RAFIK HARIRI UNIVERSITY

College of Engineering

BE 2 Summative Learning Project – MECA595

Hydroponics For Home Use

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May 2022

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Abstract

The world is suffering the consequences of pollution and global warming, and one of the more dire consequences is lack of sustainable farming methods. This is why humans have been developing soilless farming, or hydroponics, since the 1800s. However, large companies have been gatekeeping datasets to dominate the hydroponic market. In our report, we will discover the best hydroponic system for home use with integrated data collection to be able to create an open-source community.

We will be using microcontrollers to collect data and testing our system with electronic and mechanical components. We will be adding results once we have them.

Chapter 1: Introduction

With the world witnessing increasingly dire effects of climate change and pollution, trends have been shifting towards sustainable, eco-friendly solutions. Since planting, gardening, and greenhouse soils are made up of non-renewable components. According to the Food and Agriculture Organization of the United Nations, one centimeter of soil can erode in one year and takes hundreds to thousands of years to form from the parent rock (FAO, 2015). This phenomenon forced humans to find alternative ways to grow their crops, which is where hydroponics comes in.

Hydroponics is one of the alternatives to soil-based farming. It is defined as "the science of growing or the production of plants in nutrient-rich solutions or moist inert material, instead of soil" (Webster’s Dictionary, 1999). Instead of soil, a nutrient rich solution is used to grow the plants instead. The plants are either continuously suspended in the solution or aerated regularly. Hydroponics first appeared in the 1800s and has advanced so much since then that it was used in space applications. It was first discovered in Latin America and later expanded to the rest of the world. This revolutionized farming since crops can be grown anywhere in the world now. There are many reasons Hydroponics is preferred nowadays and some of which are desert locations where loam soil isn’t widely or naturally available, increasing oil prices which increased the prices of heating and cooling, or the high regulations on pest control.

There are a lot of differences between hydroponics planting/farming and soil-based techniques. The aforementioned nutrient solution should have specific amount of nutrients and acidity for the plant to thrive. The roots should also be supported instead of suspended in the air or in the solution without placement. This opens a different component that is taken into consideration which is the grow medium. The roots should not be fully immersed all the time to avoid suffocation. Finally, the circulation of the nutrient solution should be studied and precisely implemented to avoid fungus.

Even though hydroponics is becoming increasingly popular, datasets of hydroponic plants whether it was photos of roots, photos of leaves, or even numeric datasets of pH or nutrient levels are very scarce. This is why we are adding data collection to our project where we will open source our data to build a community of hydroponics users.

Chapter 2: Literature Review

2.1 Advantages and Disadvantages of Hydroponics Systems

2.1.1 Advantages

Hydroponics systems have many advantages that made them a better alternative to soil-based planting and farming. The most important feature is that it is more environmentally than traditional methods as soil is considered a scarce resource, and hydroponics conserves water and nutrients which lowers the pollution produced by the system. Hydroponics is also more economically feasible since it does not need a specific environment to be inserted in and saves cost on heating, manual labor, maintenance, and pesticides. Hydroponics are also able to give maximum yield. Troubleshooting is much easier in hydroponics since it is much easier to identify which factor is negatively affecting the plant's growth. Finally, hydroponics is highly flexible since temperature, pH levels, weight, and irrigation can be manually controlled.

2.1.2 Disadvantages

In high-scale use, depending on the type of system and the choice if plants, the cost of initial construction could be high. Because hydroponics uses precise technology and nutrients in the solution, a presence of technical and agricultural experts would be required. This is usually at the beginning of instillation and first-time use to make sure the farmer is familiar with the technology and the filtration. Observation is frequently required in hydroponics since the plants react to an imbalance in the solution or the environment much faster than soil-based farming. This is also usually required more during the first round of harvest until the owner/farmer perfects the conditions required for maximum yield.

2.2 Components of Hydroponics Systems

The In order to design a fully-automated hydroponics system for home use, it is essential to perform a literature review that covers all the components and different types of systems and their mode of action with the help of existing literature and resources. It is also important to research the existing hydroponics products in order to understand the competition and common practices and features.

Different hydroponics systems may include different components. However, the main components of a hydroponics system are growing media, air stones and/or air pumps, and net pots.

2.2.1 Growing Media

The main difference between hydroponics systems and regular planting is the medium in which the plants grow. In hydroponics systems, the growing medium replaces soil, although it does not supply the plants with nutrients alone. Instead, an independent nutrient solution is added to this medium, which is largely made up of water, and it transfers the nutrients to the plants. It is often preferred that this medium have a neutral pH, as to not upset the balance of the nutrient solution. The exact characteristics of the growing media differ from one system to the other, depending on the plant and the system [1].

2.2.2 Nutrient Solution

Nutrient solution to Hydroponic is just like fertilizers to soil. Essentially, a Hydroponic nutrient solution is a liquid filled with all of the necessary nutrients so that plant roots can come into contact for its growth [2].

