GNG1103

Design Project User Manual

Hydroponics System

Submitted by:

Hydroponics 5

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Abstract

This report covers the steps that we took in our design thinking process to develop a final solution for our hydroponic system. Starting from understanding our customer's situation we defined a problem statement that our team needed to solve. Our system needed to be cost-effective, easy-to-use, easily assembled and resource-independant. Conceptual designs lead to a prototype in development. Unfortunately, due to the COVID-19 pandemic, work on this project ceased in March and the prototype was never completed.

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1. Introduction

In the beginning of the semester, we were introduced to a real-life need that we would be solving over the course of the semester. An Indigenous community in Northern Ontario was suffering under harsh conditions and minimal resources. Without reliable running water or electricity, the community sought alternative means of providing necessities, namely food. Thus, it was our goal to design, prototype and deliver a device that could alleviate this issue: a hydroponics system that could allow for the accelerated and size-efficient growth of edible plants. With this system, the people in the community could augment their food supply, decreasing reliance on unreliable food shipments.

Fundamentally our device needed to suit the needs of the end user. We understood that the end user would be someone working with limited resources, tools, and time, as this is the reality of living in a remote and underprivileged community. As such they would expect our product to be productive and reliable without constant oversight or maintenance, as well as being safe and easy-to-work on; if it wasn't, it would be more of a hindrance and time waste than an actual benefit. As mentioned before, the community also did not have ready access to running water or electricity, so our design needed to be resource-independant, principally either producing its own electricity or not requiring any.

Our project was split between two teams. The Construction team sought to construct a study, safe and effective enclosure shed for the hydroponics systems, and the Hydroponics team (us), who sought to construct a productive and effective hydroponics system that could fit inside of the enclosure shed. With each team focused on their design goals, we followed the design procedure laid out by the GNG1103 course to great effectiveness. Unfortunately the end result of this process was not fully realized due to COVID-19 causing a University-wide closure, but the progress we made was still significant and so this report will cover what we did, and extrapolate the intended functionality from our progress.

The main idea behind a hydroponics system is a densely packed volume of growing spaces that are provided with a flowing supply of nutrient-infused water. The high concentration of nutrients in the water, as well as ease-of-access to it leads to accelerated plant growth and higher harvest yields. The design challenge is to create the means for the nutrient-infused water to flow around the plant's roots. There are many ways to do this, but typically it involves a pump cycling the water through tubes that the plants are placed in once germinated - this technique is known as the Nutrient Film Technique and it is what we chose to predicate our design on.

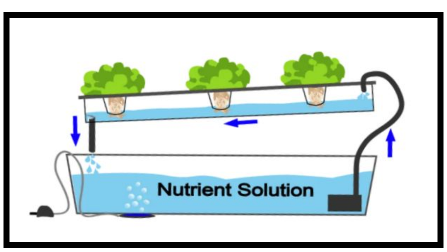

Figure 1: The principles of Hydroponics; specifically, the Nutrient Film Technique

2. How the Prototype is Made

Figure 2: Orthographic Schematics of Prototype I

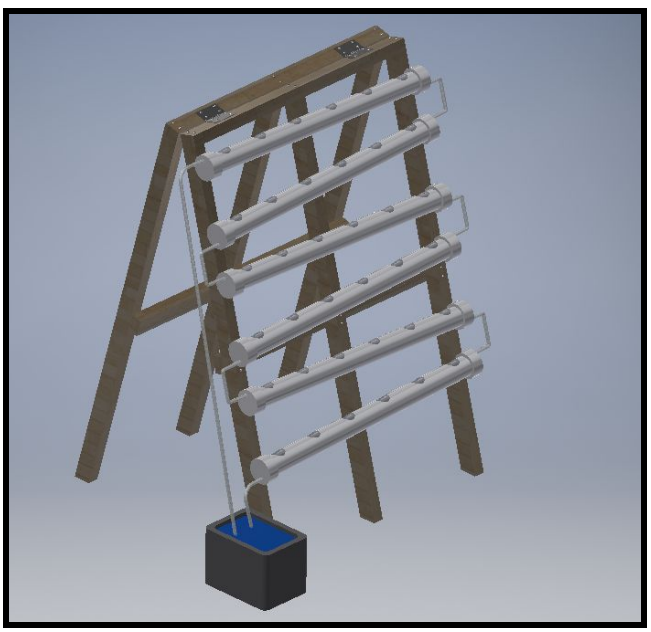

Figure 3: 3D Perspective Model of Prototype I

Our hydroponics system is composed of three structures. Firstly, the A-frame on which the piping sits, secondly, the piping itself, and thirdly, the “circulatory system” composed of a reservoir, a pump and tubing to the pipes. This section will break down the design and construction phase of the prototype into three sections respective to the three systems that our prototype employs.

