Universally Accessible Garden Final Report

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ENGR 232: Design and Communications II

Friday, April 17th, 2020

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Abstract

Methods for obtaining produce year-round pose an accessibility problem. Currently, there are products that allow for growing produce indoors year-round, but they are either prohibitively expensive or complicated. The goal of this project is to create an indoor hydroponic garden that can run year-round, be cost efficient and user friendly. To achieve this, we researched aspects of hydroponic gardening and plant needs to design a unit to achieve this goal. Due to the unpredictable circumstances that cut the school year short, we were unable to build a prototype or flesh our certain aspects of the project. Despite this, this report will outline the decision-making process, research conducted, a finalized design, and a description of exactly how it would function.

Acknowledgements

We would like to express our appreciation to all those who aided us in the completion of this project. We would like to acknowledge the support of Dr. Emeka Oguejiofor, P. Eng., and Paul Doiron, P. Eng., without whose guidance and feedback we would have struggled greatly. We also thank our classmates, for the questions and insights they gave us after presentations, which bettered the outcome of this project.

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List of Abbreviations and Symbols

CAD – Canadian Dollars

D.I.Y. – Do-It-Yourself

G.P.H. – Gallons per Hour

I.D. – Interior Diameter

P.V.C. – Polyvinyl Chloride

sqft – Square Feet

U.I. – User Interface

USD – United States Dollars

kW- Kilowatt

hr - Hour

Introduction

Problem

Current options for growing greens, herbs, and small fruits at home are not widely accessible to many people due to cost, complexity, size, or climate. The goal of this project is to fulfill this unmet demand by increasing the accessibility of the means for households to grow these items. It is important to note that this project does not attempt to completely replace one's diet but provide the ability for one to grow their own supplementary produce.

Background Information

In order to design better indoor gardening technologies, the first step is to investigate existing technologies for indoor horticulture. Two of the main technologies are hydroponics and aeroponics, which will be more thoroughly discussed in the design selection process section. Most units on the market implement a hydroponic system. These hydroponic units on the market divide into two main categories: enclosed fully automated and open fully automated. Both systems consist of a fully automated growing system, just differing in their encasement. Some people elect to build their own homemade DIY systems, as well. The following section will detail the functionality of each option and their shortcomings.

The fully automated enclosed systems include, but are not limited to, GroBox, Grobo Solid and LEAF. These systems are "Plug N' Plant", allowing the user to plug the box in, plant the seeds in the pods and the plant will start growing. The general dimensions for these systems are 27" W x 25" D x 62" H which would be about the size of a small fridge. These products are similar to a terrarium, so it is sealed and closed to the atmosphere. A terrarium is a sealed, transparent container in which plants are grown. They have sensors to control pH levels, nutrient concentration, temperature, airflow, humidity, water level and light. Some products also have an app available on your phone which allows you to track the plants growth. Although closed systems do everything when it comes to growing the plants, there are multiple issues that come with them. These products are expensive with a starting price of approximately $2500. Since they are fully enclosed there is no room for expansion, so the number of plants is limited to the number of pods. Given that most of them are the size of a small fridge, they would be difficult to install in a home with limited space.

One of the fully automated open systems is made by AeroGarden, and there are many different sizes. All AeroGarden products have fully automated grow lights that simulate the sun and have sensors to notify their user when to add water and nutrients. One of their largest products can hold 24 plants and is 36" W x 12" D x 34" H. This system is open to the atmosphere, making the plants are easy to access. Although open systems are cheaper than the enclosed systems, they can run up to $800 or more. In comparison to $2500 for a fully automated closed system this is much cheaper, but still rather expensive to grow some supplementary produce during the winter. The dimensions for an AeroGarden are quite large, and it could be difficult to find a location to put one in your house. To keep the plants from outgrowing the box, it is required to continually trim some of the larger plants. AeroGarden systems use soil-free seed pods to grow plants, but the pods are not reusable. Once the plants have finished growing, more pods need to be purchased, which can be expensive. The house must be maintained at a certain temperature and humidity year-round to keep the plants healthy.

Both the open and closed systems require electrical sources for the lights and pumps thereby increasing the costs of growing the plants.