2.2.3 Growing Pods

Hydroponic pods, also called grow pods, are compact hydroponic garden systems that let people grow vegetables and plants indoors even if they live in an apartment setting.

The pods allow indoor gardening to take place on a small scale, without the need for a greenhouse, grow tent, or elaborate growroom. Hydroponic pods vary in size from petite, tabletop units to large closets or cabinet-sized pods that can easily accommodate bushy and tall plants.

Some hydroponic pods are also airtight to contain the often pungent smell of growing plants. The more sophisticated systems provide temperature and humidity controls, grow lights, filtration, and automatic-nutrient dispensing systems. Some models are controlled by remote controls and others even allow the cultivar to utilize their smartphone to monitor and change settings [3].

Now that we have seen the basic components of every hydroponics system, we need to check how they are assembled and the different type of systems so that we can be fully informed when choosing our system.

Chapter 3: Types of Hydroponic Systems

There are hundreds of hydroponic methods, but all of them are a modification or combination of six basic hydroponic systems which are:

3.1 Deep Water Culture

3.1.1 DWC Overview

The DWC system is the most basic hydroponics system. In this system, the roots are fully submerged in water and nutrients solution (Figure 1). For this system to work effectively, the solution has to have the following :

1. Water: This is necessary as one never has to water the plants again
2. Nutrients: In order to mimic the soil-environment which is rich in nutrients that help the plants to thrive, a nutrient solution should be available for optimal plant growth.
3. Oxygen: Unlike soil, there are no gaps in water to carry oxygen to the roots of the plants. Oxygen is necessary to keep the plants from drowning.

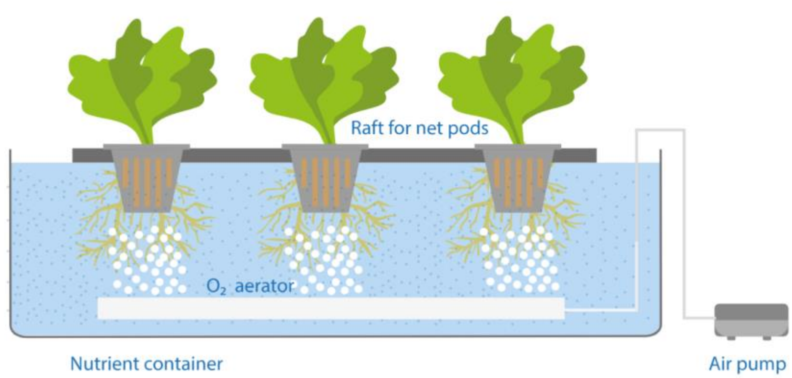


Figure 1- Deep Water Culture System

3.1.2 DWC Advantages

1) Low maintenance: Once the DWC system is set up, it requires little to no maintenance. The only thing a user has to do is renew the nutrient solution in the water every 2-3 weeks, depending on the size of the plant.
2) DIY Appeal: Unlike many hydroponic systems, Deep Water Culture systems can be set up cheaply and easily at home.

3.1.3 DWC Disadvantages

1) Limitations: DWC systems are great for growing herbs and lettuce and flowers, yet they are not very effective when it comes to fruiting and slow-growing vegetables.
2) Temperature Control: It can be harder in DWC systems to control temperatures as water does not circulate. The temperature of the solution should not exceed 20°C and not go below 15°C.

3.2 Wick Systems

3.2.1 Wick System Overview

There are few moving parts in a wick system (Figure 2 for clarification). It does not necessitate sophisticated machinery or equipment such as motors and pumps, nor does it necessitate feats of extreme planning and engineering. The wick system operates on the principle of capillary action. This is a normal, everyday occurrence that is related to the movement of water across closed tubes.

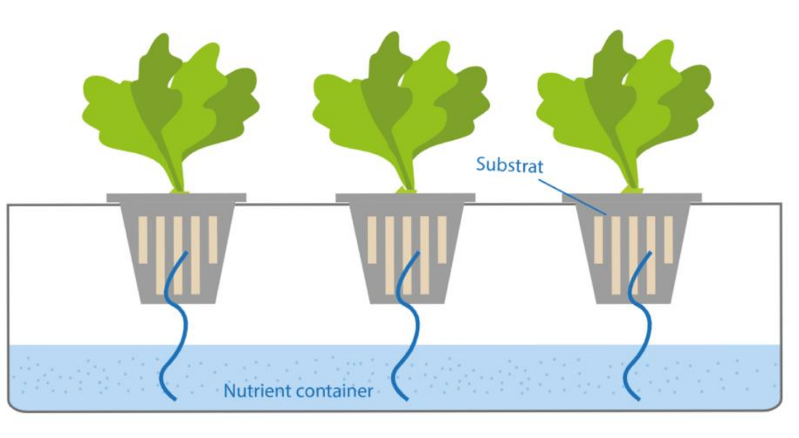


Figure 2- Wick System

Capillary action occurs because water drops are highly sticky by nature. When it penetrates a thin tube, it sticks to the walls. This sticking action results in a curved surface, called a meniscus, at the top edge of a water droplet/molecule. Surface tension is created by the internal bond between the molecules.