Although our team was tasked with creating just the hydroponics system, implying we could have mounted our piping to the wall of the Construction team’s shed, our chosen prototype utilized an A-frame, which has several benefits that we thought made it worth the extra work. Principally, it makes the hydroponics system independent from the shed, which allows the hydroponics system to be removed from the shed for whatever reason; cleaning, repair, etc, while still operating. The construction of the A-frame required two identical flat frame pieces that were joined at the top with a hinge, then linked together near the hinge to limit the opening angle. Wood was the material chosen for the A-frame, although this choice was made due to the availability of wood to us, as any material that could be constructed together and hold several kilograms of weight would easily suffice. Anything from metal spars to plastic beams could be used on a further developed version, although the ability to pick up and move the frame is important to its independance from the shed, and so the weight of the frame should be minimized with lightweight materials. By the time of the University’s closure, the A-frame was nearly completed and showed no issues of concern.

Figure 4: Work-in-progress implementation of the A-frame.

The next system is the part most integral to the hydroponics system, the piping in which the fluids cycle and the plants grow. For adequate volume for the roots, as well as maximum surface area for the nutrient film to accumulate, the pipes needed to be of a large diameter: 3 inches or more. Affordable, lightweight pipes of large diameter can only be found as either PVC (*polyvinyl chloride*) or ABS (*acrylonitrile butadiene styrene*) plastic pipes. For safety reasons, we chose to use PVC plastic over ABS plastic, as ABS plastic is not necessarily food-safe while PVC is. Additionally, ABS emits toxic fumes when being cut (high temperatures) which, considering many large holes needed to be cut for this project, was not ideal for our health. Once the piping was acquired, they were cut to six (6) lengths of four (4) feet each. Large holes (the size of which we had not yet calculated) would be drilled into the side of the pipe, making room for the perforated Dixie-style plastic cups that the plants would germinate in. They were to be laid horizontally across the face of a side of the A-frame, with a slight angle (determined experimentally) to encourage downhill water flow. Endcaps would be placed on the lower end of the pipe, with a hole drilled into it for a fitting. A vinyl hose would link the lower section of an upper pipe to the higher section of a lower pipe, causing water to flow slowly down the pipe system from the top. The fittings meant to be installed in the endcaps were planned to be standard brass fittings, but these turned out to be far more expensive than our original budget had allocated. As an alternative, we decided to try 3D-printing the fittings to reduce the cost to just that of some plastic spool.

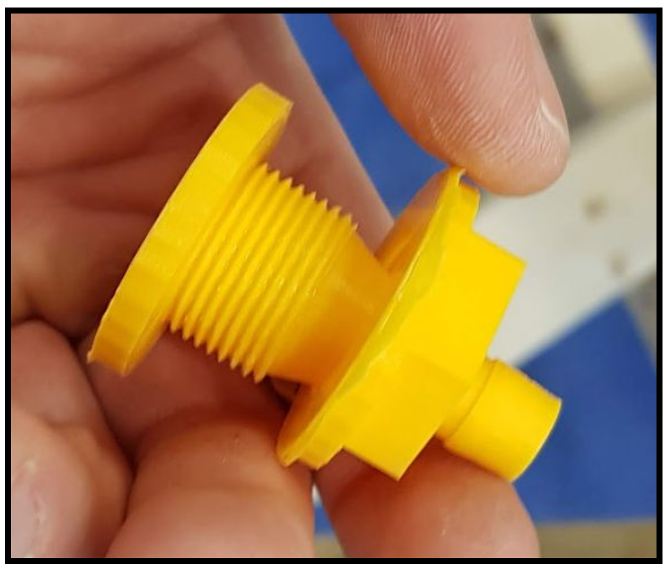

Figure 5: Prototype 3D-printed fitting. Untested.

