Ho(m)egaarden - An Automated Hydroponics Bay

ECE 183 DB - Design of Robotic Systems

Date: 15th June 2018 | Professor: Ankur Mehta | Team:Watercress

Haoyang Ye(304456202), Shounak Roy(204482466), Rehan Shah(204406948)

http://www.powerhousehydroponics.com/automated-hydroponic-gardening-systems-for-your-home/

"When human designs are rooted in nature and diversity, education and regeneration, abundance and stability emerge"

- Max Meyers

Table of Contents

1. Abstract

This is a technical report that tackles the design and development of a home-scale automated hydroponics bay. The report details the problem being solved and why hydroponics is the best solution. It also highlights the main objectives and how they have been achieved using a robotics-based solution. A comprehensive narrative of the materials and methods used over a period of 10-weeks to execute this project are presented. Key system features and corresponding test results are discussed in depth. Roadblocks and key challenges are scrutinized leading up to a lowdown of the solutions that were devised. Some insight on future developments, improvements and utility of this project as a framework to build upon is also provided.

2. Executive Summary

Hydroponics has significant advantages over traditional soil-based agriculture in terms of strain on natural resources and crop growth efficiency. Although hydroponics is an effective solution, it is quite often an expensive one. The aim here is to use robotic tools in the form of a sensor and actuator based feedback control system to build an automated hydroponics bay that can be housed in the living room. The system is designed to be smart and cost-efficient, thus making it convenient for the everyday home-garden enthusiast. The entire system combined with human in the loop (HITL) control allows for the maintenance of an optimal environment for the crop being grown. The idea is to have an aquarium like setup and the goal is to grow a single type of crop. The implementation of sensor fusion is key to this project, where multiple sensors interact with each other to track vital growth parameters like temperature, humidity, pH, etc. The human user will receive this sensor information on an application based web interface on his mobile device where the push of a button will allow him to set actuators (Oxygen Pumps, LED Strip and Valves to change nutrient solution composition) into motion which will in turn work to stabilize growth conditions depending on the sensor feedback. The end result is a smart hybrid robotic system that integrates both home automation and hydroponics to ensure user satisfaction while in a small way contributing to environmental conservation.

3. The "Why?"

3.1. Problem Statement

Soil-based agriculture places a strain on water resources and leads to a decrease in arable land for farming. Coupled with explosive population growth and a corresponding rise in the demand for food, this has led to a drastic increase in food prices.[1] Many solutions have been proposed to counter this problem and one that has gained a lot of traction is Hydroponics.

3.2. Background and Related Work

Hydroponics is essentially the art of growing plants without soil. The roots of the plant are in general supported by an inert medium with the roots exposed to a nutrient solution. The growth process occurs within a controlled and regulated environment.[2] The basic premise behind why hydroponics is so effective is that if you give a plant exactly what it wants and when it wants, then the plant will be as healthy as genetically possible. Some of the major advantages of hydroponics over traditional soil-based agriculture are listed below in the form of statistics -

- Uses upto **90% less water** than soil-based agriculture
- Can accommodate **4 times the crop density** in the same space
- **No seasonal dependency** for crop growth
- **Bigger**, **faster** and **stronger** growth
- Results in **20 times traditional yield**
- Requires **less fertilizer** and generates **less waste** [3]

Hydroponics is a niche technique and not a lot of farmers and gardeners have adopted it, much less home-garden enthusiasts. A few hydroponic installations are commercially available but they are often too intensive and expensive for a home environment. For instance, an intensive aquaponics garden installation that an MIT startup - Grove Labs offers, on average costs $4200.[4] This figure is altogether too high to make such a system affordable to a vast majority of households. In addition, it takes a lot of involvement on the part of the user to effectively engage with these complex systems and not everyone has the requisite technical knowledge or wants to dedicate that kind of time to their plants.[5] `The solution to reduce unnecessary human involvement is to automate the system but a quick survey of such commercially available systems will immediately show you that comprehensive automated systems on average will set you back ~$1000.[6] These considerations lead into the motivation for the robotic system discussed herein.

3.3. Motivation and Scope

Robotic projects today have an arguably greater focus on areas such as biomimetics, vehicular autonomy (Advanced driver Assistance Systems), humanoids and even medical tools. Although there exist a few recycling robots, telepresence robots and harvesting robots[7], in general Robotics seldom features as a solution to the many environmental problems that plague the planet. This might be because people can't envision an immediate cause-effect relationship between robotics and environmental conservation. Robotics could potentially be a very useful tool in optimizing resource usage so as to avoid strain on the planet's resources. The deterrent thus far has been the high capital investments involved with setting up such complex robotic control systems. The aim here is to build a framework where scaling involves only minimal incremental costs and not a whole scale system revamp. This project is intended as a solution to a real-world problem designed with limited resources and at a relatively low cost (Frugality Engineering).

3.4. Novelty and Value

This projects' unique value lies in combining multiple gains. Increasing accessibility to hydroponics by lowering costs, keeping the complexity low so more people are willing to adopt this solution and creating an umbrella under which gardening enthusiasts, robotics enthusiasts, environmentalists and the average user can coexist.

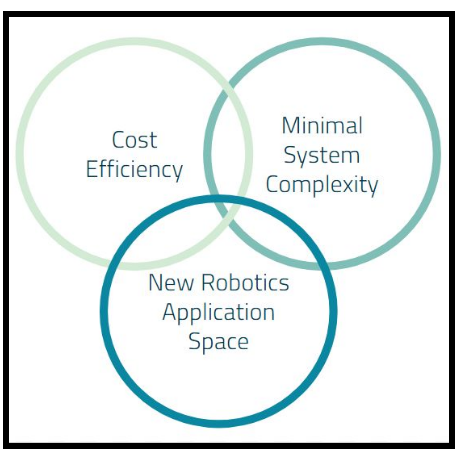


Figure 3.1: *Our Project's Unique Selling Proposition*

4. The "What?"

4.1. Project Considerations

The many key considerations for the project are highlighted below -

- **Crop Choice and Growth Environment**: This is fundamental to the system and there were essentially 3 options to choose from. The first was some sort of fruit or vegetable for home benefits where the produce can be grown, harvested and eaten at home. The second was a cash crop such as mushroom, strawberry or basil that could be grown for profit. The third was a plant like Marijuana that could be grown for recreational or medicinal distribution. In the end, the choice was a vegetable with a simple growth cycle - Watercress. The ideal growth environment is specific to Watercress and is discussed in detail in section 5.1.2.
- **Vital Parameter Identification**: Keeping track of several growth parameters is one of the most important tasks in hydroponics so certain key ones were identified. They include ambient light, humidity, temperature and nutrient solution parameters such as pH, dissolved oxygen and concentration of dissolved solids.

- **System Capacity**: Because this is a system designed for home use and this is just the construction of a test prototype, the capacity has been limited to 6 crop growth locations. Multiple seeds of Watercress are planted at these locations to ensure dense growth.

- **Type of Actuation System**: Some of the actuators that control light and oxygen are consistent for any hydroponics system but the irrigation system is the one that most depends on the setup. There was a toss up between drip and flow irrigation systems and it was decided that a variation of a drip irrigation system would better suit our single plant system. A streamlined flow of solution from a container, through a valve and directly into the nutrient solution is utilized. This prevents the problem of clogging that comes with drippers.

- **System Maintenance and Durability**: This has to do with the physical design of the system. The setup here is aquarium-like and is built of hard plastic. This is a durable material as opposed to a metal structure that would be corroded by the nutrient ions in the nutrient solution. All the actuation systems are also designed with similarly durable materials and are positioned such that there is no possibility of a liquid-electrical contact to ensure longevity of the devices.

- **Human Involvement**: The initial aim for this system is to have maximum human control although we aim for this to be easily handled by the user through 'smart' solutions. The system could eventually be scaled up by increasing sophistication and thus autonomy.
- **Other Crucial Considerations**: Arrangements have been made for a nutrient solution that has a balanced combination of primary and secondary macronutrients and also the required micronutrients. A growth chamber has been built that supports the plants and gives the roots access to the nutrient solution. There is also a reservoir to house the nutrient solution and a timer of some sort that is used in conjunction with the users to better handle the actuation system.

4.2. Robotic System Component Overview

Multiple sensors and actuators are utilized in this Automated Hydroponics Bay to maintain an optimum growing environment for the crop.

- **Temperature Humidity Sensor (Figure 4.2.1)**: This 2-in-1 sensor is attached to the side of the bay to measure temperature and humidity of the environment.

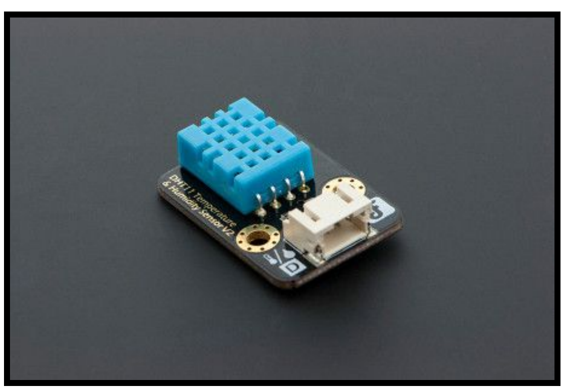


Figure 4.2.1: *Temperature Humidity Sensor.*

- **PH Sensor (Figure 4.2.2)**: This sensor measures the PH value of the solution in the bay and sends the data to the controller.

Figure 4.2.2: *PH Sensor.*

- **Light Sensor (Figure 4.2.3)**: This sensor measure the ambient light level and sends the data to the controller.

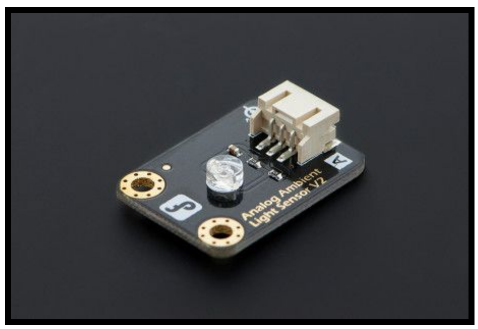


Figure 4.2.3: *PH Sensor.*

- **Total Dissolved Solid (TDS) Sensor (Figure 4.2.4)**: This sensor measures the concentration of the ionized solid within the nutrient solution and sends the data to the controller.

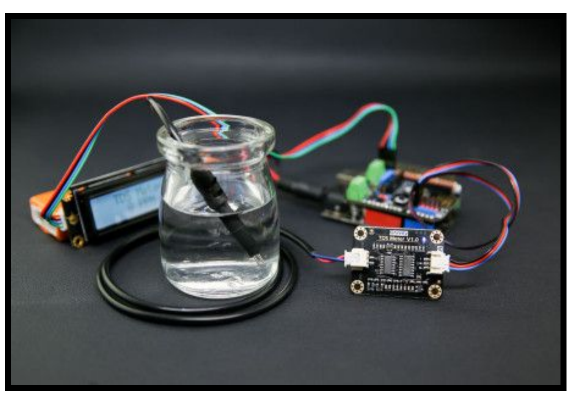


Figure 4.2.4: *Total Dissolved Solid Sensor.*

- **Electric Valves (Figure 4.2.5)**: There are four valves in our system. Four of them control the flow of the nutrient solution, acidic solution, alkaline solution, and water. The valves are subjected to the control of the microcontroller. An additional valve can be added to facilitate drainage. They have a minimal pressure requirement of 0.02 MPa (3 psi).

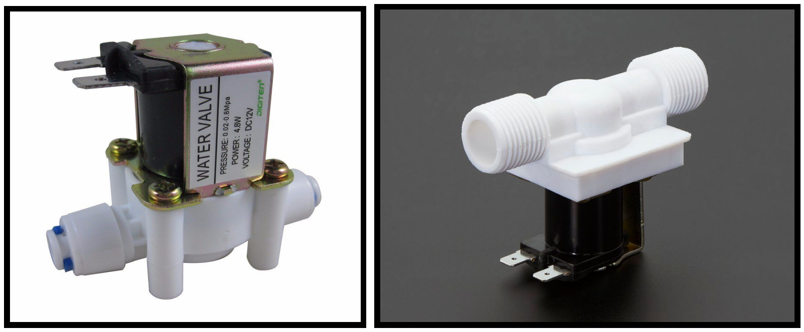


Figure 4.2.5: *Drain valve (left) and valve for solutions (right).*

- **Oxygen Pump (Figure 4.2.6)**: The oxygen pump will supply oxygen to the nutrient solution. It is operated under the assumption that the amount of oxygen consumed by the crops will not change to a great extent so the pump will operate on a routine basis or under the user's control.