The water continues to move upwards when the adhesive force between the water droplet and the capillary walls is greater than the surface tension. The length of capillary action is determined by gravity and the thickness of the tubes/porosity of the substance. A wick system in hydroponics uses the capillary action of water to transport water and nutrients from a reservoir to the plants. Because we're talking about hydroponics, plants will serve as the grow medium, rather than dirt. Each plant will be connected to the reservoir by at least one wick, ideally two. For greatest efficiency, the latter is frequently placed directly beneath the growing surface or tray. Water and dissolved nutrients will migrate from the reservoir due to capillary action.

The components needed for this system are similar to the ones needed for the DWC system, but it also needs wicks to deliver water to the roots as they are not fully submerged in water.

3.2.2 Wick System Advantages

1) Simplicity: A wick system can be set-up by anyone and does not demand excessive attention after it is running.
2) Space-efficient: Wick systems are unobtrusive and can be installed anywhere, seeing as they do not need electricity to run. It is a perfect system for educators, beginners or anyone interested in exploring hydroponics.

3.2.3 Wick Systems Disadvantages

1) *Limitations:* Lettuce and herbs like rosemary, mint, and basil grow quickly and don't require a lot of water. Tomatoes, on the other hand, will struggle to grow in a wick system due to their high nutritional and hydration requirements. Other plants can't survive in a constantly damp atmosphere. Carrots and turnips, for example, will not thrive in a wick system.
2) *Susceptible to Rot:* The humidity and dampness of a hydroponic wick system are constant. As a result, fungal outbreaks and rot in the organic growing media and on the roots of your plants are possible.

3.3 Nutrient Film Technique Systems

3.3.1 NFT Overview

Plants are suspended above a stream of continuously flowing nutrient solution that washes over the ends of the plant's root systems in nutrient film technique (NFT) systems. The plant channels are tilted, allowing water to run down the length of the grow tray before draining into the reservoir below. The reservoir's water is then aerated using an air stone. The nutrient-rich water is then pumped out of the reservoir and back to the channel's top by a submersible pump. The nutrient film technique is a hydroponic recirculating system. It is shown in Figure 3.

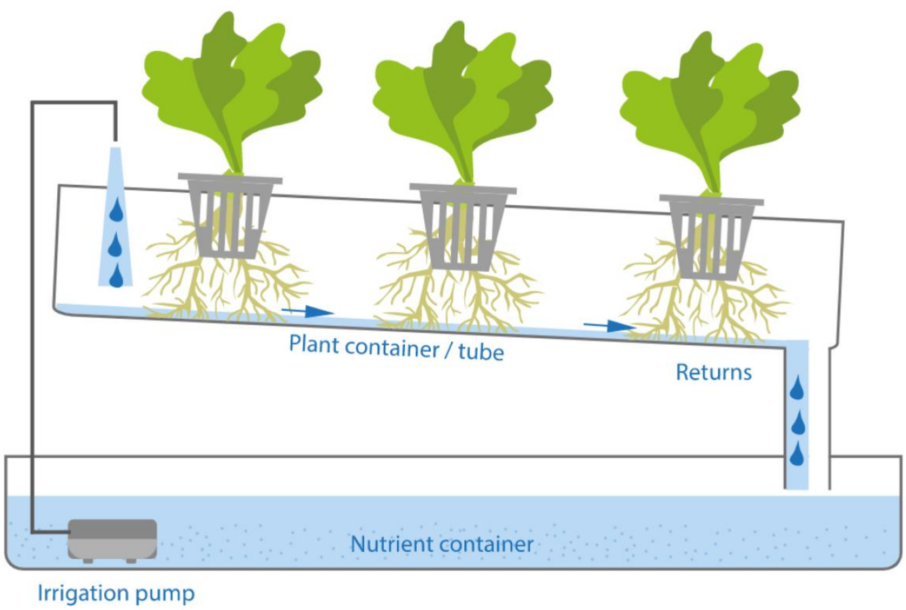


Figure 3- Nutrient Film Technique

3.3.2 NFT Advantages

1) *Low Consumption:* Because NFT hydroponics recirculate the water, they do not require a large amount of water or nutrients to function. The constant flow also makes salt accumulation on the plant's roots more difficult. Nutrient film technique systems also do not require growing media, which saves money and the hassle of replacing it.
2) *Modular Design:* Systems for nutrient film technique are ideal for large-scale and commercial endeavors. It is very simple to expand once one has one channel up and running. It's a good idea to have a separate reservoir for each channel. This way, if a pump fails or a disease spread in the water, one won't have to shut down the entire operation.