Unfortunately, the piping system is largely speculative, as we did not progress beyond cutting pipes to size and test-printing a fitting before the University shut down. However, we encountered no issues with what we did complete.

The third system is the circulatory network that actively moves water through the piping. The nutrient solution starts in the reservoir, which was just a bucket with a lid in our case. The pump is mounted on the reservoir, and its output goes to the highest pipe at the top of the system via a long vinyl tube. The nutrient solution passes through the piping system, and then is drained back into the reservoir where the cycle can restart. Our chosen pump was a 25W marine pump, as it could easily provide adequate pressure to move water up about five (5) feet vertically. The following calculation supports this belief:

Power required for 100L/h ($3\times10^{-5}\ m^3/s$*) of water up 5ft (1.6m) at 100% efficiency?*

$$P = \rho\ Q\ g\ h \text{ (density * volume flow rate * gravity * height)}$$

$$= (1000kg/m^3) * (3\times10^{-5}\ m^3/s) * (9.81m/s^2) * (1.6m)$$

$$= 0.5W$$

Considering pump inefficiency, fluid friction losses, and other inefficiencies, the actual wattage required to operate the system will be higher, likely in the order of several watts. Thus our choice of a 25W gives us ample headroom for optimal operation, and possibly even expansion of the hydroponics system. The power source for the pump would be a solar panel provided by the University, which should be able to output somewhere in the vicinity of 25W at a sufficient voltage to operate the pump. The specifics of this are vague as we were not able to secure a solar panel by the time of the shutdown. However any solar panel with the ability to provide more than six (6) volts and several watts would be enough to operate the pump and move sufficient water.

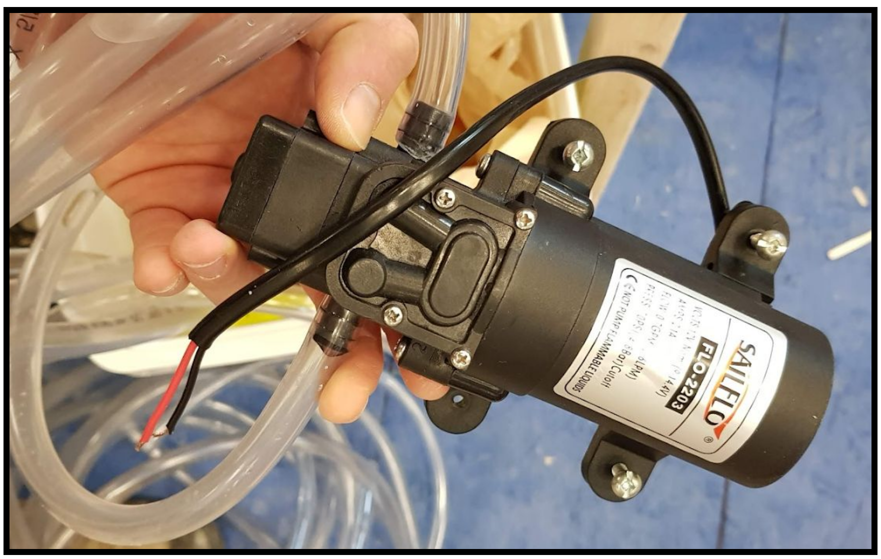

Figure 6: The chosen pump, a 25W marine pump, and its associated vinyl tubing

a. BOM (Bill of Materials)

i.	**3x** 10ft length, 3’’ diameter, PVC Tubing	$52.71
ii.	**6x** 3’’ diameter PVC Endcaps	$17.82
iii.	**2x** Door Hinge	$4.75
	1. Tax on above purchases	$9.79
iv.	**12x** 3” diameter pipe clamps	provided by University
v.	**1x** 25W Marine Pump	provided by University

vi.	**1x** 25W Solar Panel	provided by University
vii.	**1x** Tube of silicone caulking	provided by University
viii.	approx. **10'** of clear vinyl tubing	provided by University
ix.	approx. **40'** of 2-by-4 lumber	provided by University
x.	approx. **30x** woodscrews	provided by University
xi.	approx. **1x** PLA (*polylactic acid*) 3D-printing spool	provided by University
xii.	approx. **6'** of small-gauge wire	provided by University