Figure 4.2.6: *Oxygen pump.*

- **LED Array (Figure 4.2.7)**: An LED array is used as a supplement to natural light when the weather is cloudy or sunlight is unable to reach the crop. Red and blue lights are used which respectively enhance plant production/germination and plant photosynthesis.

Figure 4.2.7: *Red and blue LED strip..*

- **Web Interface**: An application based web interface is used to communicate with the hydroponics system. The system sends sensor data to the app which can be viewed by the user on his mobile device. The user can also use the web interface to send commands to the actuators to control the growth conditions.

5. The "How?"

5.1. Technical Implementation Details

5.1.1. Technical Implementation Overview

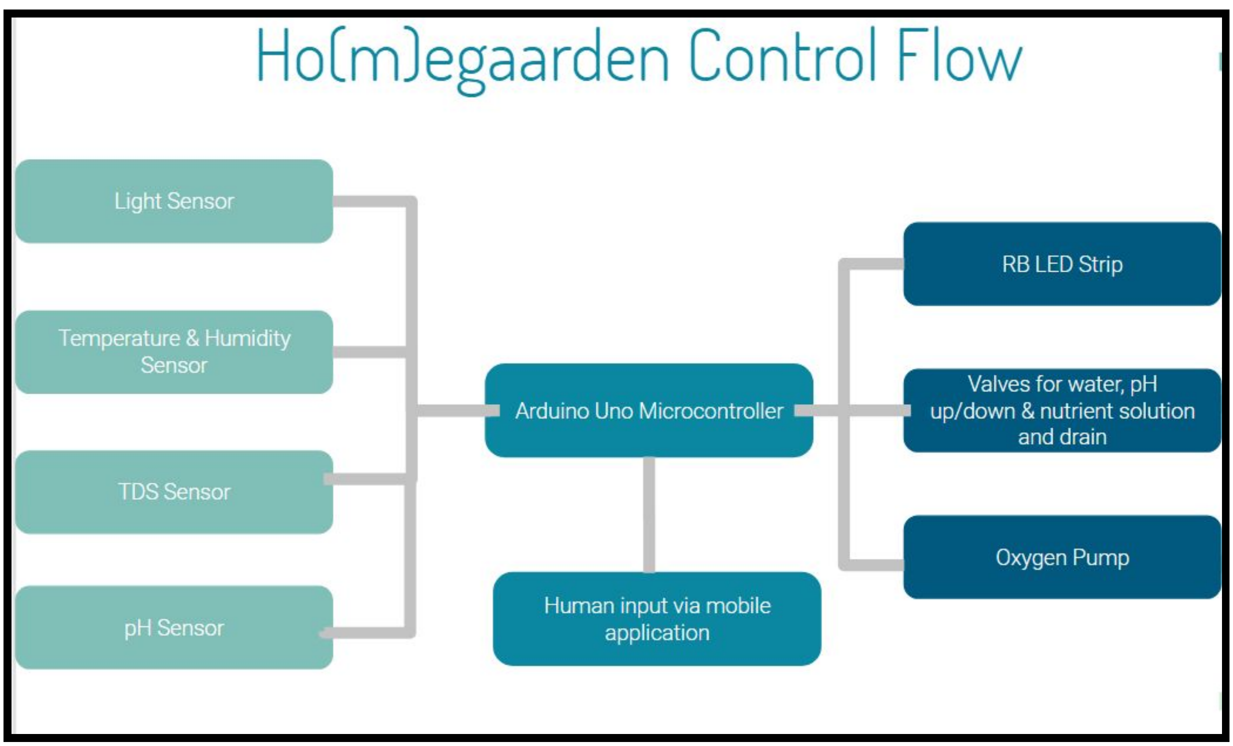


Figure 5.1: *The Flow of Control in the Robotics System*

- **Sensor Fusion**: The first task was to test all the sensors individually to make sure that they work with the Arduino and use the respective libraries to get data from the sensors. Once all the sensors had been tested individually, the sensors were tested in conjunction with each other.

- **Actuator Testing**: The next task was to program the actuators to work with the Arduino. In order to do this, the same methodology was followed as the sensor fusion task. First each actuator was tested individually and then tested in conjunction with others. The final sub-task was to test the sensors as well as the actuators together.

- **Model Construction:** In order to demonstrate the utility of this project, a model hydroponics bay was built that can be controlled via our robotics system. The idea for the model was to have a hard plastic tub filled with a nutrient solution. There would be a supporting structure floating on the solution on which the plant will be grown. All the sensors and actuators were mounted onto this model. As a consequence this would enable the monitoring and changing of the solution pH, the nutrient concentration , the amount of ambient light and the requisite oxygen flow. There would potentially also be a drain on the model to replace the nutrient solution mixture periodically.

- **Creating Web Interface**: The final task was to build the web interface to control the hydroponics system. The web interface consists of a mobile application the user can use to interact with the Arduino. As a result, the user will be able to change the plant's vital growth parameters without having to be in the proximity of the plant itself.

5.1.2. Plant Growth

Watercress, as the name suggest has a strong affinity to water and thrives when grown in hydroponic systems. To maintain constant wetness, a floating system is ideal and that is what has been designed here.

- **Step 1:** A series of 3cm x 3cm cubes have been cut in a 3 x 2 arrangement on a styrofoam board that can compactly fit the rockwool plugs so that they don't fall through. The cubes are not very close to the edges to prevent weakening of the styrofoam. This raft will support the growing plants.

- **Step 2:** One rockwool plug is fitted into each hole and some water is added so that it expands in place and fits snugly.
- **Step 3:** This setup is placed in our aquarium like structure and placed in an area that gets several hours of sun each day. During darkness, an LED strip is used to provide light.
- **Step 4:** The hydroponic nutrient solution is made by adding a few tablespoons of nutrient mixture to about a gallon of water and mixing very well.
- **Step 5:** Tubing from the oxygen pump is immersed in the nutrient solution to oxygenate and enrich it.
- **Step 6:** The styrofoam board is set afloat on the nutrient solution. The watercress seeds are inserted into the small cavity on top of each of the cubes and under ideal conditions the seeds germinate within a week.[8]

Table 5.1: *Summary of growth conditions for watercress*

Watercress Growing Considerations[9]	
Growth Features	**Description**
Growing Culture	Hydroponics - Simple Floating System
Plant Height	Expected ~6 inches (in our system)
Preferred pH Range	Ranges from mildly acidic(pH=6.0) and mildly alkaline(pH=7.5)
Seed Germination Period	5-6 days in our system
Support Medium	Rockwool cubes
Sun & Lighting Requirements	Prefers full sun but tolerates some shade
Water Requirements	Above average, thrives in Hydroponics
Nutrient Requirements	Primarily potassium, iron and phosphorous

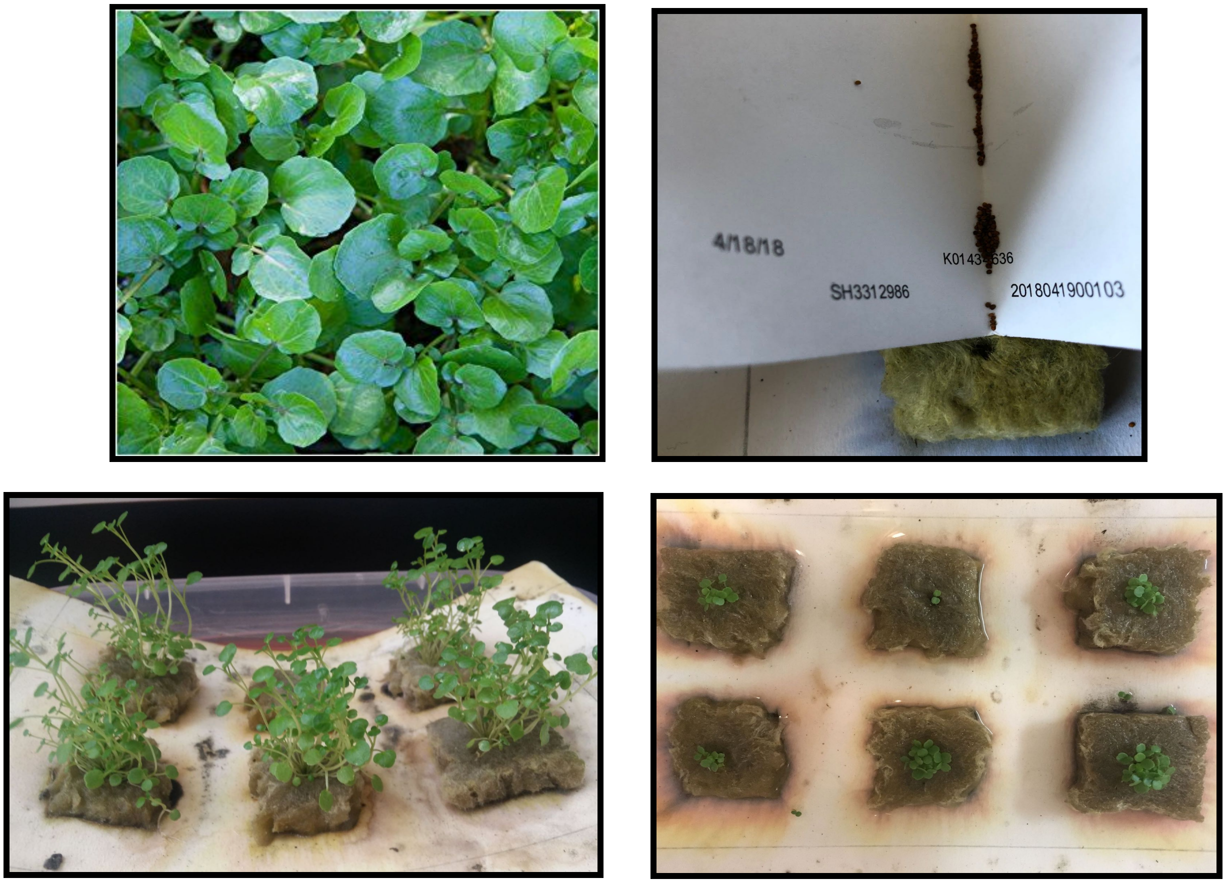


Figure 5.2: *Clockwise from top left - 1) The crop of choice: Watercress 2) Seeds being inserted into the Rockwool Cubes 3) Watercress germination in our system 4) Watercress growth after 3 weeks in the system*

Due to prior lack of knowledge with gardening and specifically hydroponics setups of all our team members, industry opinion was obtained from the experts after a visit to Greencoast Hydroponics in Venice, Los Angeles. The major takeaways included -

- Trade secrets for growing Watercress
- Correct Ingredients for the nutrient solution
- Ideas for resource optimization within the system
- Information about potential challenges including algal/fungal growth

To actually test whether hydroponics actually enhances and improves crop yield, watercress seeds were planted both in soil and in the rockwool plugs in the system for a comparative study. **Over the course of 3 weeks, the plants in the hydroponics system grew significantly better than the ones in the soil and also looked significantly healthier.** This served as one of the biggest validations for why this project was undertaken.

5.1.3. Model Design and Construction

The model is based on a 32 sq-ft Hefty plastic storage container as shown in Figure 5.3.1.

Figure 5.3.1: *Storage Tub that serves as the base for the Model*

A simple diagram of the model is shown in Figure 5.3.2. Two valves each are mounted on the inner wall of sides **1** and **3** respectively in the regions **a**, **b**, **c**, **d**. Region **e** on the outer wall of side **4** houses the holder for the air pump. On the inner wall of side **2**, the sensors and the microcontroller are mounted in region **f**. On the outer wall of side **2**, two breadboards are stuck in regions **g** and **i**. Region **h** contains the holder for the battery pack and region **j** is where the outlet relay module will be placed.