Building a D.I.Y. hydroponic indoor growing system requires extensive knowledge of gardening and hydroponics. The result of a D.I.Y. indoor unit is an open gardening system with a large footprint. Since DIY units are not automated, they can be labour intensive and they require constant monitoring of the water, pH and nutrient levels.

Greenhouses are enclosed external structures where plants are grown in climate-controlled conditions. The walls and roofs are transparent – often glass or plexiglass – to let in sunlight. In colder climates, they need to be heated, like a house, and they require extra lighting, both of which heavily influence the operating costs. They need to be in an open area to get enough sunlight during the day. Greenhouses have a large footprint and may not be feasible for those who live in apartments or urban areas where space is limited. Pests, weeds, and lack of air circulation are issues that can occur in a greenhouse that would not be an issue if the system was used indoors.

Need for a Solution

Through extensive research, it has been determined that a demand for in-home garden products exists, and that current options are insufficient in meeting this demand. Demand for an increased accessibility for these products depends on people having a desire to grow their own produce. People may want to grow their own produce for multiple different reasons.

Firstly, those dissatisfied with the produce offered at their local supermarket stand to benefit from their own production. Whether they are disappointed in the quality of the produce, or just the fact that much of it is imported, rather than local, growing their own produce is a great solution. Many options offered in grocery stores are distributed by large scale supply chain models which can under-serve areas where chain stores are not as economically viable, such as remote rural areas. A survey conducted by the Nunavut Bureau of Statistics in 2016 found that the price of food in the Northern territory can cost as much as three times the national average (Skura, 2016), due to the high cost of transportation to these areas. This area resides in a colder climate where farming is not viable and has not been achieved. The traditional inhabitants of the area, the Inuit people, have existed almost entirely on hunting for food. This highlights a need for fresh produce that could be potentially grown at home.

Secondly, people are incentivized to grow their own foods due to the benefit of locally sourced produce. Sourcing from distance requires methods to preserve food that can lower food quality. For example, pesticides implemented by large scale production can compromise the health of foods. The Center for Eco genetics and Environmental Health, University of Washington, cites studies finding that chronic, low-dose exposure of pesticides can lead to respiratory issues, memory disorders, birth defects, and cancer. (Health Risks of Pesticides in Food, 2013) The transportation of food over long distances also requires preservatives known to have adverse health effects. The methods for transportation also pose an environmental risk, with most using fossil fuels for energy.

Finally, there is an already existing demand for in-home garden products. AeroGrow, a publicly traded company specializing in home garden products, has a market cap of over forty million ($40M) USD as of February 2020. While this asserts a demand for these products, the price of AeroGrow units only allow them to be available to higher income earners. As a result, there is still a need for more accessible options.

Design Selection Process

Design Criteria

When looking at developing an in-home garden that is more accessible than those already on the market, we had to consider many different criteria. After research and discussion, it was determined that a successful project would incorporate three main criteria:

1. Accessibility
2. Efficiency
3. User-friendliness

The main objective of this project is to create accessibility through affordability. This means keeping the costs as low as possible, while providing a high-quality product that is reliable. This also means that any maintenance costs should be minimal. When it comes to efficiency, the produce must grow as fast as possible, without having large operation costs to come with it. The garden should be efficient in its power and water usage, so it won't have any large impact on the bills at home. The third main criterion is user-friendliness, meaning the garden must be easy to use by someone without technical skills. Set up and required maintenance, such as cleaning, should be simple enough that one can do it by following a set of instructions. This project aims to raise the standard in this market for these three previously mentioned metrics.

Types of Gardens

There are a variety of growing mediums used in indoor gardens. Several options were researched as possibilities, all of which have unique benefits and disadvantages. The conventional method is to just plant directly in soil. The advantage of this type of garden lies in its simplicity, and its familiarity to people who may have grown vegetables outdoors before. These gardens are also more forgiving than hydroponic setups, since they dry out much slower if the water supply is interrupted. Unlike the other growing mediums researched, soil gardens often require pesticides to ensure the highest quality produce, and some of the negative effects of pesticides have been previously stated.

One of the most widely used alternatives to a soil garden is a hydroponic setup. In this setup, the roots are placed in another porous material such as coconut fiber or gravel. A nutrient solution is then pumped through to deliver water and nutrients. Hydroponic gardens grow faster than soil gardens and yield more produce. Since the runoff solution drains back to a reservoir, more water is conserved and recycled.