3.3.3 NFT Disadvantages

1) *Pump Failure:* Plants will dry out if the pump fails and the channel no longer circulates the nutrient film. If the crop is not supplied with water, it can perish in a matter of hours. The upkeep of an NFT hydroponic system necessitates vigilance. The pump's performance must be closely monitored.
2) *Overcrowding:* The channel can become clogged if the plants are too close together or if the root growth is too vigorous. Water will not be able to flow through the channel if it is obstructed by roots, and the plants will starve. This is especially true of the plants at the channel's bottom.

3.4 Ebb and Flow Systems

3.4.1 Overview

Ebb and flow hydroponics works by flooding a grow bed with nutrients from a reservoir below it (Figure 4). A timer is built into the reservoir's submersible pump. When the timer goes off, the pump starts filling the grow bed with water and nutrients. When the timer expires, gravity slowly drains the water from the grow bed and returns it to the reservoir. The system includes an overflow tube to ensure that flooding does not exceed a certain level and damage the plants' stalks and fruits. In contrast to the previous systems, the plants in an ebb and flow system are not constantly exposed to water. The plants absorb the nutrient solution through their root systems while the grow bed is flooded. The roots dry out as the water level drops and the grow bed empties. The dry roots then oxygenate in the time between floods. The time between floods is determined by the size of the grow bed as well as the size of the plants.

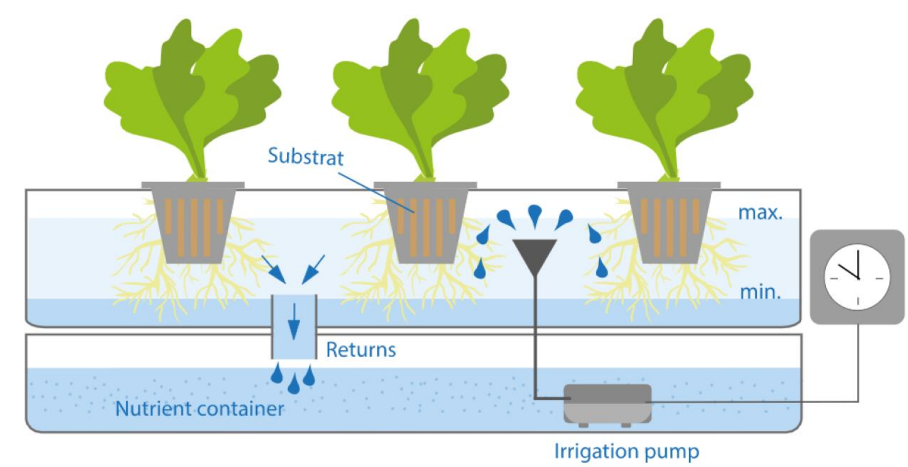


Figure 4- Ebb and Flow System

Almost any type of vegetation can be accommodated by ebb and flow systems. The primary constraint is the grow tray's size and depth. Root vegetables, unlike lettuce or strawberries, will require a much deeper bed. Ebb and flow crops include tomatoes, peas, beans, cucumbers, carrots, and peppers.

Some of the most popular growing media in ebb and flow hydroponics are "grow rocks" and expanded clay pebbles (hydroton). These are washable and reusable, lightweight, and will retain moisture while also draining. This is a critical characteristic in ebb and flow systems.

3.4.2 Ebb and Flow Advantages

1) *Versatility:* More plants can be grown in an ebb and flow system than in most other hydroponic systems. Fruits, flowers, and vegetables all thrive in ebb and flow hydroponics.
2) *DIY Appeal:* Though more expensive to set up than other DIY systems like wick and deep-water culture, ebb and flow systems sustain a much broader scope of plant life than they can.

3.4.3 Ebb and Flow Disadvantages

1) *Pump Failure:* If the pump in a hydroponic system fails, plants will perish, just like in any other hydroponic system. Ebb and flow systems must be monitored to ensure that its performance does not jeopardize the health of the plants. Plants will not receive an adequate amount of water and nutrients if the water rushes in and out too quickly.
2) *Rot & Disease:* An ebb and flow system requires sanitation and maintenance. Root diseases and rot can develop if the bed does not drain properly. Mold and insects

can breed in a dirty ebb and flow system. Crops will suffer if cleanliness is not maintained. Furthermore, some plants do not respond well to the rapid pH change caused by flooding and draining extremes.

3.5 Drip System

3.5.1 Drip System Overview

The aerated and nutrient-rich reservoir in a hydroponic drip system pumps solution through a network of tubes to individual plants (Figure 5). This solution is slowly dripped into the growing medium surrounding the root system, keeping the plants moist and nourished. Drip systems are the most popular and widely used hydroponics method, particularly among commercial growers. Drip irrigation systems can be as simple as individual plants or as complex as large-scale irrigation operations.