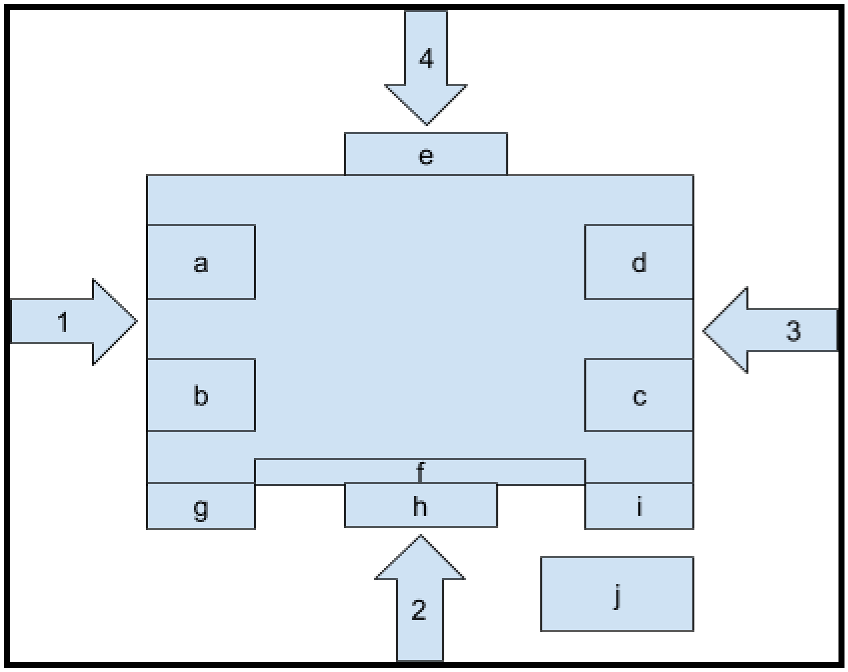


Figure 5.3.2: *Diagrammatic Layout of the Model*

The model is assembled using multiple methods. The sensors and all the holders are mounted with screws and nuts. The solution valves, the air pump, and the battery pack simply rest on the holders. Double-sided tapes are used to attach the LED strip and the two breadboards onto the model.

Each sensor is mounted onto a piece of styrofoam board (shown in figure 5.3.3) with two M6-1 x 40 mm flat cap screws and nuts (shown in figure 5.3.4). Then with two screws and nuts of the same kind, the board is mounted at region **f** in figure 5.3.2 (shown in figure 5.3.5). In this way, modularity is implemented because the user can either replace the sensors individually or change the entire sensor set just by unscrewing two screws. There is also additional space for the user to add more sensors to the system.

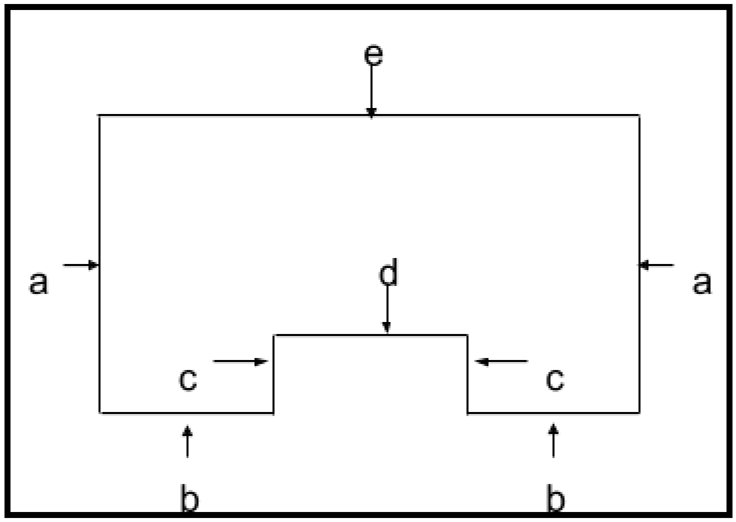


Figure 5.3.3: *Diagram of the board that the sensors are mounted on. The two sides labelled 'a' , 'b' , 'c' are 15.2 cm, 9.5 cm, 3.5 cm long respectively. The side labelled 'd' is 10.7 cm long and the side 'e' is 29.7 cm long.*

Figure 5.3.4: *Picture of screw and nut used to mount sensors*

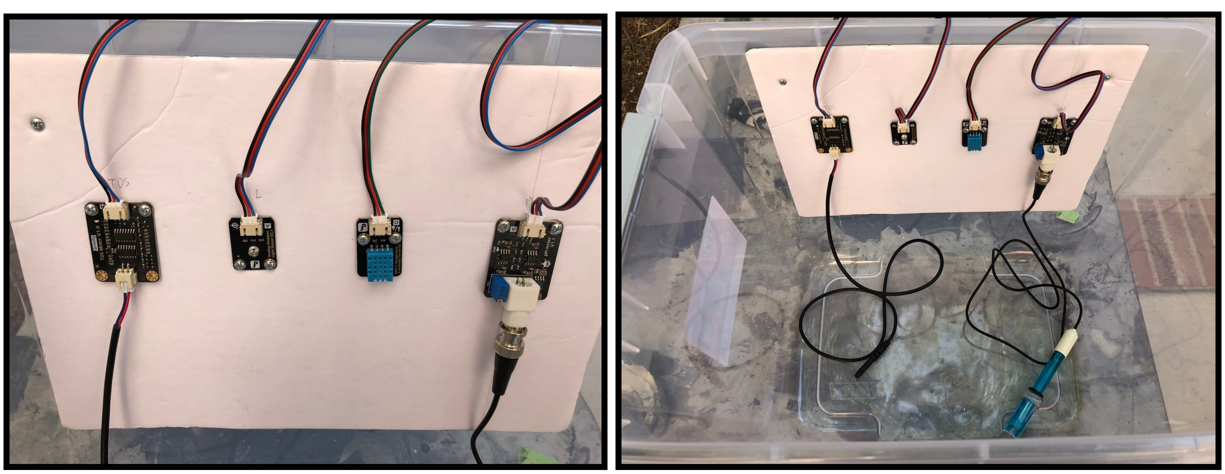


Figure 5.3.5: *Picture of sensors mounting onto the board (left) and board mounting onto the container (right). On the left, the sensors from (L-R): TDS sensor, Light sensor, Temperature Humidity sensor and PH sensor.*

For the holders, two M6-1 x 20mm socket cap screws and M6-1.0 DIN 439B Jam nuts (shown in figure 5.3.6) are used to mount each holder. Four 3D-printed forklift holders (shown in figure 5.3.7) are mounted at the regions **a**, **b**, **c**, **d** in figure 5.3.2 (shown in figure 5.3.7). Each solution valve connected with a square solution container (shown in figure 5.3.8) rests on one holder (shown in figure 5.3.9). L-shaped holders (shown in figure 5.3.10) are mounted at regions **e** and **h** in figure 5.3.2. Just by unscrewing two screws, the user can replace broken holders or mount larger holders for larger or heavier valves or oxygen pump.

Figure 5.3.6: *M6-1 x 20 mm socket cap screw and M6-1.0 DIN 439B Jam nut.*

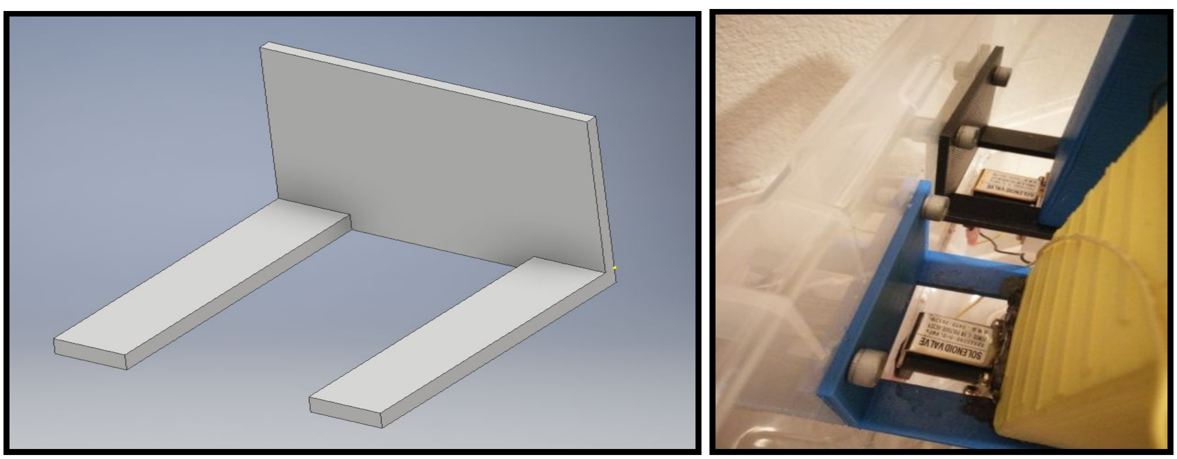


Figure 5.3.7: *CAD Model of forklift holder on Autodesk Inventor (left) and picture of mounting (right). The holder's back wall, it is 80mm long, 55mm wide and 3.175mm thick. The tip of the rectangular extensions are 80mm away from the back wall. The extensions are 17.5mm wide and 5mm thick.*

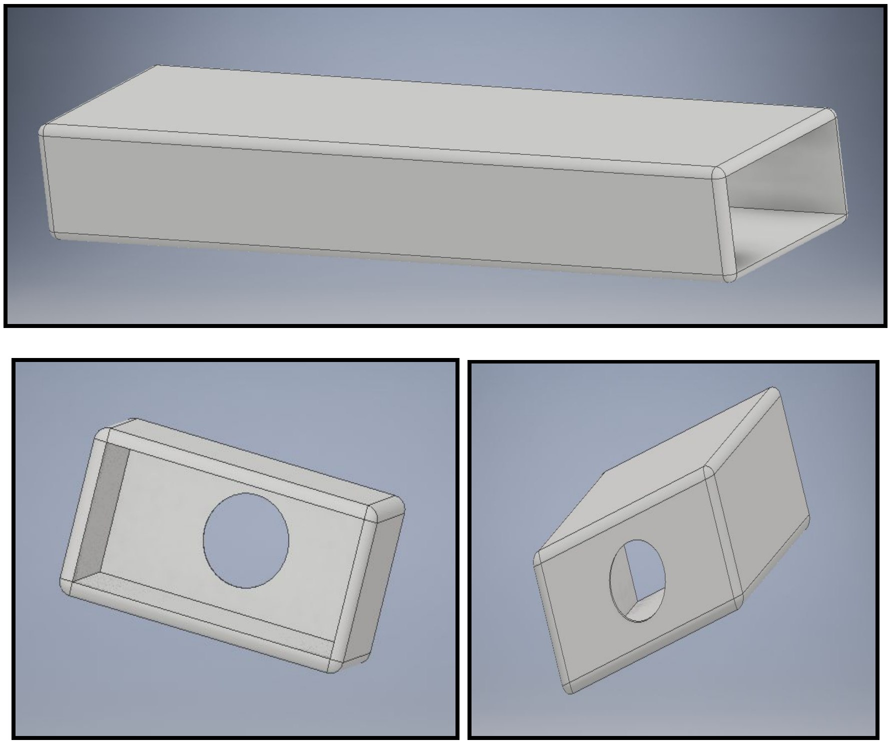


Figure 5.3.8: *3D CAD models of container body (top) and that of container connection (bottom left and right).*

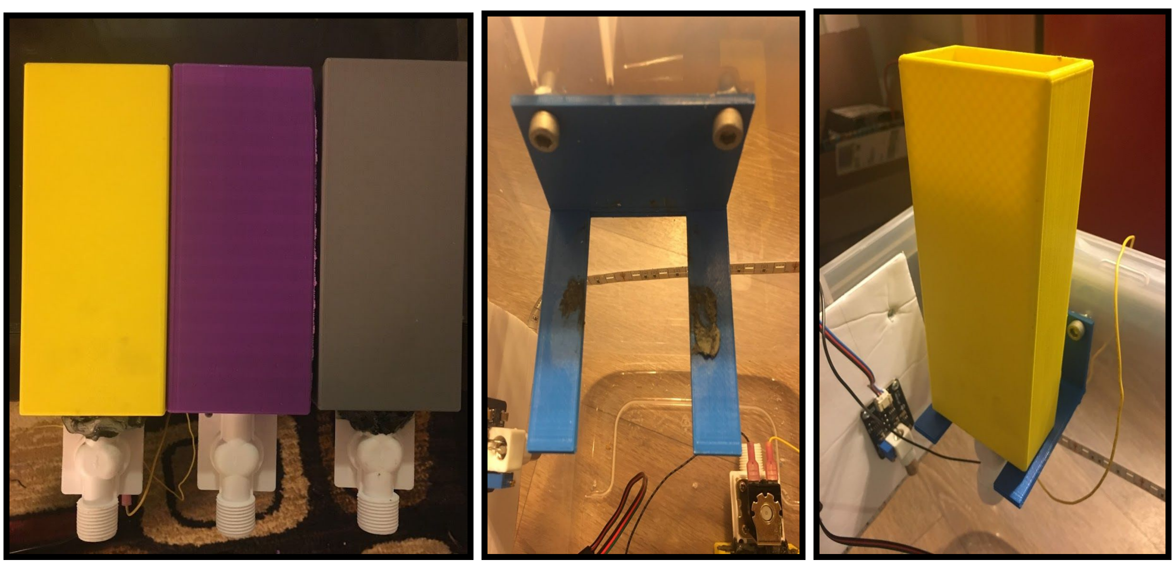
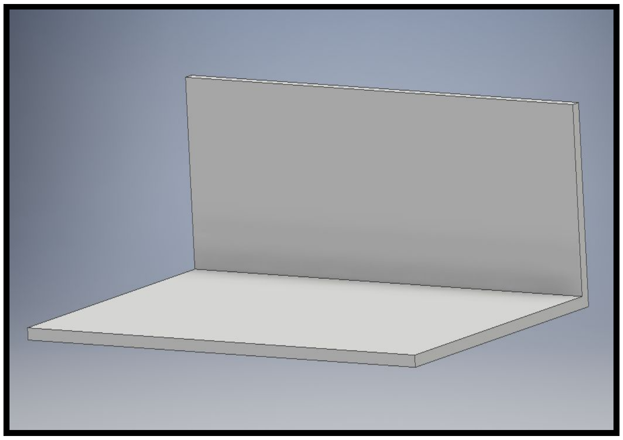