They are also pest resistant. The downside of these systems is the complexity added by introducing electronic and mechanical systems which include, but are not limited to, power supply, pumps, and sensors. Plants in these gardens can also be at risk when the system fails, due to the reliance on mechanical processes. There are many possible configurations for hydroponic systems, diagrams of two hydroponic setups considered for use in our project can be found in the Appendix.

The final growing medium considered is an aeroponic system. In these gardens, the plant's roots are left suspended in the air and misted with a nutrient solution. These systems are even more water and nutrient efficient than hydroponic systems, and they grow faster and yield more. Aeroponic gardens are also more space efficient as the plants are not competing for nutrients. The downside of these systems is the additional complexity, since aeroponic systems require more maintenance and inspection. Since water and nutrients are very specifically targeted to the plants, any failure in the system will cause the plants to die very quickly.

With the information and the criteria presented above, it has been determined that the project will implement a hydroponic set up. This type of system maximizes efficiency without being too complex. It should also be cleaner than a soil garden indoors, and more affordable than other hydroponic and aeroponic systems.

Component Selection

In order to achieve our set goals, we had to select components that aligned with our design criteria, creating a prototype that was accessible, efficient, and user friendly. This means that many aspects of the system needed to be automated. In order to achieve this, we decided to include a humidity as well as a PH sensor in our design. This also necessitated a microcontroller as well as a display in our design in order to display meaningful information in real time to someone who is not familiar with gardening. We chose to use an Arduino UNO for this as several group members were already familiar with it. To further increase accessibility, we decided to automate the grow lights as well as the pump through the microcontroller, which required a 2-channel relay module. We also decided to automate the humidity within the enclosure using an ultrasonic mist-generator (atomizer) that ran on 5V power and could be connected directly to our microcontroller. We decided on an LCD display that displays 2 lines of 16 characters of text due to the limited number of free pins remaining on the microcontroller. Due to the number of free pins remaining, we also decided to include three buttons in our design that allows for the movement between different information screens, as well as the adjustment of the light timing directly through this interface.

The selection of lighting was a big decision, as if we didn't pick the correct type or size of light our growing options would be limited. There are three groups of photoreceptors in plants: phototropins, cryptochromes, and phytochromes. Phototropins and cryptochromes are active in lower range wavelengths of light, UV (A) and blue, while phytochromes are sensitive to red and far red wavelengths. With this information, we decided a full spectrum grow light would be best, as it would allow us to emit whichever wavelength we need. (CANNA Research, n.d.) To determine the size of light to purchase, we looked at what area the lights cover from certain heights, and simply chose one that was affordable and met our other requirements.

The hydroponic components of the prototype were decided on with the help of the vast wealth of information that can be found online concerning D.I.Y. hydroponics. Based on dimensions of our prototype we decided on an 80 G.P.H. submersible pump feeding into a 'T' shaped section of half inch I.D. PVC pipe. The main loop would consist of half inch I.D. vinyl tubing, and there would be six quarter inch I.D. lengths of tubing running to drip emitters in the net pots of each plant. Further details on this piping system are included in the "Design Outcome" section.

Our selection of the materials for the configuration of the enclosure for our prototype was cut short by the early end to the semester. As it stood when classes were cancelled, we planned to use PVC pipe as the frame for our enclosure, due to its cost effectiveness as well as its ease of assembly with joint connectors readily available in different shapes/configuration. PVC pipe also had the advantage of allowing us to place the electrical components/connections of the prototype in a watertight environment away from the humidity within the enclosure. The enclosure would be encased in some sort of plastic material with a zipper for access to keep the humidity in.

Project Specifications

Plants need certain conditions to grow properly. While designing this garden, the biggest problem will be making sure the plants are provided with everything they need. A pH of 6.0-6.5 will need to be maintained for the plants to absorb the optimal level of nutrients. (What is The Best pH for Hydroponics?, 2019) The solution must consist of nitrogen, potassium, phosphorus, calcium, magnesium, sulphur, iron, manganese, copper, zinc, molybdate, boron, and chlorine to provide the plants with all the needed nutrients. (Hydroponic Nutrient Solutions, 2020) The air humidity in the unit will also have to be adjusted because the average humidity in a house during the winter is around 30-40% while plants require at least 50% humidity, some needing up to 70-80%. (Ideal Humidity For Indoor Tomato Plants, 2016) The recommended temperature of a hydroponic unit is within the range of 17-25°C, which is around room temperature. This means the design does not need a temperature control, as having it at the temperature of the room will be sufficient. Most plants that are being investigated as options grow to be around 1-2 feet tall, which will be a main deciding factor in our design dimensions and take around 2-3 months to be ready to harvest.

