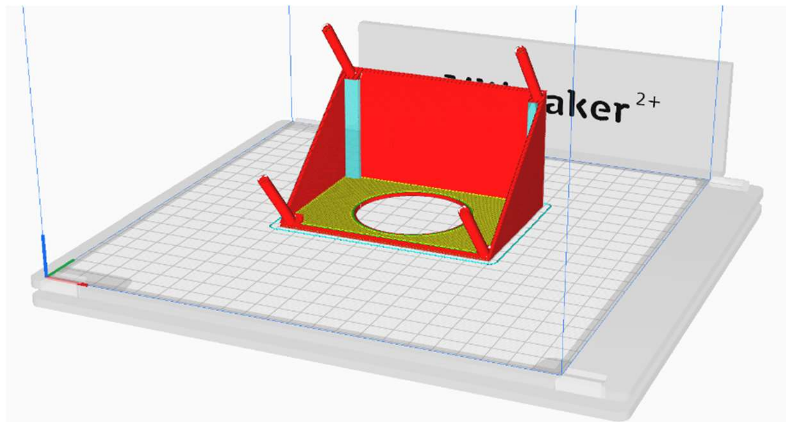
Video 3: Nutrient System
Click to follow link: https://www.youtube.com/watch?v=vX-vEAgLK2w

After compiling the code for the touch screen the code took up 25 percent of the arduino's memory (approximately 1500 lines of code). This means that there is plenty of extra memory for future additions to the code and to ensure good running speed of the arduino.

Structural and Delivery System Test

For Prototype 1, we used rigid foam to create a model of a single panel of one grow unit in our system. We used 3D printed cups for the part that will hold the plant and built the panel and the part responsible for holding the cup from rigid foam. The entire process took 3 hours for 3 cup holders, meaning a rate of 1 assembled cup per hour. With 36 cups for the whole system, creating only the individual panels would require 36 hours of work. This is not plausible, so we revised our design to include 3D printer cup holders and cups. This will make the production process significantly easier taking approximately 2 hours to print one cup holder.

Figure 28: 3D Printed Cup Holder



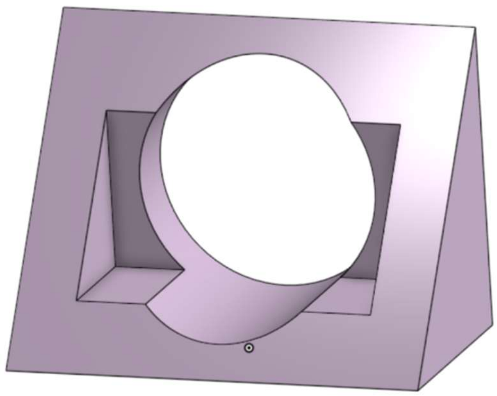


Figure 27: Original Cup Holder

In testing glues, we found that super glue dissolved the foam making it an unsuitable choice of glue. For wood glue the test joints broke at the joint due to a lack of strength from the wood glue. The original gorilla glue was stronger than the wood glue however the expanding capabilities of the glue caused the joints to expand and become unflushed with the surface. Finally, there was clear gorilla glue that had reasonable joint strength and did not expand like the original gorilla glue. Since we were not totally satisfied by this we decided to do some more research on what glues were good at gluing foam. Upon doing some research we found a glue called foam fusion which creates a thermal bond between the two pieces of foam. While we were unable to get our hands on this glue for prototype 1 based on our research, foam fusion is the strongest glue available for joining foam together. We will be testing this glue in prototype 2.

After completing the one panel of side units we took the 3D printed plant cups and used yarn to simulate the roots coming out of the cups. We then placed the cups in the panel. Next, we poured water on the top of the panel to simulate water pouring down the sides. We were primarily interested in seeing if the water was diverted by the plant cups and roots. After completing the test we were satisfied that water flowed properly down the sides of the panel covering each plant. In fact, from the test we conducted we observed that the roots will actually assist the water flow straight down the sides without diverting. The test video 2 demonstrates this test.