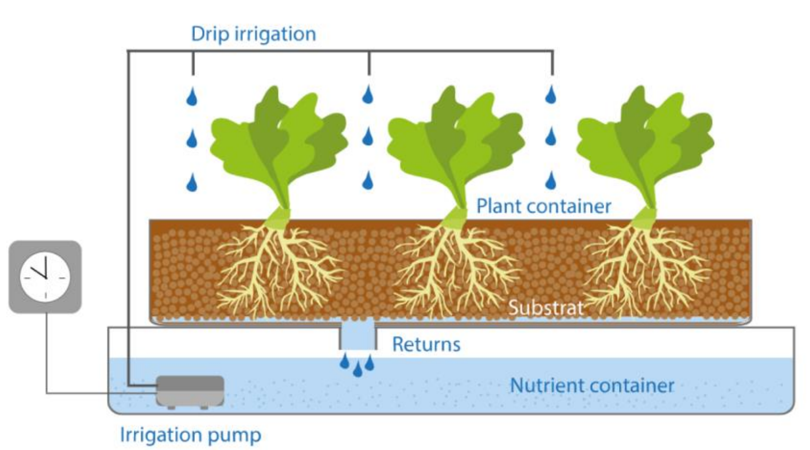


Figure 5- Drip System

There are two types of drip system hydroponics configurations: recovery and non-recovery. In recovery systems, which are more popular with smaller, at-home growers, excess water is drained from the grow bed and recirculated during the next drip cycle. Excess water drains out of the growing media and runs to waste in non-recovery systems. This method is preferred by commercial growers. Though non-recovery drip systems may appear to be wasteful, large-scale growers are extremely frugal with their water usage. These drip systems are only intended to deliver the exact amount of solution required to keep the growing media surrounding the plant damp. Non-recovery drip systems use complex timers and feeding schedules to reduce waste.

3.5.2 Drip System Advantages

1) *Variety of plant options:* A drip system is capable of supporting much larger plants than most other hydroponic systems. This is one of the reasons why commercial growers find it so appealing. A properly sized drip system can provide ample support for melons, pumpkins, onions, and zucchinis. Drip systems hold more growing media than other systems, allowing them to support these plants' larger root systems. Slow draining media, such as rockwool, coco coir, and peat moss, work best with drip systems.
2) *Scale:* Drip systems are easily capable of supporting large-scale hydroponics operations. If a grower wishes to add more plants, new tubing can be connected to a reservoir and solution diverted to the new vegetation. New crops can be added to an existing drip irrigation system; as additional reservoirs with different timer

schedules tailored to the needs of the new plants can be added This is another factor that contributes to the popularity of drip systems in commercial hydroponics.

3.5.3 Drip System Disadvantages

1) Maintenance: There is a significant amount of maintenance involved if one grows plants at home using a non-recovery drip system. You must constantly monitor the pH and nutrient levels in your solution, draining and replacing as needed. Because delivery lines can become clogged by debris and plant matter, they must be washed and flushed on a regular basis.
2) Complexity: Drip irrigation systems can quickly become elaborate and complex projects. This is less important in professional hydroponics, but it is not the best system for home growers.

3.6 Aeroponics

3.6.1 Aeroponics System Overview

Aeroponics systems suspend plants in the air, exposing their naked roots to nutrient-rich mist. Aeroponics systems are enclosed frameworks, such as cubes or towers, that can hold a large number of plants at the same time. Water and nutrients are stored in a reservoir before being pumped to a nozzle that atomizes and distributes the solution as a fine mist. The mist is typically released from the top of the tower, cascading down the chamber. Some aeroponics systems mist the plant's roots continuously, similar to how NFT systems expose the roots to the nutrient film at all times. Others work more like an ebb and flow system, misting the roots at regular intervals. Aeroponics does not require substrate media to thrive. Because the roots are constantly exposed to air, they can consume oxygen and grow at a faster rate.

Aeroponics systems use the least amount of water of any hydroponic system. In fact, growing a crop aeroponically uses 95% less water than growing it in an irrigated field. Their vertical structure is designed to take up as little space as possible, allowing multiple towers to be housed in a single location. With aeroponics, great yields can be produced even in confined spaces.