Figure 5.3.9: *Valves with containers (left), holder mounted (middle), and valve rests on the holder (right). The connection between the valve and container is sealed with M-Seal.*



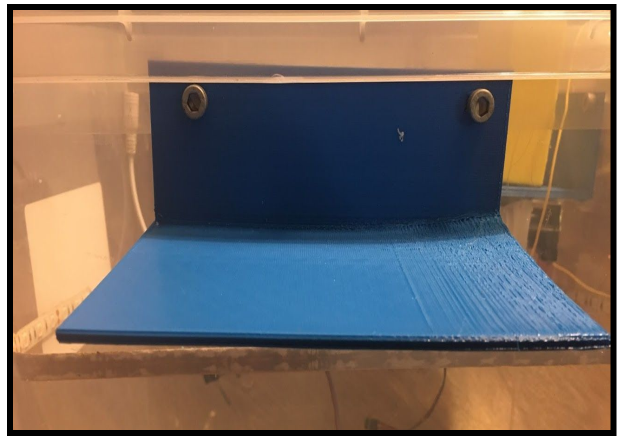


Figure 5.3.10: *3D CAD model of L-shape holder on Autodesk Inventor(left) and picture of mounting (right). The horizontal side of the L is 150mm x 90mm and the vertical side is150mm x 53.175mm. The walls of the holder are 3.175mm thick.*

The LED strip is taped around the inner sides of the model (shown in figure 5.3.11) and the two breadboards are attached to the outer sides of the model with double-sided tape. The breadboard at region **g** in figure 5.3.2 carries the NMOSFET circuits (shown in 5.3.12) for the valves which is powered by the 12V battery pack (shown in figure 5.3.12) placed at region **h**. The breadboard at region **i** in figure 5.3.2 acts like a voltage bus for all sensors which are powered by the 5V output from the Arduino Uno. Placing the switching circuit on a breadboard instead of a Printed Circuit Board (PCB) allows the user to add more switching circuits for more valves easily. Due to budgetary constraints, using a breadboard is preferred over buying a specific voltage bus.

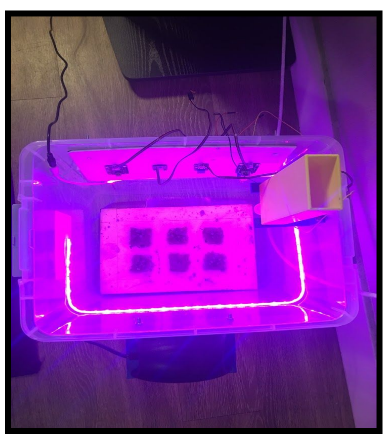


Figure 5.3.11: *Photo showing the LED attached around the inner sides of the model.*

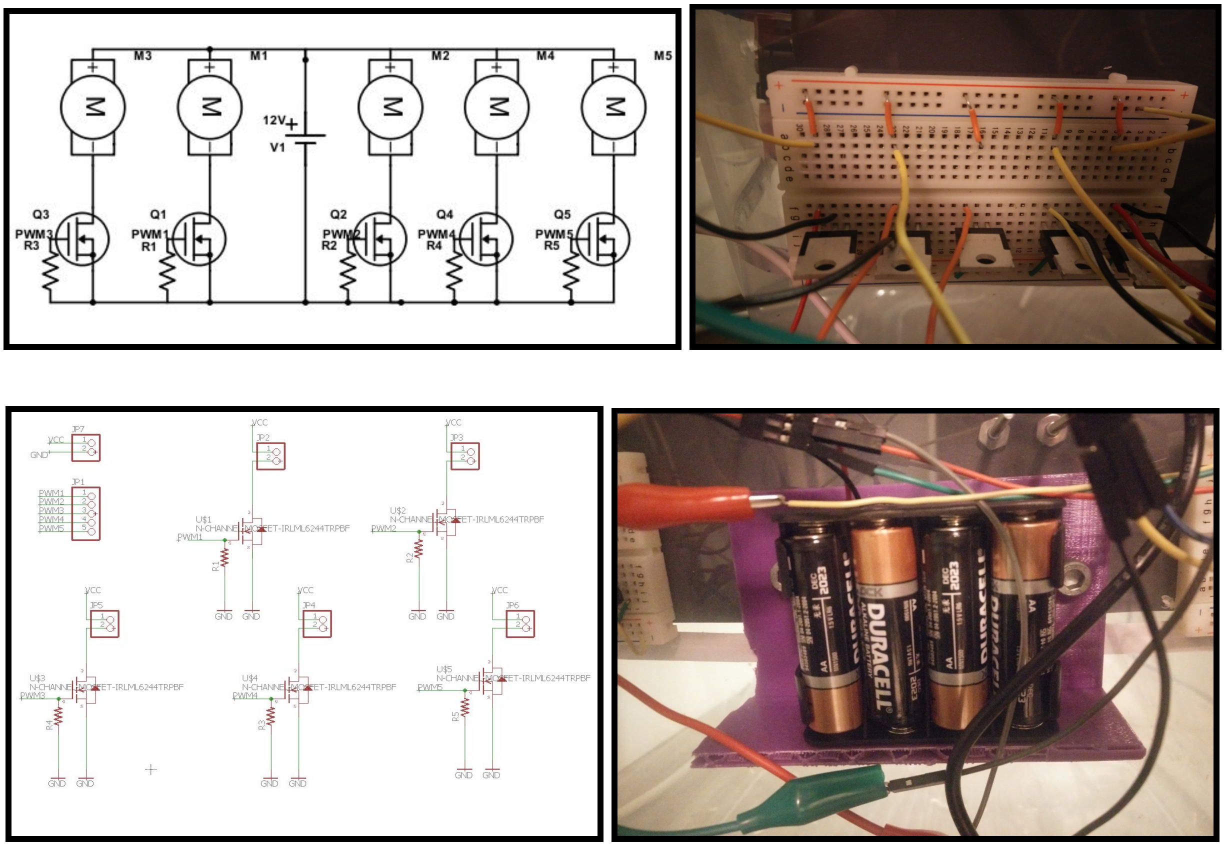


Figure 5.3.12: *Simple diagram of switching circuit (upper left), the actual implementation (upper right), the EAGLE schematic of the circuit (bottom left), and the battery pack (bottom right).*

5.1.4. Sensor Fusion, Testing and Integration

Each of the sensors was first tested individually and then in conjunction with each other. Test data for each of the sensors is shown below. The output is from the Arduino serial monitor. The Github link in the appendix contains all the sketches used for testing.

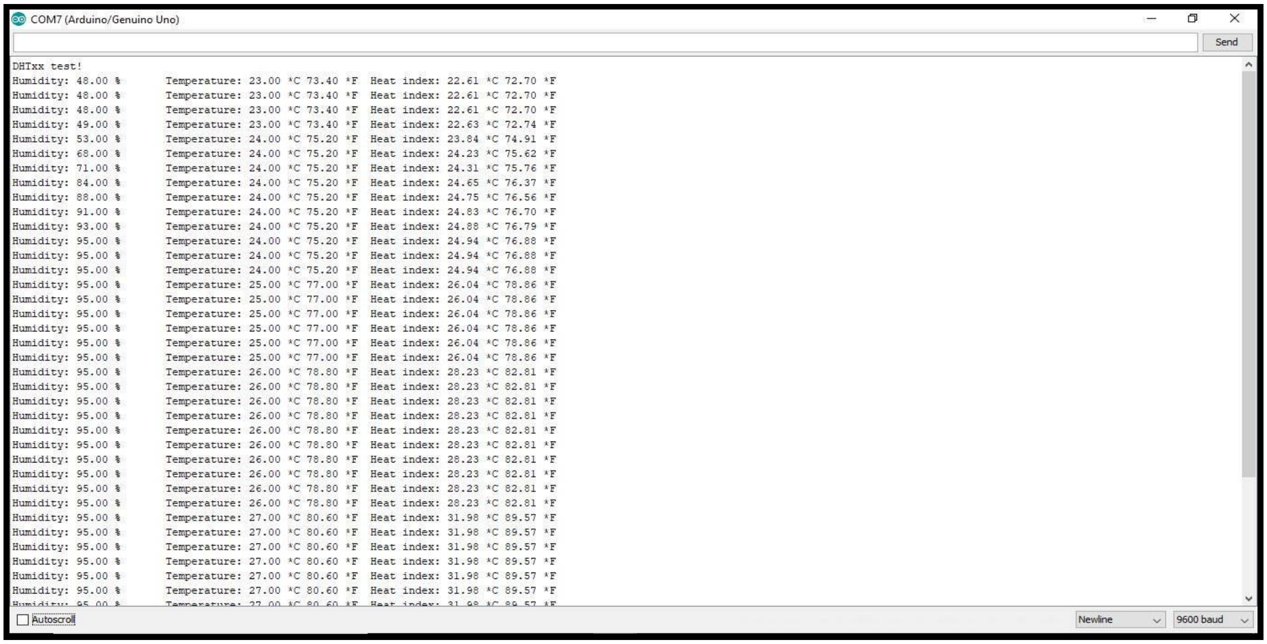


Figure 5.4.1: *Temperature reading from the temperature sensor. The plant was expected to grow in around 26 degrees celsius hence the sensor was tested in this range*

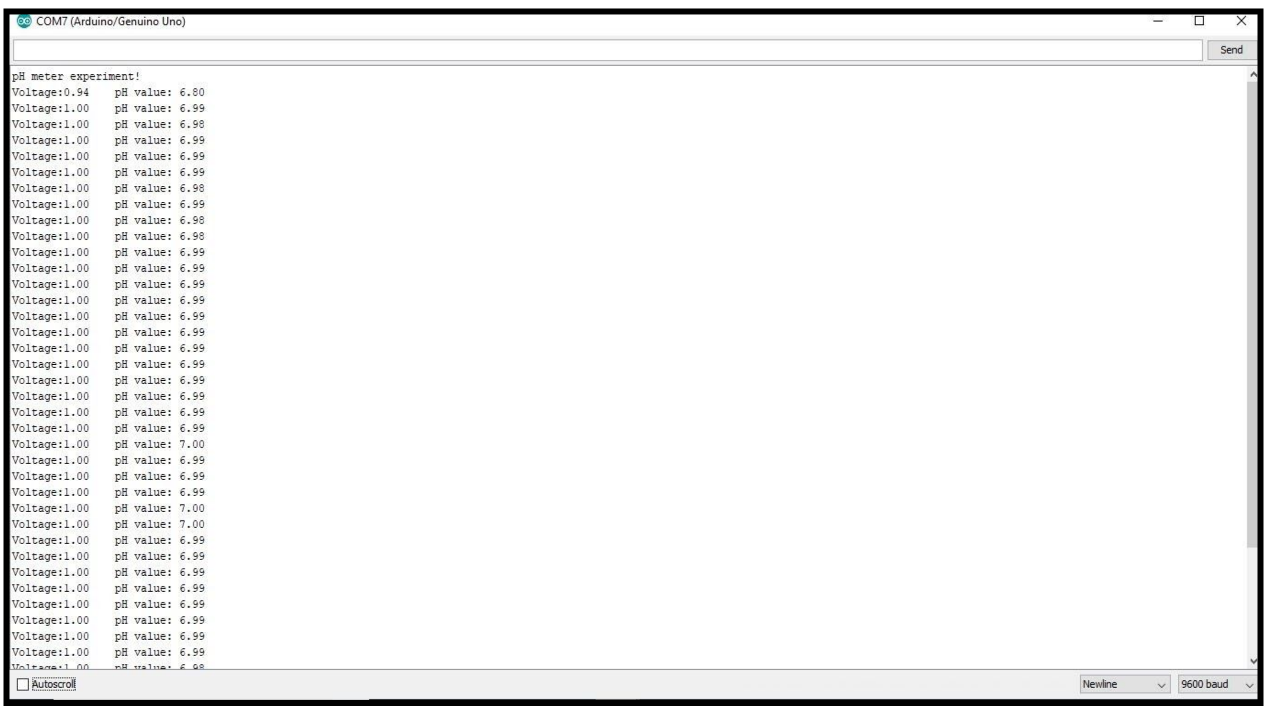


Figure 5.4.2: *pH sensor tested in water which is neutral and had a pH of 7 (found using a pH tester solution)*