Figure 29: Cup with Yarn

Figure 30: Back View Unit Panel

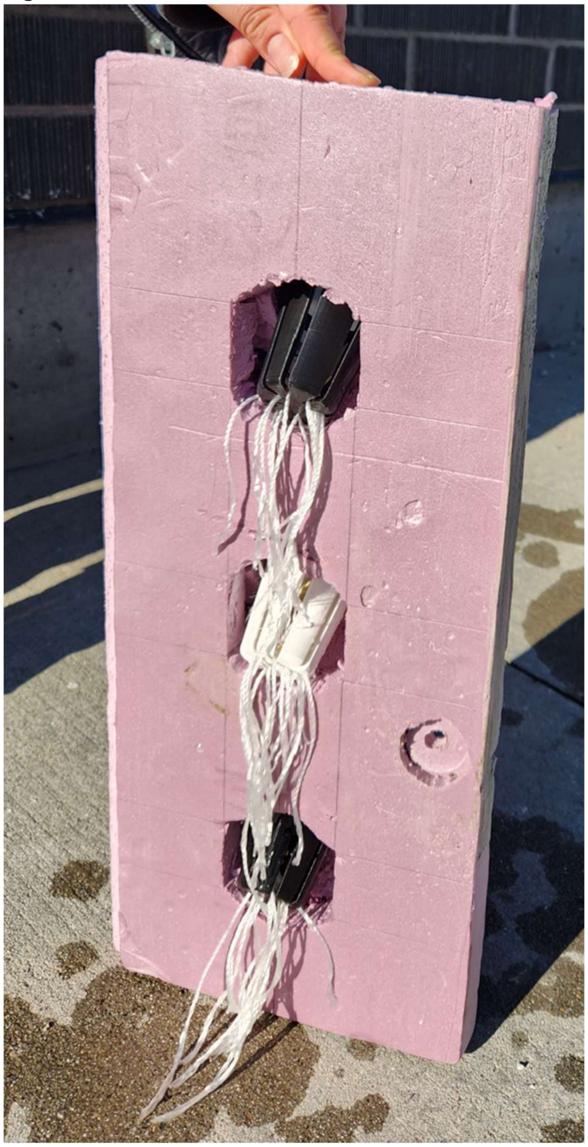


Figure 31: Front View Unit Panel

Video 4: Structural and Delivery System

Click to follow link:
https://www.youtube.com/shorts/6iZKRg8BHkg

Conclusions and Recommendations for Future Work

We have learned a lot when working on the process for our prototype. We learned that it is crucial to test out sections of the hydroponic individually as it showed us multiple issues that would have not been caught without it. An issue we had was the cup holders created from rigid foam created a mess, was hard to shape and did not secure well which meant it would have not been able to carry a heavy load. We found this mistake when constructing our first prototype and we were able to replan our mistake. Without finding this issue so early, we would have not been able to have enough time to 3D printing 36 white cupholders. We also learned that communication, listening, open minded and working together are an important aspect for creating a product that each team member is satisfied with. We used many aspects of each other's individual design when creating *Vertigro* and we are all proud of our final product. It is also important to find time out of your busy schedule to work with your whole team and have great time management.

For future groups, the best way to be the most productive when recreating our work would be to have great time management. Do not let work get piled up when creating Vertigro because you would have to rush the process. Start 3D printing the cup and cupholders as soon as possible; the cupholders are most important because you would need this to construct each individual unit. Make sure each individual team members are productive and constantly are assigned to do a task, so no one is wasting time. Always communicate to each other when you are assigned a task that you are uncomfortable with so everyone can be satisfied when working on a specific task with a good attitude. Improve our work by focusing on the nutrient system. Make sure that all bugs are solved, and multiple helpers are spotting/helping issues as it goes.

While constructing *Vertigro*, there was a struggle in finding time to complete everything we wanted in a nice pace fashion. As we had to rush the finishing touches, we had to settle for issues we faced. Some issues we faced was waiting for the construction adhesive to dry as it took 7 days. The design day was going to be presented in less than a week from gluing the foam pieces together, so we had to use a blow-dryer to quicken the drying process. Since there was still concern in waiting for the glue to dry, we used flex paste which can dry in water however, that was an expensive decision as a small bucket is around 30$ to 50$. If we had extra time, this issue would have not been a problem. With extra time we would also redo the printing of the 3D distributor plate. We had to improvise in our design as someone had stolen/lost our original piping which meant the measurement of our distributor plate hole was incorrect and needed to be trimmed. We had to improvise by using a piece of wood to fill the gap. However, if we had the time, we would have reprinted this. Another part we would have done with more time is perfecting the coding of the Arduino as we noticed some small bugs when turning off the pump with the touchscreen. For the aesthetic design, we were originally going to customize the hydroponic by adding an indigenous design for our client. However, we had no time in advancing in our idea. Lastly, with more time we would have run more testing to ensure no leakage and extra additions *Vertigro* would need. We would have loved to use real plants and examine the hydroponic growing process.

APPENDICES

APPENDIX I: Design Files

Table 2. Referenced Documents

Document Name	Document Location and/or URL	Issuance Date
ArduinoCode	link	March 1 2023
Cup.stl	link	March 1 2023
Cupholder.stl	link	March 1 2023
Touchscreen.stl	link	March 1 2023
waterIN/OUT.stl	link	March 1 2023
Distributor plate part 1	link	March 1 2023
Distributor plate part 2	link	March 1 2023
Maker Repo link	link	March 10 2023