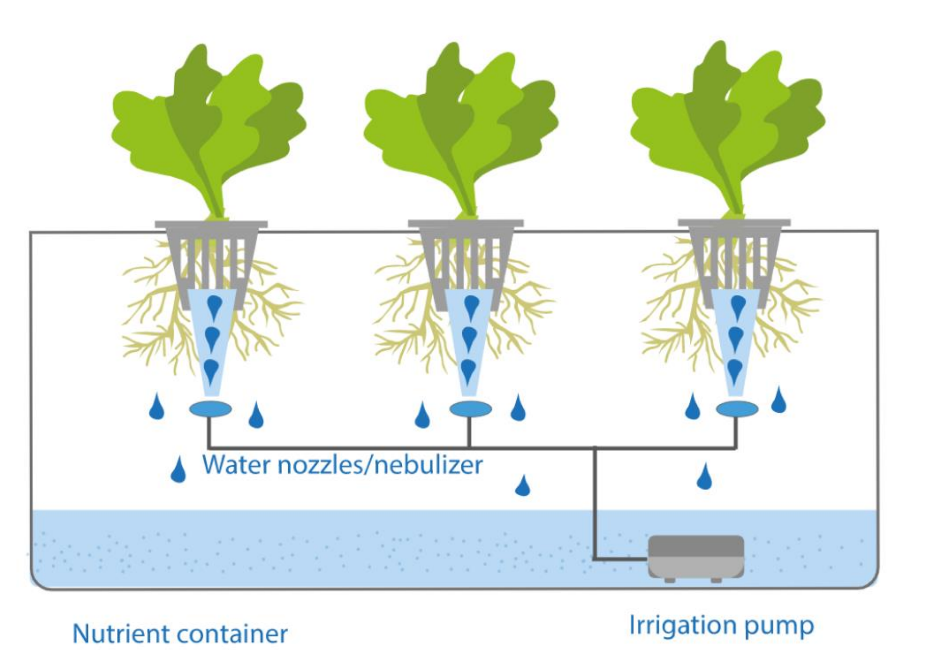


Figure 6- Aeroponics System

Furthermore, because of their increased oxygen exposure, aeroponic plants grow faster than hydroponically grown plants.

Aeroponics allows for year-round harvesting. Vine plants and nightshades such as tomatoes, bell peppers, and eggplants thrive in an aeroponic environment. Lettuce, baby greens, herbs, watermelons, strawberries, and ginger all thrive in this environment. Fruiting trees, on the other hand, are too large and heavy to be grown aeroponically, and underground plants with extensive root systems, such as carrots and potatoes, cannot be grown.

3.6.2 Aeroponics Advantages

1) *Oxygen Surplus:* The extra oxygen taken in by the bare roots boosts the plant's growth. Aeroponics are not only the most environmentally friendly hydroponic system, but also one of the most efficient. They are adaptable, customizable systems that consistently deliver high-quality results.
2) *Mobility:* Aeroponic towers and trays can be easily moved from one location to another without interfering with plant growth. To keep the roots from drying out during transportation, mist them with a spray bottle. Furthermore, aeroponic systems are ergonomically designed and maximize space. Aeroponics allows for higher plant densities than other hydroponics systems.

3.6.3 Aeroponics Disadvantages

1) *Expensive:* Aeroponics is more expensive to set up than other hydroponic systems. A fully functional system, complete with reservoirs, timers, and pumps, can cost thousands of dollars to set up. A DIY aeroponics system can be built for much less money, but it is a much more difficult task than a DIY deep water culture or wick system.
2) *Maintenance:* Aeroponics systems maintain a delicate balance, and if it is disrupted, the results are disastrous for your plants. If your timer does not go off or a pump fails, you risk losing your entire crop unless you manually mist the roots. To keep root disease at bay, keep the root chamber clean on a regular basis. Aeroponic systems, in general, require more technique to succeed than other systems.

After having a deeper understanding about each system, its advantages, and disadvantages, we will look at competitors, their specifications, and the types of systems they use so that we can choose the most suitable system for our project.

Chapter 4: Competitors

Looking at different products will help identify competition and hydroponics for home use techniques. The research on this topic will only cover products intended for personal and home use and will not take into consideration projects intended for commercial or large-scale usages. Several features of each product will be taken into consideration. The information is collected from the official websites of the products and based on reviews from professional and beginner gardeners.

According to Hannah Twigs from The Independent UK, the following are the best 9 hydroponics kits:

4.1 Akarina 01 starter pack: £169.99

According to Twigs, The Akarina 01 is the easiest plug and play hydroponics kit for the beginner indoor gardener, with minimal setup, three removable culture trays that make seeding and watering extremely easy, and an LED light with an integrated timer and dimmer function (Figure 7). Twigs and her team insist that it is one of the most aesthetically pleasing kits they tested, and it works well as a lamp in any room. The starter kit includes gourmet loose-leaf salad, which grows quickly in a hydroponics system and takes about 40 days to mature (or fewer with baby leaf).

Younger plants only need to be watered once per week. The user will need to increase the watering to twice a week near the end of the grow cycle, or during a heatwave, as Twigs and the team tested, so it requires a bit more attention than some of the other kits they tested. The light is set to turn on for 16 hours per day and can get quite warm to the touch, but this can be adjusted, turned off, or dimmed if desired. Because of the white exterior, algae discoloration is more visible. Akarina suggests refreshing the water in the culture trays and wiping them down with a cloth if it becomes too much. The flagship model is the Akarina 01, but there are two others available.