Total **$85.07**

b. Equipment list

i. For construction of the A-frame
  1. Drill, square head
  2. Hammer

ii. For construction of the Piping
  1. Drill Press with Hole Saw attachment
  2. Caulking gun

iii. For construction of circulation system
  1. Computer, 3D Printer w/ PLA spool
  2. Soldering Iron w/ solder, electrical tape

3. How to Use the Prototype

It is difficult to explain the workings of a prototype that exists only in ideas and rough schematics, especially given many small details are left intentionally vague to be determined by the parts available to us at the time. However, extrapolating from what we have and what we planned to do, the operation of the hydroponics system should be very straightforward, if not essentially automatic.

For most hydroponics setups, the plant of choice is germinated in a paper towel. Once the plants begin to sprout, they will be placed in plastic Dixie cups, with perforated lower area and bottom, to allow water flow. These plant-cups will be inserted into the holes in the pipe of the hydroponics system. The reservoir will be filled with approximately ten liters of water, and some amount of plant fertilizer/nutrients in the water. The exact amount depends on the type of fertilizer used and the plant variety chosen; research is necessary.

Once this is done, the hydroponics system can be left alone. The sunlight hitting the solar panel will power the pump during the daytime hours, cycling the nutrient solution for most of the day. At night, the system is inactive, but the plants do not require constant nutrient solution flow over them 24/7; a few hours a day is sufficient.

4. How to Maintain the Prototype

Obviously with construction only just started, very little can be said about the maintenance and reliability of the system. So, this section is largely speculative.

In terms of structural reliability, there exists very little structural load to worry about. The entire system weighs several kilograms and is supported by sturdy wood. The water from the hydroponics system should not leak anywhere, so wood rot is not a primary concern. The electrics are very simple and low voltage, just a solar panel wired to a pump. With proper soldering and heat shrinks/electrical tape, there should be no chance of electrical shorts/breaks.

There is also almost no "load" on the system, the only wear that the system sustains is water running through the pipes and the pump operating. We suspect that the pump, being the only device in the system that has moving parts, would be a likely failure point. But it is operating well under its maximum capacity, and so should last several years before failure. Another potential worry is the integrity of the sealed fittings and tubing connections. The tightness of tubing connected to nipple-type fittings relies on the elasticity of the tubing, which becomes loose and stiff over time. And our 3D-printed fittings being installed into plastic creates a weak plastic-plastic seal that would eventually degrade. Failure here is inevitable, and likely accelerated by changing temperatures that the project would be subject in its operating location. However if everything is installed properly, we can delay failure for years or longer.

5. Conclusions and Recommendations for Future Work

The plan to finish the project goes as follows: we would have tested the 3D printed fittings and drilled the holes for the cups in the PVC pipes which were tasks that could have been done simultaneously. The next step would have been to drill the holes in the end caps and install the fittings if they were showing no sign of leaking. After that, the next lab would have given us the time to assemble the vinyl tubing connecting the PVC pipes, hook up the pump to the system, and mount the assembly onto the A-frame. From there we would have done testing to ensure the system is functioning as expected, and correct any design or assembly flaws that could arise (leaks, flow problem, etc).

Before assembling the whole system, we would have tested the 3D printed fittings on a panel made by a material similar to PVC to make sure they are not leaking. We would have drilled a whole about the size of the fitting in the panel then insert a rubber ring in the screwing part of the fitting and push the screwing part through the drilled hole and then screw the other part of the fitting and insert the tubing in the other end. We would have then spilled a generous amount of water on the panel and check if water was leaking through the fitting. Once this test was done and the rest of the system was assembled, we would have been ready to test our final prototype as a whole. Provided the prototype passed the testing, it would be ready for delivery.

In conclusion, this project was progressing well and according to plan; no major issues were encountered and the path forwards seemed clear. Should the University have not shut down due to

COVID-19, it is likely we would have a functional prototype that met our design criteria, and would satisfy the needs of our end user. We would have more insight to share on the continuation of this hydroponics system's development once the project was finished.

APPENDICES

APPENDIX I: Design Files

>>> All deliverable files, schematics, and other files can be found at the MakerRepo page <<<

APPENDIX II: MakerRepo Link

>>> https://makerepo.com/ymain094/hydroponics-ftw <<<