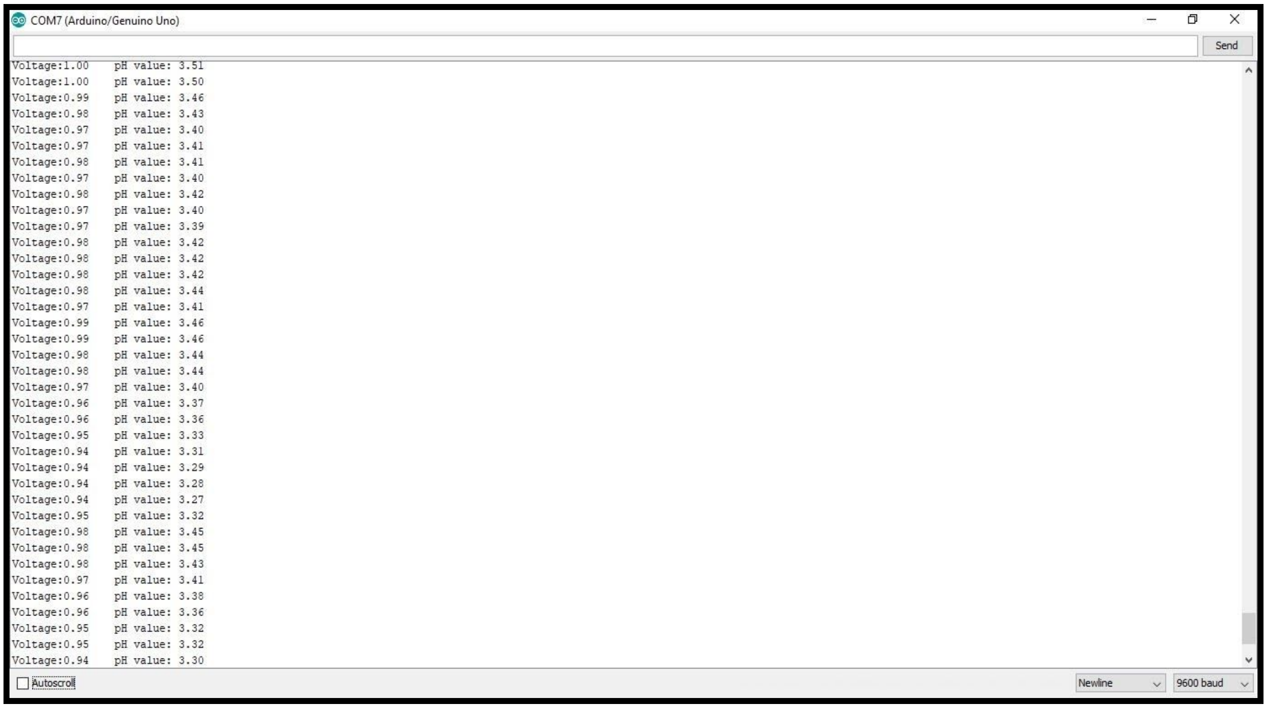


Figure 5.4.3: *pH sensor tested in acidic solution which had a pH of 3 (found using a pH tester solution)*

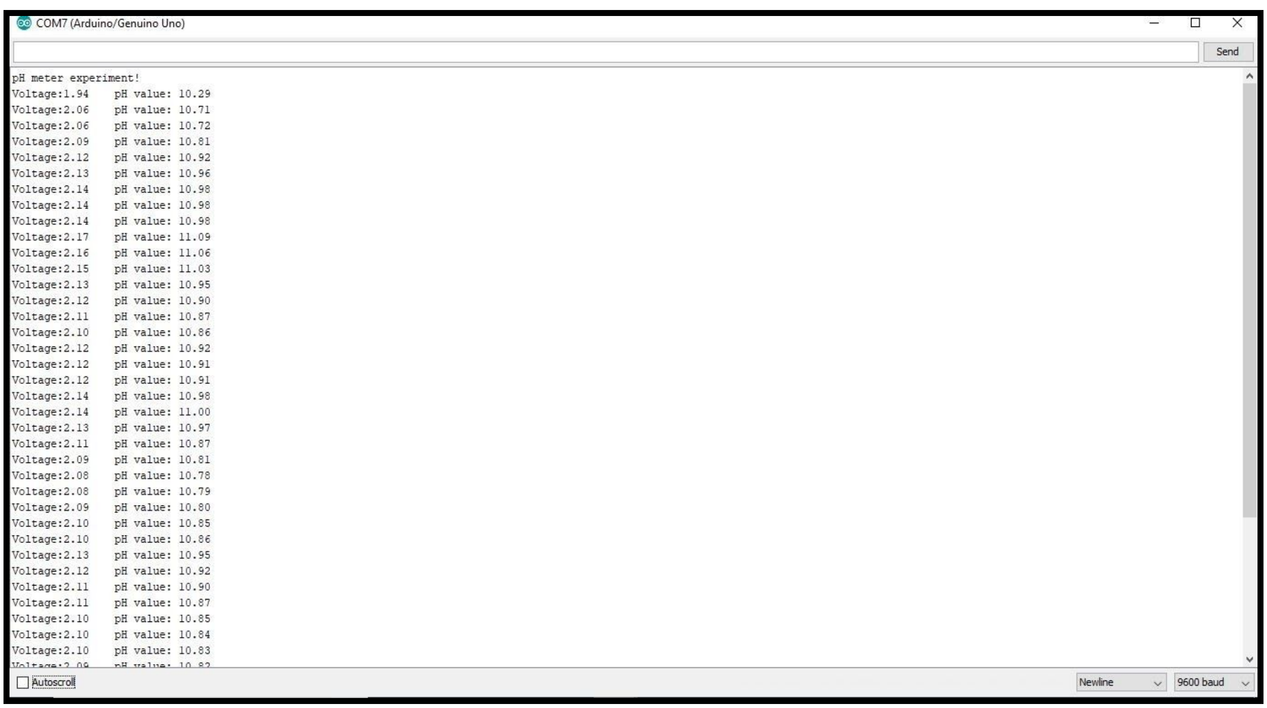


Figure 5.4.4: *pH sensor tested in alkaline solution which had a pH of 10 (found using a pH tester solution)*

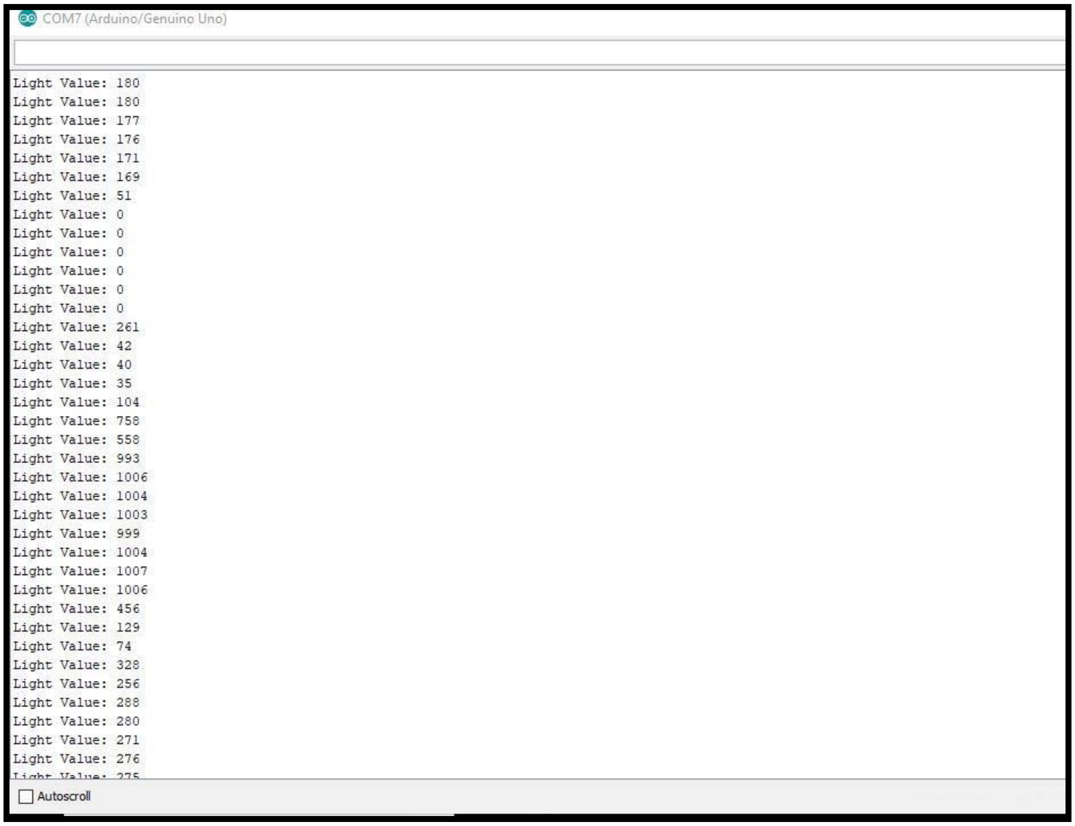


Figure 5.4.5: *Light sensor tested in darkness (light reading 0), indoors (light reading ~250) and outdoors (light reading > 900)*

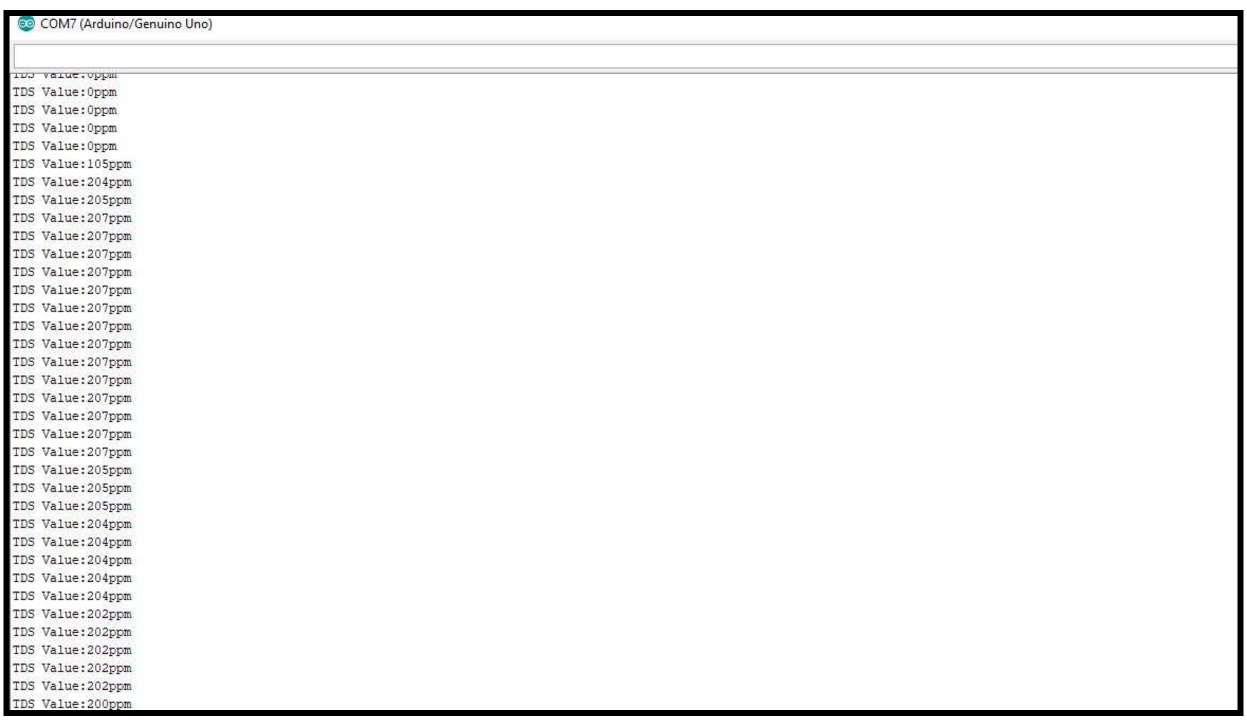


Figure 5.4.6: *Total dissolved solids sensor tested in tap water (low TDS concentration)*