It comes with these specifications labeled:

1) 1 x 0.5g pack gourmet loose-leaf salad seeds, 100ml bottle liquid nutrients
2) Grow cycle: approximately 40 days (5 weeks)

Figure 7- Akarina 01

4.2 Seed Pantry Grow Pod 2: £65.00

According to the team, Seed Pantry's grow pod 2 is a simple and affordable kit that fits nicely on a desk or windowsill (Figure 8). It's a little smaller than some of the others they tested. The grow pod itself appears to be quite high-tech, and the packaging is modern and entirely recyclable. The adjustable LED light, which can be turned on and off and has an inbuilt timer, the smart controller, which beeps when it needs watering, and the seed spacer covers, which clip on the top of the grow pods and space out the plants as they grow were all favorites. The kit only includes enough nutrient-infused growing medium for one cycle, so the user will need to buy more (£3.50) for a second harvest. Seed Pantry claims to be clean, but the team had some growing medium and water spillage, so they advise caution when filling and watering the pods.

The user can select between Italian basil, a basket of fire chili, and sweet 'n' neat cherry tomato. The team chose tomatoes and chilies, which sprouted in about 10 days and took about five weeks to grow to a foot tall. Three months later, no fruit has sprouted. Seed Pantry also provides a seed subscription box as well as a variety of grow kits, including starter kits for children.

It comes with these Specifications labled:

1) Three seed packs (includes Italian basil, basket of fire chili, sweet ‘n’ neat cherry tomatoes), advanced grow medium with nutrients.
2) Grow cycle: around 7 weeks for chilis and tomatoes to appear.

Figure 8- Seed Pantry Grow Pod 2

4.3 Miracle-Gro AeroGarden Harvest: £170, Amazon

Miracle-Gro is well-known for its fertilizers and plant care, so it's only natural that it's expanded into hydroponics (Figure 9). It has several models, but the Harvest, with 6 pods, a red/blue LED system with a timer function, and a control panel that tells you when to add water and nutrients, is unquestionably the most elite while remaining reasonably priced. The Harvest includes a gourmet herb seeds kit with pre-sewn plugs of Genovese basil, curly parsley, dill, thyme, Thai basil, and mint, as well as grow domes for optimal germination and a full season of liquid nutrients. These will have to be purchased again for the following season.

Twigs and her team especially like the adjustable light panel, which can be moved up and down as the plants grow taller, the pre-sewn plugs, which can be placed straight into the unit and are mess-free, and the inbuilt pump, which circulates the water several times a day to prevent sediment buildup for healthier plant roots. We had a problem with some of the plugs: the parsley and thyme didn't sprout at all (on their website, Miracle-Gro says it will replace dud pods for free), while both types of basil grew much faster and taller than the others, eventually blocking out the light for the dill and mint, stunting their growth. The basils grew taller than the light panel which caused the leaves to get burnt.

The specifications that were listed with the package:

1) Six pods gourmet herb seed kit (includes Genovese basil, curly parsley, dill, thyme, Thai basil, mint), patented nutrients
2) Grow cycle: around a month to 5 weeks

Figure 9- Miracle-Gro System

4.4 Ikea Krydda/Vaxer Grow Kit: £63.50, Ikea

The Ikea grow kit has recently become popular on Instagram, inspiring a new generation of hydroponic gardeners. It includes enough plugs, growing medium, and nutrients for multiple cycles, but seeds are sold separately (£1.50 per pack). There are also instructions on how to clean the pumice stones before reusing them. This kit takes a little longer to set up because it comes flat packed (it is, after all, Ikea) and must be assembled, and it also requires the user to germinate seeds in a nursery box (which is provided) before planting (figure 10)

It can be difficult to replant the delicate seedlings grown on stone-wool plugs (which absorbs water and provides a good base for the roots) into the baskets with pumice stones without damaging them. Twigs discovered that they did not plant the plugs deeply enough, exposing some of the roots, causing the plants to collapse. However, once the seedlings have been replanted, things become much easier because there is a water level and a funnel to make topping up simple. The red/blue LED light allows the user to grow all year, but it lacks an integrated timer.

The plants grow quickly and well, but they can become overcrowded, so it is advised to use fewer than the eight provided grow pots and spread them out a bit. Ikea also sells a two-tiered model.

The specifications that were labeled on the box:

1) Growing media, nutrients available
2) Grow cycle: 4-5 weeks

Figure 10- Ikea System

4.5 Botanium: £59.00, Botanium

Botanium is a "smart" plant pot that automatically waters plants several times per day, resulting in less fuss and more growth. The water tank lasts several weeks and has a convenient window on one side so you can see when it needs to be topped up. Botanium uses a porous growing medium that retains a lot of water without draining the roots while also providing an aerated environment for the roots, resulting in faster growth and more control.