Taking all these needs into consideration the garden will likely be able to grow these varieties of plants:

- Leafy Greens: Lettuce, Spinach, Kale, and Cabbage
- Herbs: Basil, Parsley, Cilantro, and Mint
- Dwarf/Cherry Tomatoes
- Mini Bell Peppers
- Strawberries

Software Design

Due to the same circumstances that prevented us from building a prototype, we deemed it impractical to write code that we had no way of testing. Since the different components of the prototype were spread out amongst us across the country, any code we wrote would most definitely not work as intended since we had no means of properly debugging it. Despite this we laid out exactly how the U.I. of the prototype would function through the L.C.D. display and the three buttons. These three buttons will be referred to as “left”, “select”, and “right”, and would have been identified with the symbols ‘<’, ‘+’, and ‘>’ respectively. The U.I. would have consisted of 2 distinct screens and 4 distinct states. A mockup of what each screen would look like is shown in Appendix 1.3. A flow chart that lays out exactly how the U.I. would function is shown in Appendix 1.4. In addition to this, the software would also use the humidity sensor and the ultrasonic atomizer to maintain the humidity within the enclosure at 55%. The timing of the pump would also have been hardcoded into the software, but in order to determine with any certainty how it should be set, we would have to have a prototype built. That would allow us to measure the rate that the solution moves out of the drip emitters and flows back into the reservoir. The software in the prototype would have also performed the additional function of shutting down the pump and displaying a message when the PH sensor, which would have been suspended in the reservoir just above the intake for the pump, is no longer submerged. This would serve as a failsafe to prevent damage to the pump if something were to go wrong.

Analysis

Economic Analysis

Production Cost

Below is a list of materials with their associated costs, shipping included. Buying in bulk for larger scale production would further lower these prices. Some items can only be purchased in packs therefore could be used for production of multiple units. All prices are in CAD.

1x 45W Full Spectrum LED Grow Light- **$30/unit**

1x 80 GPH Submersible Water Pump- **$13/unit**

1x 5V 2 Channel Relay- **$3/unit**

1x Temperature & Humidity Sensor- **$2/unit**

1x (Pack of 5, 1 required) 20mm Ultrasonic Misters- $16.73 /5 = **$3.35/unit**

1x (Pack of 12, 6 required) 3" Net Pods- $4.80/2 = **$2.40/unit**

1x Power Bar- **$13/unit**

1x 8'x20' Heavy Duty Tarp for unit exterior (fits 2 units)- $20 /2= **$10/unit**

2x 100cm Canvas Zipper- $5 x2= **$10/unit**

1x (Pack of 4, 1 Required) Wash Basin /Water Reservoir- $22/4= **$5.5/unit**

1x Velcro Tape 16ft (fits 8 units)- $10/8= **$1.25/unit**

1x Arduino Uno - **$25/unit**

1x LCD Display 3"x1.5"- **$5/unit**

3x PVC Pipe 2"x10' (30' total, 24' needed)- $14x3x 24/30 = **$33.6/unit**

4x PVC Elbow Joint 3-way- $3x4 = **$14/unit**

Materials cost of making only one unit= $230.53 CAD

Materials cost per unit= $171.10 CAD

*Due to being unable to create a prototype the time to assemble is unknown

Power Usage Cost (Nova Scotia Power Winter Day Rates)

Unit Energy Usage: 51W

$0.08878/kW.hr x 8hr= $0.62/kW

\$0.242/kW.hr x 12hr= \$2.41/kW

\$0.158/kW.hr x 4hr= \$0.63/kW

0.051kW x (\$0.62+\$2.41+0.63)/kW= **\$.19 / Day**

*Winter rates used due to higher rate

Engineering Analysis

Throughout this design project, several types of engineering analysis were employed, mainly electrical engineering, and fluid mechanics. Had an actual prototype been made structural engineering would have been employed as well.