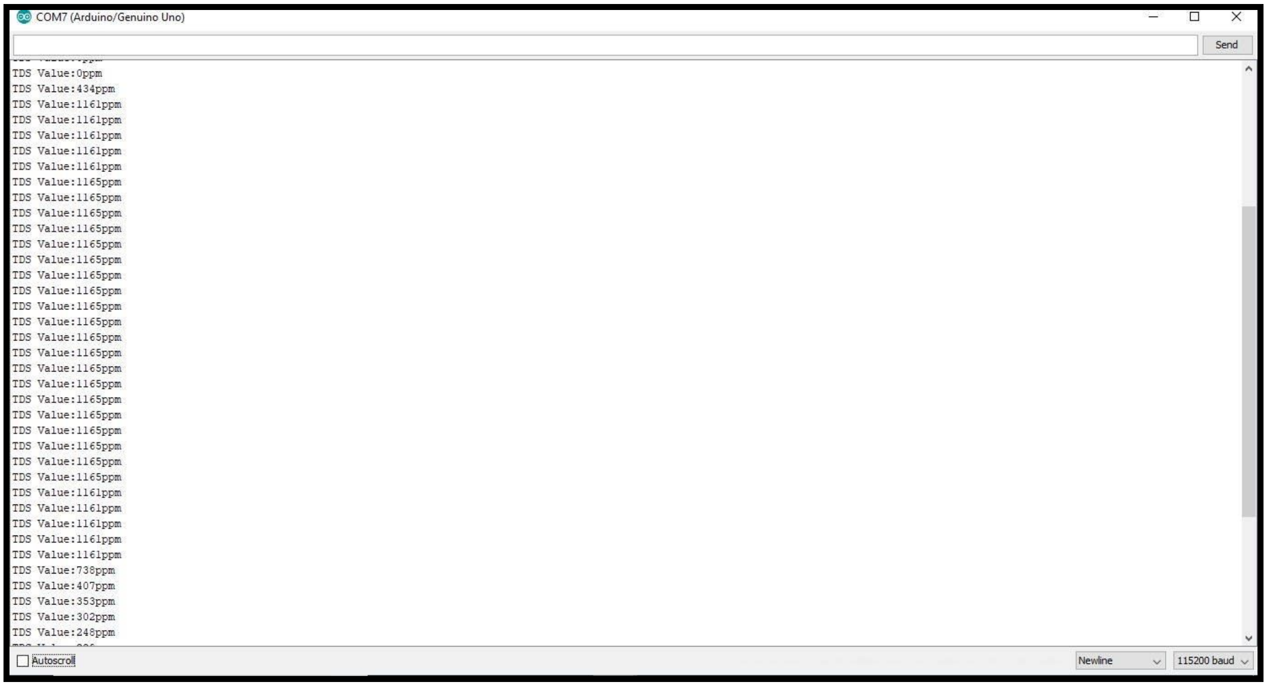


Figure 5.4.7: *Total dissolved solids sensor tested in saltwater solution (high TDS concentration)*

5.1.5. Actuator Testing and Integration

The first thing is to test the valves. Due to pressure requirements of the valves, a certain amount of liquid is needed for the valves to be operational. After connecting the valves and the containers, the container is filled and the valves is turned on until there is no longer any water flowing through the valves. **After testing, it is clear that the solution valves are operational when the containers are filled by a third of their sizes or more (shown in figure 5.5.1).** The drainage valve requires a little less water to be operational.

Figure 5.5.1: *Photo of testing the solution valve. Left photo shows a straight water flow when the container is full. Middle photo shows a weaker water flow when the container is half-full. Right photo shows almost no water flow when the container is a-third-full.*

After the valves, the air pump is firstly tested to make sure it is functional and later a self-made tube, due to budget considerations, is connected to the air pump. The tube is made by connecting several fruit punch drink straws and sealing the connections with tape. The testing of the LED strip is similar to that of the air pump (shown in figure 5.5.2). Then the two actuators are tested together using the four outlet relay module (shown in figure 5.5.3). The relay has one ALWAYS ON outlet, one NORMALLY ON outlet, and two NORMALLY OFF outlets which where the oxygen pump and the LED strip are connected. The Arduino uses a digital output port to control the relay module. Compared to a **self-build relay[10]** for electronics using 110V, this relay module is more expensive yet safer to operate and it saves the time and effort of building a relay. As mentioned in the previous section, the relay module is placed next to the box, the LED strip is stuck against the inner sides of the module, and the air pump rests on a holder (shown in figure 5.5.4).

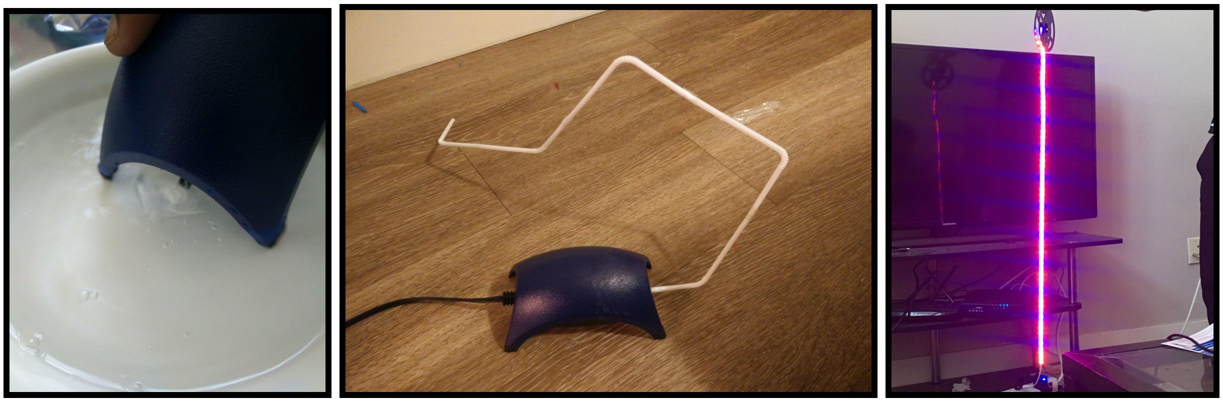


Figure 5.5.2: *Oxygen pump generating bubbles (left), oxygen pump with tube (middle), and LED strip turned on (right).*

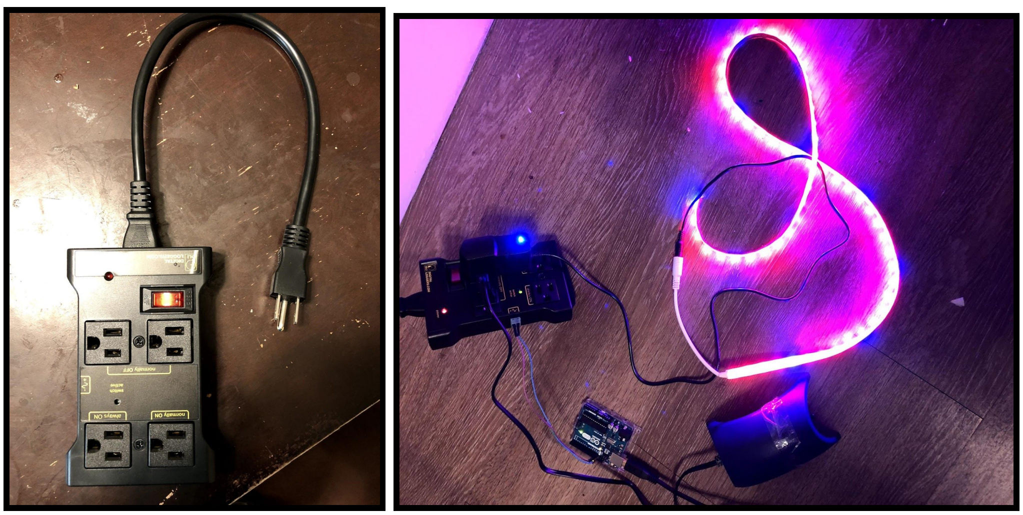


Figure 5.5.3: *Four Outlet Relay Module (left) and controlling LED strip and oxygen pump at the same time with the relay module (right).*

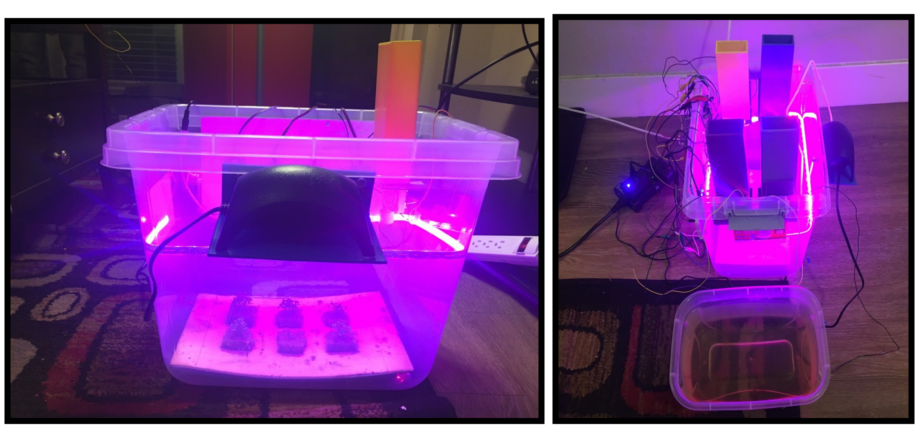


Figure 5.5.4: *Placement of oxygen pump (light) and placement of air pump, LED strip, and relay module (right).*

During actuator integration, some digital output pins cannot be used for controlling the switching circuit. When the digital pins number 5,7,10,11,12,13 are used to control the switching circuit, the wifi shield is unstable and disconnects easily. Therefore, digital pins 4, 6, 8, 9 are used to control the switching circuit. Digital pin 2 is used for controlling the Temperature, Humidity sensor. Digital pin 3 is used to control the relay module. Moreover, for the valves, they can still be functional even though the battery pack supplies around 10V.

5.1.6. User Interface Design and Development

The idea behind the user interface is to make it easy for the user to read sensor outputs and actuate the system based on these readings. A mobile application was chosen as the user interface since it provides easy accessibility compared to a web application. In order to implement the user interface the Blynk platform was used. Blynk is an IOT platform to control Arduinos and other microcontrollers and microprocessors with a mobile application. It has an API that can be used to communicate between the Arduino and the application. On the user side to design the interface there are various buttons and displays that can be used. For this project four labelled value displays were used for the four sensor readings - light, temperature, total dissolved solids and pH. Five buttons were used for the actuators - the four valves (pH up, pH down, nutrient solution and water) and the IOT power relay (to control the LED strip and oxygen pump).