Electrical engineering played a significant role in this project. Designing the electrical "guts" of the garden was a straightforward process as all the selected components were capable of running on the 5V of DC power supplied by the microcontroller, with the exception of the grow light and the pump. To control these components, we incorporated a 2-channel relay which is capable of switching the 120V AC power these require to run. The complete circuit diagram for these electronics can be found along with the list of pin connections for the microcontroller in Appendix 1.1 and Appendix 1.2 respectively.

Fluid mechanics was also used in the project. To determine pump sizing the following formula was used:

$$\text{growing tray area (sqft)} \times 20 = \text{minimum pump size (G.P.H.)}$$

(Fernandez, 2015) resulting in these calculations:

$$2 \text{ sqft} \times 20 = 40 \text{ G.P.H. minimum pump size}$$

Since the minimum pump size is 40 G.P.H., pumps that size and larger were considered. An 80 G.P.H. pump was decided on, as that size exceeds the minimum required for our tray size, and it would be able to pump high enough to reach the tray from the reservoir.

Had a prototype been able to be built, further calculations and testing would have been done to determine the ideal pump power, drip rate and the timing schedule. In order to do these calculations, a prototype was needed to actually run tests to aid decision making in which settings to use that would result in optimal plant growth.

Design Outcome

The frame is constructed from 2" PVC pipe with the dimensions 3'x2'x1'. These dimensions allow for space to accommodate the 2' grow space that was determined to be able to grow most options that were explored, as well as to be able to accommodate the growth of 6 plants with proper spacing. The material was chosen primarily for its reasonable price at $1.4/ft, but it comes with the added benefits of being lightweight, durable, as well as the hollow insides can be used to run electrical wiring. To enclose the unit, it is tightly wrapped on all sides in a transparent heavy-duty tarp. Two vertical canvas zippers are installed on both sides of the front face, and a horizontal Velcro strip is installed along the bottom. This allows the whole front face to flip up and over the top while the unit is being accessed. Once again, these choices were made to keep costs low, due to hard material alternatives costing anywhere from two to three times as much. This method of enclosing the unit achieves the seal that was required to control for humidity. The AutoCAD drawing for our design can be seen below in Figure 1.

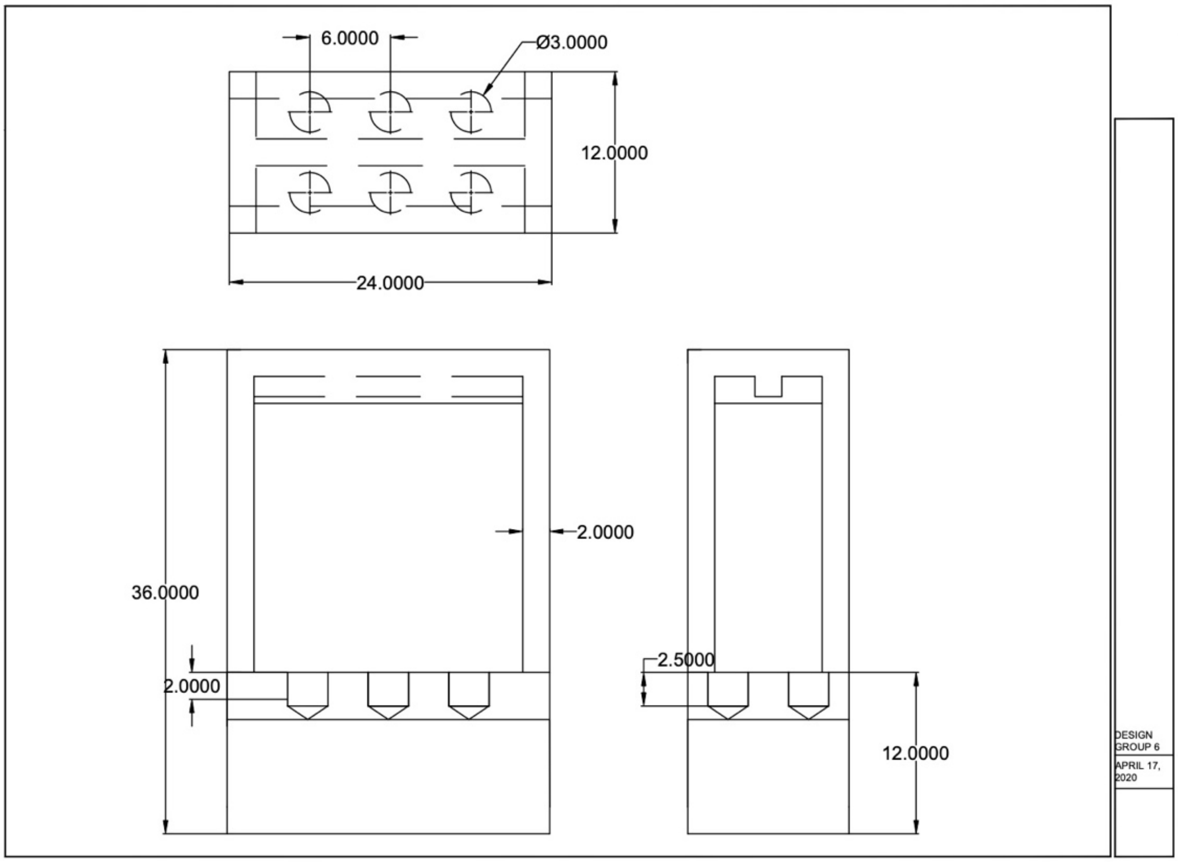


Figure 1: AutoCAD Drawing

To get the nutrient solution to the plants, our design uses an 80 G.P.H. submersible pump feeding into a ‘T’ shaped section of half inch I.D. P.V.C. pipe. The base of the T leaves the output of the pump vertically (rising straight up). The two ends of the top of the T then connect with two semi-circular loops of half inch I.D. vinyl tubing which run in the same horizontal plane as the top of the T. This loop then feeds six quarter inch I.D. lengths of vinyl tubing which run to drip emitters in the net pots of each individual plant. The piping system is shown below in Figure 2. These drip emitters ensure a slow, yet constant stream of nutrient solution reaches each individual plant. The reason for this configuration is to ensure constant pressure throughout the main loop of the tubing and therefore a consistent flow of solution to each drip emitter.

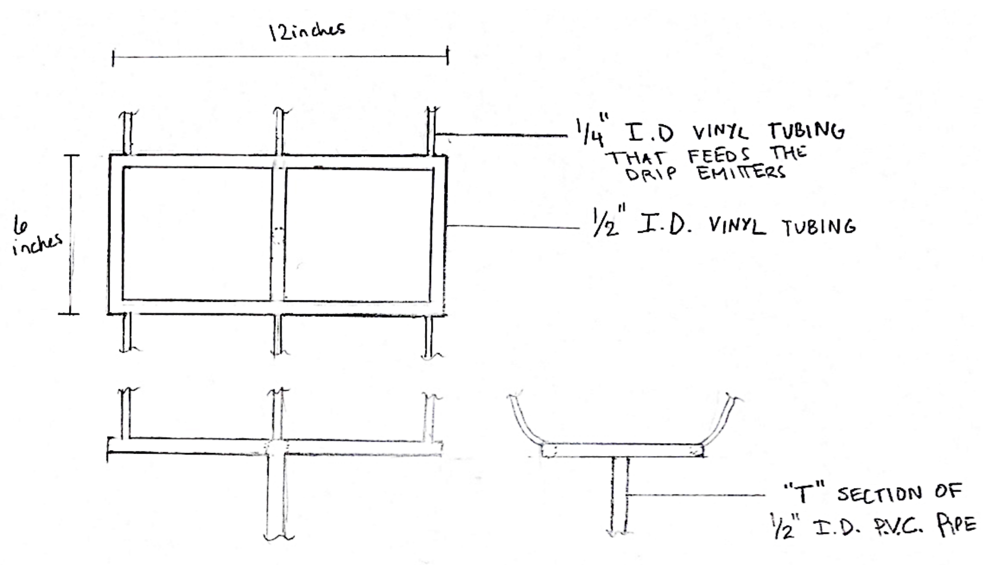


Figure 2: Piping System

Conclusion

Next Steps

Due to the early cancellation of classes, we were not able to finish this project the way we initially intended to. We had already picked out products we intended to order to build the prototype, so, the next steps for us would entail actually building the prototype. This would start with building the frame and getting the grow tray and reservoir in. Once those are both assembled, we would be able to install the smaller components: the net pots, pump, piping, drip emitters, and all the electrical components. With the prototype fully constructed, testing of the systems would then begin. We would work to find the most suitable setting of our pump, and from there move on to the timing schedule. Once the pump and timing are figured out, the final step would be programming everything into the microcontroller and making sure everything runs as it should. We would then be able to actually test the garden's ability to grow produce.