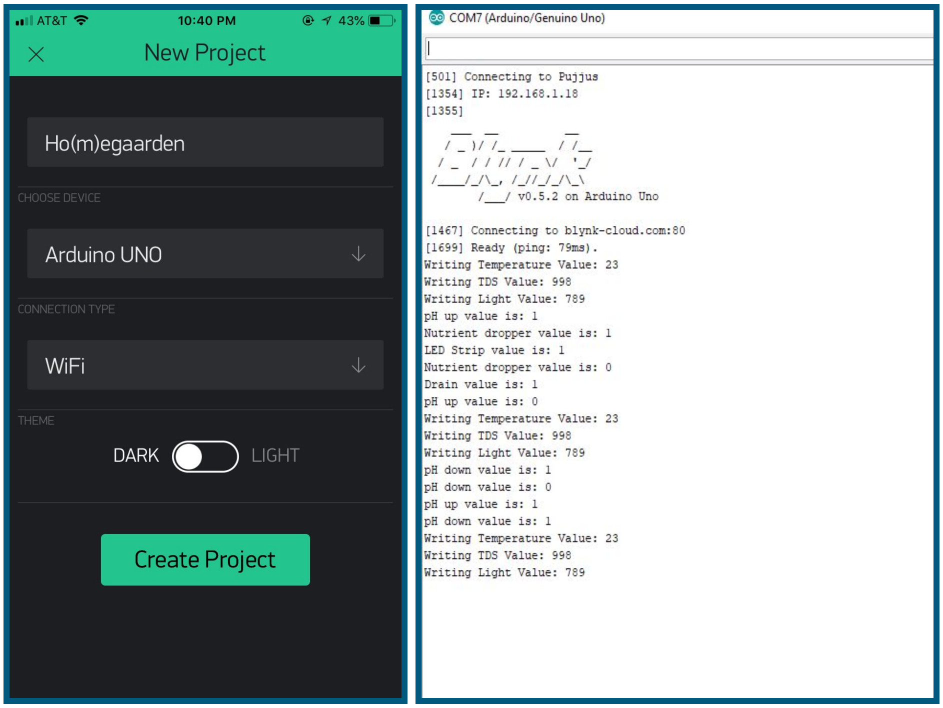


Figure 5.6.1: *Creating a new project in Blynk (left) and output from Arduino serial monitor when the application connects to the Arduino (right)*

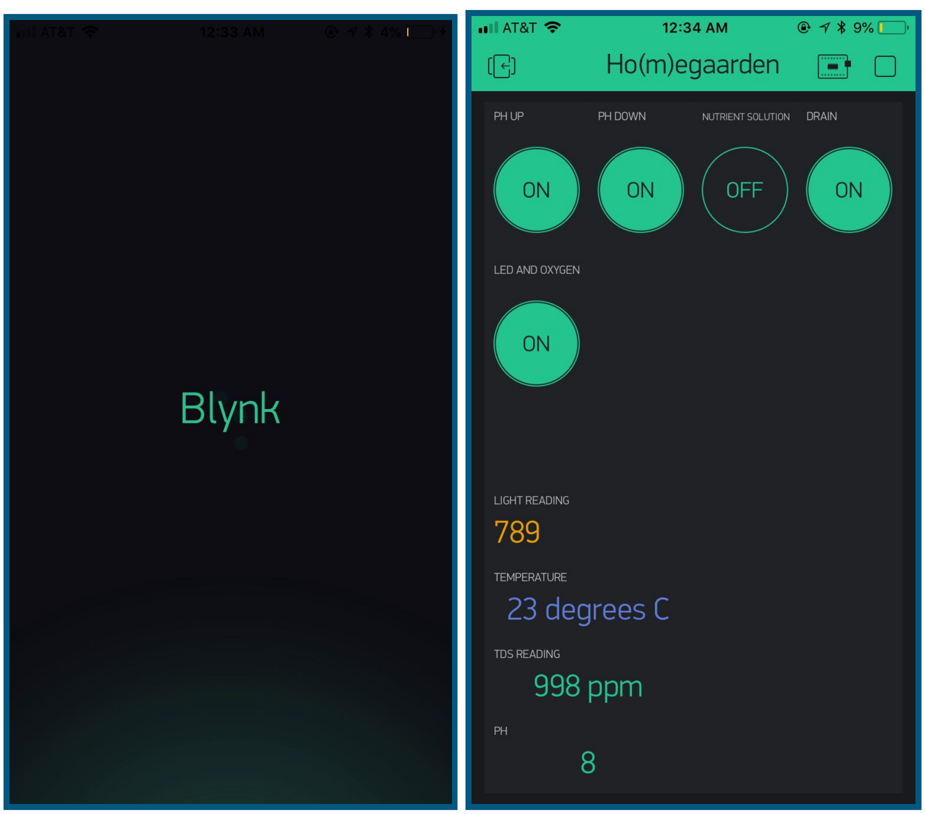


Figure 5.6.2: *Final UI: Screen on opening the application (left) and screen for the project with all the functionality (right)*

6. The "When?"

6.1. Project Duration

The expected timeline for this project was ten weeks. The time duration breakdown for each individual task is shown in Figure 6.1.

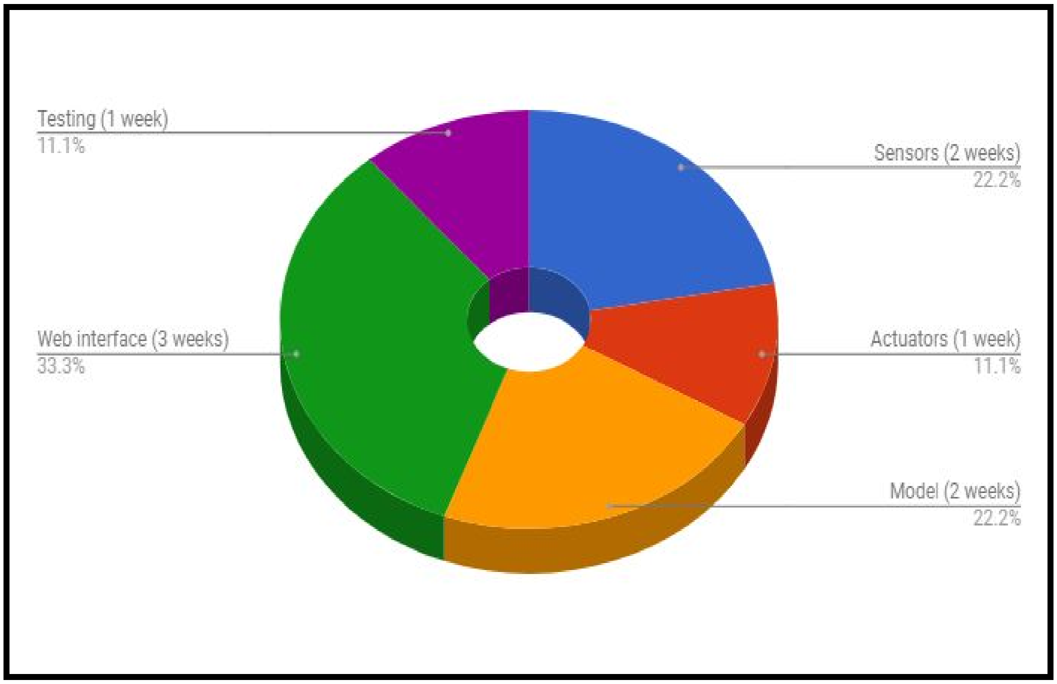


Figure 6.1: *Time Distribution For Major Tasks*

6.2. Weekly Plan With Deliverables and Grading Rubric

The weekly milestones were adhered to and met the expectations of the pre-set grading rubric every week during the course of this final design project.

Week 1:

Task	Deliverable	Score Allocation	Score Achieved
Receive sensors	Show received parts	5/10	5/10

Test each sensor individually	Code for testing at least 2-3 sensors	5/10	5/10
Total		**10/10**	**10/10**

Week 2:

Task	Deliverable	Score Allocation	Score Achieved
Continue testing sensors	Code for each individual sensor	4/10	4/10
Make all sensors work together	Video/demo of sensors working together	6/10	6/10
Total		**10/10**	**10/10**

Week 3:

Task	Deliverable	Score Allocation	Score Achieved
Receive actuators	Show received parts	2/10	2/10
Test each actuator individually	Code for each actuator	2/10	2/10
Begin making demo model	Show basic structure of model	3/10	3/10
Evaluate sensor performance	Graph of sensor outputs	3/10	3/10
Total		**10/10**	**10/10**

Week 4:

Task	Deliverable	Score Allocation	Score Achieved
Make all actuators work together	Video/demo of actuators working together	5/10	5/10
Continue building demo model	Show model being built and difference from previous week	5/10	5/10
Total		**10/10**	**10/10**

Week 5:

Task	Deliverable	Score Allocation	Score Achieved
CAD model for tubes to be used with valves	CAD model	4/10	4/10
Switching circuit for valves	Picture of circuit	3/10	3/10
Add arduino controlled power strip to design	Photo	3/10	3/10
Total		**10/10**	**10/10**

Week 6:

Task	Deliverable	Score Allocation	Score Achieved
Start final placement of sensors in model	Photo of model	4/10	4/10
3D print the tubes designed earlier	3D printed tubes	4/10	4/10

Insert seeds into model	Picture of seeds in model	2/10	2/10
Total		**10/10**	**10/10**

Week 7:

Task	Deliverable	Score Allocation	Score Achieved
Continue finalizing placement of sensors	Updated picture of model	4/10	4/10
Test valves with the tubes printed	Picture of valves	4/10	4/10
Start building web interface	Picture/URL for UI	2/10	2/10
Total		**10/10**	**10/10**

Week 8:

Task	Deliverable	Score Allocation	Score Achieved
Finalize actuator placement in model	Picture of updated model	5/10	5
Continue working on web interface	Picture/URL of UI	5/10	5
Total		**10/10**	**10/10**

Week 9:

Task	Deliverable	Score Allocation	Score Achieved
Fix any issues with model and clean up wires	Picture of updated model	5/10	5/10

Finalize UI	Picture/URL of UI	5/10	5/10
Total		**10/10**	**10/10**

Week 10: End to End System Integration and Testing

Week 11: Live Demo

6.3. Timeline with Milestones: Gantt Chart

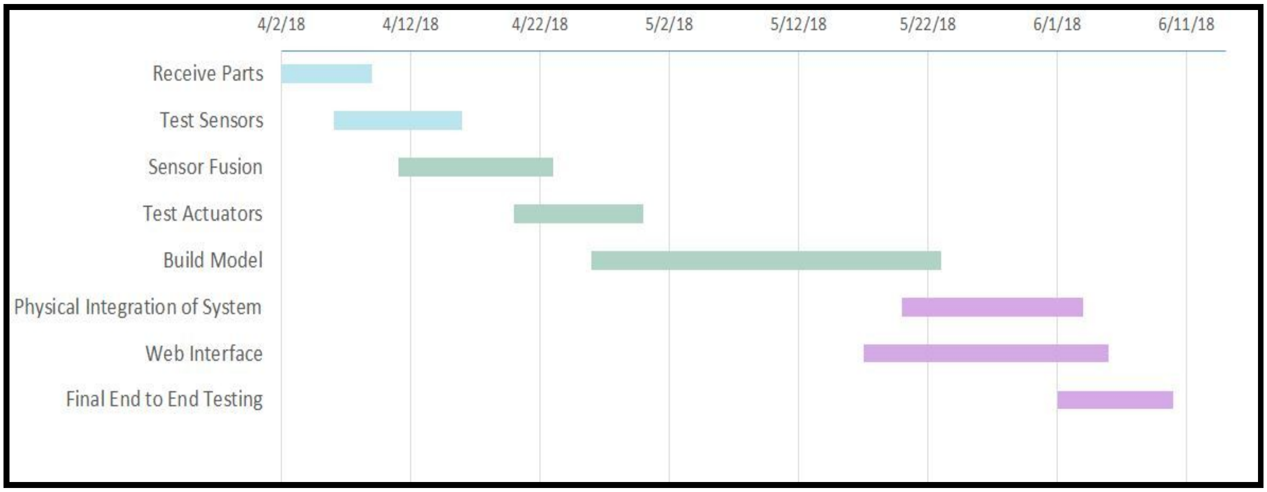


Figure 6.2: *Gantt Chart Highlighting Project Plan*

7. Final Deliverables

7.1. List of Final Deliverables

- **Design Diagrams**
- **Physical Prototype**
- **Description of Test Procedures**
- **Experimental Data**
- **Computer program code / Flow Chart / Documentation**

This list of final deliverables is encapsulated in this technical report with links to code, videos and additional test data provided in the appendix. The physical prototype was successfully demonstrated on the designated demo day.