Lessons Learned

One of the biggest takeaways from this project was group communication. As engineers we will almost always being working with groups of people: other engineers, contractors, clients, etc. Keeping on top of the project grew much harder when the pandemic hit, and we all moved home. At that point, communication became that much more vital. Maintaining weekly check-ins and keeping tabs on what everyone else was doing were major in the completion of our project. Working together towards the goal of completion, teamwork, is vital in any group effort.

A big lesson regarding the design of the project was understanding that there is an associated cost with anything that is trying to be added. Many portions of our original idea had to be modified or left out in order to stick to the goal of affordability and keeping the costs low. This was good practice in making choices about the value versus its corresponding cost and trying to retain the original goal of the design while navigating this aspect.

Another lesson taken from this experience is to be prepared, and to expect things to go wrong. Large factors outside of our control lead to the cancellation of classes and our group spread over the country. This caused a large stress on the group, since we were no longer able to meet up in person, and because we couldn't build a prototype. We had to adapt in order to get the project done. Many online video calls and our team group chat going almost nonstop were key in finishing our project.

A final takeaway is accountability. When working in groups, you must be accountable to not only yourself, but to your group members as well. If you don’t complete your part in a timely manner, you can throw off the entire project. You also have to be okay with calling out group members who aren’t doing their share of work. Being accountable is a necessary life skill.

Appendix I: Circuit Diagram:

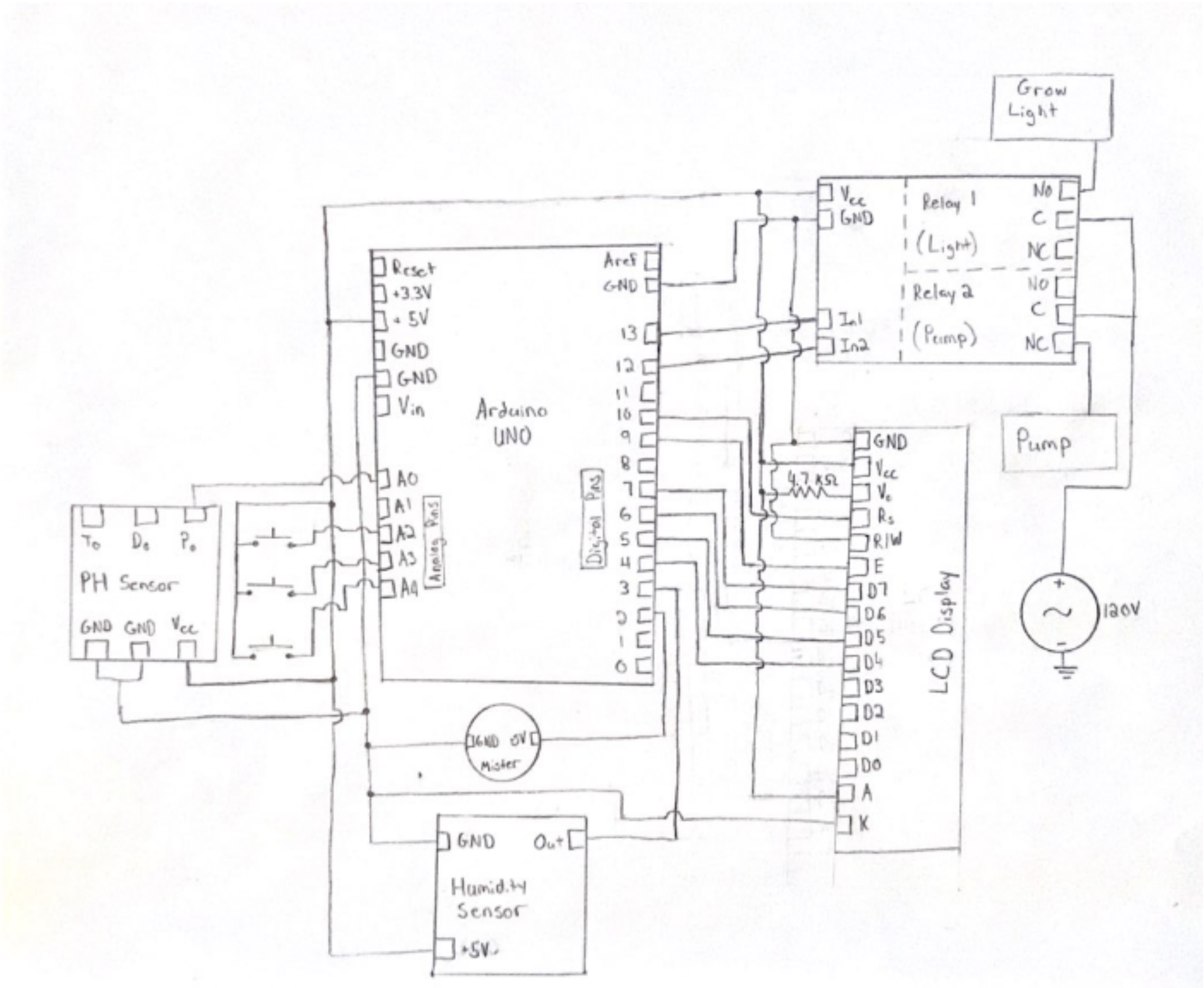


Figure 3: Circuit Diagram

Appendix II: Arduino Pin Connections:

<u>Outputs:</u>

Digital Pin 2 -> Ultrasonic Mister

Digital Pin 13 -> Light Normally Open Relay (In1)

Digital Pin 12 -> Pump Normally Open Relay (in2)

Digital Pin 10 -> LCD Registry Select (Rs)

Digital Pin 9 -> LCD Enable (E)

Digital Pins 4,5,6,7 -> LCD Data 4, 5, 6, 7 (D4, D5, D6, D7)

<u>Inputs:</u>

‘<’ Button -> Analog Pin 2

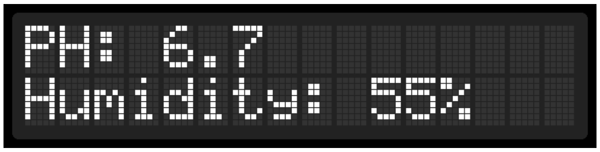
‘+’ Button -> Analog Pin 3

‘>’ Button -> Analog Pin 4

PH Sensor -> Analog Pin 0

Humidity Sensor -> Digital Pin 3

Appendix III: U.I. Mock-up



```
PH: 6.7
Humidity: 55%
```

Figure 4: U.I. Screen 1

```
Light Timer:
07:00 -> 19:30
```

Figure 5: U.I. Screen 2

Appendix IV: U.I. Flow Chart

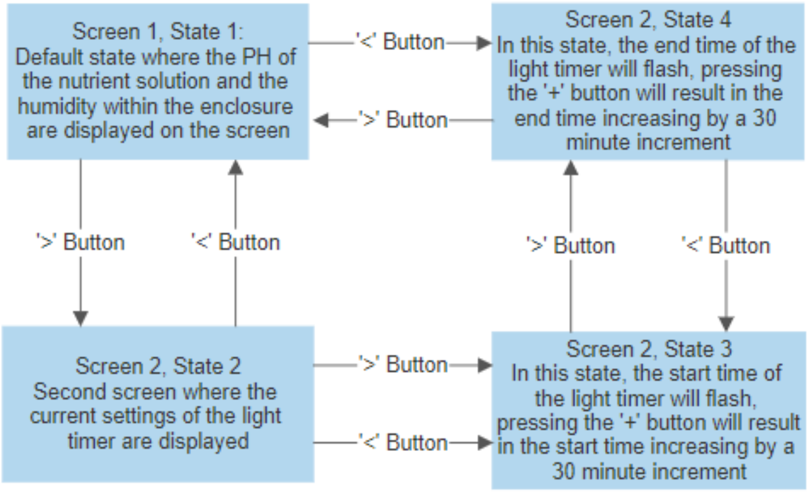


Figure 6: Flow Chart

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