8. The "How Much?"

8.1. Budget and Bill of Materials

Name	Product Number/ Manufacture Number	Description	Price/unit	Amount	Total Cost
Temperature, humidity sensor	DFR0067	Analog Temperature Humidity Sensor for Arduino	$5.20	1	$5.20
PH meter kit	RB-Dfr-483	Analog PH meter for Arduino	$29.50	1	$29.50
Analog TDS sensor	SEN0244	Analog TDS sensor/meter for Arduino	$12.90	1	$12.90
Light sensor	DFR0026	Analog Ambient Light sensor for Arduino	$3.50	1	$3.50
Nutrient Solution	hf-GSGB32	GH FloraNova Grow solution	$19.57	1	$19.57
General Hydroponic ph Control Kit	GH1514	PH control kit	$8.18	1	$8.18
Storage solution	MT-CLBLK-100	PH probe KCL storage solution	$11.06	1	$11.06
Relay module	2935	Controllable Four Outlet Power Relay Module	$24.95	1	$24.95
Solution Valves	997	Plastic Water Solenoid Valve	$6.95	4	$27.80
Drain Valve	ROCON-341	DC 12V ¼'' Inlet Feed Water Solenoid Valve	$7.49	1	$7.49
Oxygen pump	105687	Non-UL air pump for aquarium	$4.89	1	$4.89
LED Strip	B01LO55GAS	LED plant grow strip light	$12.95	1	$12.95
Arduino Uno	Arduino 2877	microcontroller	$0.00	1	$0.00
Jumper wires	PRT-11026	Connection wires	$0.00	1	$0.00
12V Battery Holder	B01C7ZFC6W	AA Battery 12V Clip holder box	$5.66	1	$5.66
Battery	N/A	1.5v alkaline battery	$0.00	8	$0.00
Box	N/A	32-qt Hefty Box	$12.03	1	$12.03
3D-printed container	N/A	3D-printed solution container	$0.00	4	$0.00
3D-printed valve holder	N/A	3D-printed forklift holder	$0.00	4	$0.00
3D-printed pump holder	N/A	3D-printed L-shape holder	$0.00	2	$0.00
M6-1 screws	749605	M6-1 x 40mm Stainless Pan	$0.00	12	$0.00

		Head screw			
Everbilt screws	574257	Everbilt 6mm-1.0x20mm socket cap screw	$0.00	12	$0.00
M6 Jam Nuts	0141488	M6-1.0 DIN 439B Jam Nut	$0.00	12	$0.00
nuts			$0.00	12	$0.00
Total					**$185.68**

*These are just initial setup costs and some of the materials will last for months if not years. Recurring costs for project maintenance may include replacing pH, TDS probes, batteries and plant growth material that are relatively inexpensive given the time scale

9. Challenges and Solutions

- **Valves**: The valves had a pressure requirement which had to be met in order for them to operate. In order to meet this pressure requirement a special container was designed for each valve and 3D printed as described in the earlier sections. This enabled the liquid to be held at a greater height hence generated more pressure, allowing the valves to operate.
- **Controlling appliances that require 110V with an Arduino**: The oxygen pump and LED strip used required 110V to operate and plugged into wall power outlets. In order to control these appliances with an Arduino we used an IOT power relay as described in the previous sections. The IOT power relay allowed us to turn the actuators on and off as needed.
- **Drainage**: To drain the system a valve was proposed to be inserted at the bottom of the model. However, due to a limited time frame this could not be implemented. Future attempts at improving this system could introduce this valve to easily drain the system. Introducing this drain will allow the user to drain the system and prevent algal and chloride build up.

10. Future Developments

The robotic system is currently fully functional but as with any design project, it can be raised a notch and made more intensive with marginally higher capital investments and more thorough planning and execution. In this regard, certain features have been identified that when added can positively enhance this project -

- **Increased Automation:** The system in its current state requires the user to monitor the growth parameters and act on it to ensure the conditions are stable. This process can be entirely automated. The arduino control code for all the sensors and actuators can be reworked to include preset thresholds for the sensor outputs. Whenever these thresholds are breached, the actuators can automatically work to restore stability. For instance the arduino can receive information about the pH falling out of a desirable range from the pH sensor. It can then send a signal to activate the pH up/pH down valves to drip the appropriate solution into the nutrient mixture.

- **LED Display Shield:** An LED shield display with an interactive touchscreen can be mounted on the side of the system. These will provide a live digital readout of all the sensor measurements and maybe even allow the user to control actuators through touch-based interaction. This is a feature that would cut down on continuous mobile app access if the user is at home. **It would also create a more immersive human-robot interaction where the user can engage more directly with the system.**

- **Live Camera Feed:** This feature would involve a camera mount that would allow for a top view of the system and can transmit a live video/photo feed to the user if he is offsite. Through facilitating remote monitoring of plant growth, this would allow the user to keep tabs on algal/fungal growth in the system and be mindful of any foreign object in the system.

- **Waterproofing:** The use of effective agents such as liquid electrical tape to waterproof all the actuators, sensors and associated electronic components could be a viable add on which can prevent a system breakdown in the unlikely event of liquid-electrical contact.

- **More Intensive Sensor Network:** A more intensive sensor network is a potential add on for a hobbyist willing to spend the required extra dollars. The system as it is, is extremely capable of supporting a wide variety of plant growth but better pH sensors that last longer under constant immersion, better light sensors that have a wider sensing range and provide us with deterministic luminous intensity values, can easily be integrated into the system. In addition, water temperature sensors, specific nutrient sensors, dissolved oxygen sensors, leaf wetness center and a lot more eccentric sensors can be attached to the system to give the user a greater degree of control over the plant growth process.

- **Fine-tuned Actuation:** The actuator functionality in the system is more utilitarian than sophisticated. However, in keeping with the scalable feature of the system, it is easy to graduate to submersible air pumps (eliminates the need for a holder and external tubing), replace the current plastic valves with brass solenoid valves (no pressure requirement, compatible with more kinds of liquid, more effective solution handling and storage) and add an LED array with more feature control (brightness, timing, etc.)

- **Optimal System Layout:** Additional time allotted to the design and planning process could ensure that the system has more streamlined wiring, less cluttered space allocation for the different system components and has a better aesthetic appeal. **The ultimate goal is for the design to look like a product and not a project.**

Figure 9.1: *System Enhancements - Future of Ho(m)egaarden as discussed above*

11. Conclusion

The conclusion from this undertaking is that even on a limited budget, it is still possible to develop an automated hydroponics home gardening system that monitors and adjusts key parameters to sustain the most preferred environment for a target crop. Although challenges arose in hardware and software integration, this hydroponics system has been successfully implemented and is capable of monitoring light, temperature, ph, and TDS parameters and utilizing actuators to sustain the preferred environment for watercress. The mechanical segments of the model are constructed with easy-access durable materials and both the sensors and the actuators can be easily accessed and replaced like modules. Further, the system can be controlled remotely with a user-friendly interface and can be later developed or upscaled in the future based on user requirements.

12. References

[1] R. Reddick, "Hydroponics and the future of farming", Big Picture, 2016. [Online]. Available: https://bigpictureeducation.com/hydroponics-and-future-farming. [Accessed: 09- Jun- 2018].

[2] J. dos Santos, A. Lopes da Silva, J. da Luz Costa, G. Scheidt, A. Novak, E. Sydney and C. Soccol, "Development of a vinasse nutritive solution for hydroponics", Journal of Environmental Management, vol. 114, pp. 8-12, 2013.

[3] R. Farah, "Hydroponics vs Soil: 7 Reasons Hydroponics Wins", Epic Gardening, 2012. [Online]. Available: https://www.epicgardening.com/hydroponics-vs-soil/. [Accessed: 09- Jun- 2018].

[4] T. Park, "MIT startup brings urban agriculture indoors", MIT News, 2015. [Online]. Available: http://news.mit.edu/2015/mit-startup-grove-labs-brings-urban-agriculture-indoors-1110. [Accessed: 09- Jun- 2018].

[5]M. on Moon, "20 Advantages & Disadvantages of Hydroponics That You Should Know | Green and Vibrant", Greenandvibrant.com, 2017. [Online]. Available: https://www.greenandvibrant.com/advantages-disadvantages-of-hydroponics. [Accessed: 09- Jun- 2018].

[6]F. Hydroponics, "Automated Hydroponic Equipment, Supplies & Growing Kits", Fullbloomhydroponics.net, 2018. [Online]. Available: http://www.fullbloomhydroponics.net/hydroponic-systems/. [Accessed: 09- Jun- 2018].

[7]E. Guizzo, "5 Robots That Can Help Make the Planet Greener", IEEE Spectrum, 2011.

[8]C. Quarters, "How to Grow Watercress Hydroponically | Hunker", Hunker.com, 2018. [Online]. Available: https://www.hunker.com/12597300/how-to-grow-watercress-hydroponically. [Accessed: 09- Jun- 2018].

[9]"How To Grow Watercress | Herb Gardening Guide", Herbgardening.com, 2018. [Online]. Available: http://herbgardening.com/growingwatercress.htm. [Accessed: 09- Jun- 2018].

[10]Basics, C. and Basics, C. (2018). Turn Any Appliance into a Smart Device with an Arduino Controlled Power Outlet. [online] Circuit Basics. Available at: http://www.circuitbasics.com/build-an-arduino-controlled-power-outlet/ [Accessed 12 Jun. 2018].

13. Appendix

13.1. Web Links To Project Materials

Name	URL
Temperature Humidity sensor	https://www.dfrobot.com/product-174.html
PH meter kit	https://www.robotshop.com/en/gravity-analog-ph-meter-kit.html
Analog TDS sensor	https://www.dfrobot.com/product-1662.html
Light sensor	https://www.dfrobot.com/product-1004.html
Nutrient Solution	N/A (Bought on site at GreenCoast Hydroponics)

KCL storage solution	N/A (Bought on site at GreenCoast Hydroponics)
General Hydroponic ph Control Kit	https://www.amazon.com/dp/B000BNKWZY/ref=asc_df_B000BNKWZY5412685/?tag=hyprod-20&creative=394997&creativeASIN=B000BNKWZY&linkCode=df0&hvadid=193139379506&hvpos=1o3&hvnetw=g&hvrand=8069057050493983454&hvpone=&hvptwo=&hvqmt=&hvdev=c&hvdvcmdl=&hvlocint=&hvlocphy=9061122&hvtargid=pla-309085180504
Solution Valves	https://www.adafruit.com/product/997
Drain Valve	https://www.amazon.com/ZAOJIAO-Normally-Closed-Solenoid-Connect/dp/B0743CSRFF/ref=sr_1_6?ie=UTF8&qid=1528183204&sr=8-6&keywords=12V+valve
Oxygen pump	https://www.chewy.com/tetra-whisper-non-ul-air-pump/dp/133138?utm_source=google-product&utm_medium=cpc&utm_campaign=f&utm_content=Tetra&utm_term=&gclid=CjwKCAjws6jVBRBZEiwAkIfZ2rK4sJhqWP23aI2lgKBSzp8pQHskolf_agGh8svrWJfZvakVtFaMbRoCKxwQAvD_BwE&gclsrc=aw.ds
LED Strip	https://www.amazon.com/dp/B01LO55GAS/ref=asc_df_B01LO55GAS5404520/?tag=hyprod-20&creative=395033&creativeASIN=B01LO55GAS&linkCode=df0&hvadid=241883109355&hvpos=1o1&hvnetw=g&hvrand=6632798357593370382&hvpone=&hvptwo=&hvqmt=&hvdev=c&hvdvcmdl=&hvlocint=&hvlocphy=9061122&hvtargid=pla-395339181786
Relay Module	https://www.adafruit.com/product/2935?gclid=CjwKCAjw9e3YBRBcEiwAzjCJuhogw1iK763MYta1Ykgh18wPTH7KSVYiz4HKNZ48j8q3A1gsxxc_6RoCn-8QAvD_BwE
Arduino Uno/Raspberry Pi	https://www.mouser.com/ProductDetail/Arduino/2877/?qs=0XlZGzED1NaiMhNo5b2aJg%3D%3D&gclid=EAIaIQobChMIxrGN-vTt2QIV2JJ-Ch1tmw0TEAQYAiABEgI4u_D_BwE
Jumper wires	https://www.sparkfun.com/products/11026
12V Battery Holder	https://www.amazon.com/SMAKN%C2%AE-8PCS-Battery-Holder-Black/dp/B01C7ZFC6W/ref=sr_1_4?s=electronics&ie=UTF8&qid=1521755715&sr=1-4&keywords=12v+battery+holder
Battery	https://www.amazon.com/Duracell-Coppertop-Alkaline-AA-Batteries/dp/B003CZX4A8/ref=sr_1_10_a_it?ie=UTF8&qid=1528220186&sr=8-10&keywords=duracell+aa+batteries
M6-1 x 40mm screw	https://www.homedepot.com/p/M6-1-x-40-mm-Stainless-Pan-Head-Phillips-Metric-Machine-Screw-843258/204283804?MERCH=REC-_-rv_nav_plp_rr-_-NA-_-204283804-_-N
M6-1 x 20mm screw	https://www.homedepot.com/p/Everbilt-6-mm-1-0-x-20-mm-Plain-Steel-Metric-Socket-Cap-Screw-2-Piece-803348/204274289
M6 Jam Nut	https://www.fastenal.com/products/details/0141488;jsessionid=UktCPxiimjaK6YPuMzKC7L-a.443d7b2e-1555-3602-a586-c0d73327934b?sortby=navsattr11&sortdir=ascending&r=~%7Ccategoryl1:%22600000%20Fasteners%22%7C~%20~%7Ccategoryl2:%22600072%20Nuts%22%7C~%20~%7Ccategoryl3:%22600080%20Jam%20Nuts%22%7C~

Box	https://www.target.com/p/hefty-32-quart-storage-tote-stronger-plastic-pro-storage-container-in-dark-gray-with-bright-stackable-hi-rise-lid/-/A-50262264

13.2. Github Link

Github: https://github.com/rehan141196/Homegaarden