The Botanium can be used for vegetables or flowers, but it is recommended that you plant dwarf varieties that will not outgrow the container. Seeds (basil, chili pepper, cherry tomato, and coriander are recommended) are an extra £3.30. The seed packets include easy-to-follow instructions for planting and caring for the plants, such as how much light and nutrients are required, how long it takes for them to sprout, and how tall they will grow. The team grew tomatoes, which germinate in about a week but take 1-2 weeks to sprout. Growth has been slow so far (at the time of writing) – Botanium recommends carefully removing all but the tallest seedlings to avoid competition and maximize growth, as well as assisting the plant in pollinating once the flowers have bloomed (after a few months). In addition, the group experimented with coriander, which grew much faster and thrived in a sunny spot on a windowsill.

Botanium does not include a growing light. This isn't as important in the summer because there is plenty of light, but if users don't have a sunny spot in their house or want to continue growing in the winter, they will need to purchase a grow lamp.

The specifications listed for consumers:

1) Growing medium, pipette bottle with liquid nutrients, seeds are extra (basil, chilli pepper, cherry tomato, coriander, £3.30 extra)

2) Grow cycle: 2-3 weeks for coriander, 4-5 for tomatoes (but no fruit)

Figure 11- Botanium System

4.6 Growgreen hydroponic tube: £44.99, Amazon

The Hong Kong-based EasyIn-06 system Growgreen is a bench-top, tube-shaped hydroponic system that can accommodate six plants. The kit is available on Amazon but does not include nutrients, seeds, or instructions, though it does provide a demo video on its website to walk you through the setup and growing process. The kit includes an external pump (with a USB port) that circulates water (and nutrients, if used) through the tube to help save water and prevent sediment and algae buildup. Growgreen suggests leaving the pump running for 12 hours per day. Because it lacks an LED lamp, it must be placed in direct sunlight. The tube is double-layered, providing thermal insulation in both hot and cold temperatures.

The kit includes 12 sponge plugs, but it is recommended that seeds be germinated on damp kitchen paper in a plastic box before transferring to the tube – which can be quite fiddly. Twigs and her team decided to grow spinach and watercress and discovered that the EasyIn-06 was the ideal environment for them – they had fully-grown crops in two weeks, which was faster than some of the other kits they tested.

The system specifications specified:

1) Equipment is given
2) Grow cycle: 2 weeks (but no seeds provided)

Figure 12- Growgreen System

4.7 Competitor Comparison Matrix

In order to make use of the information presented above and observe trends and benchmarks, the data collected is tabulated in Table 1.

	Akarina 1	Seed Pantry Grow Pod 2	Botanium	Aspara Nature Smart Grower	Growgreen Hydroponic Tube	Ikea Krydda-Vaxer Grow Kit	Trend
Size	320 x 320 x 350 mm	L26.5cm x W11.5cm x H11.5cm	14 x 14 x 25 cm	53.5 x 35 x 37 cm	48.6 x 11.9 x 11.6 cm	Variable	
Pump			Water Pump	Application Controlled	Air Pump		N/A
Grow Light	Dimmable White Light	Adjustable: Red/Blue spectrum	White Light Sold Separately	Variable Spectrum LED		White Light Sold Separately	
Timer	2 settings	1 setting	1 setting	Application Controlled			
Planting Cycle	Germination to Harvest	Germination to Harvest	Germination to Harvest	Germination to Harvest	No Germination / Harvest	Germination to Harvest	Germination to Harvest
Watering needs	Once per cycle	Alarm tells you when to water	Once per cycle	Application Controlled	None needed	Once per cycle	Once per cycle
Assembly	None needed	None needed	Grow Light	Assembly needed once	None needed	Needed	None (some) needed
Price	€ 169.99	€ 72.00	€ 59.00	USD 2,900.00	€ 45.00	€ 63.00	
Type of plants	Gourmet looseleaf salad seeds	Cherry Tomato, Chilli Pepper, Basil Seeds	Cherry Tomato, Chilli Pepper, Basil, Coriander, Thyme, Tatsoi	Leafy vegetables, herbs, fruits, flowers, root vegetables	Salad Vegetables	Herbs, lettuce, pak choi, chard	N/A
Growth Medium	Vermiculite: magnesium-aluminum-iron silicate	Unspecified: not set up by user	Unspecified: porous growing medium absorbs a lot of water, while also providing an aerated environment for the roots	Unspecified	Air Stone	Rock wool	N/A
Effective Insulation System							
Weight	2.1 kg - 3.9 kg	1.2 kg	0.96 kg	11.2 kg	1.5 kg	Variable	
App Connectivity							

Table 1- Competitor Matrix

Legend	
	Present
	Absent
	Small
	Medium
	Big
	Inexpensive
	Average
	Expensive

Table 2- Competitor Matrix Legend

The criteria taken into consideration in Table 1 are the size and weight of the device, the presence of pumps, grow lights, timers, effective insulation systems, and an app connectivity option, the planting cycle and watering needs required, the growth medium used, and the overall price. The trends observed are a small and lightweight device, the presence of a grow light and a timer and an effective insulation system. The planting cycle in most of the competitors is germination to harvest, and most devices require watering only once per cycle. The price range for most devices is £59 to £72, which is on the less expensive side. In addition, most devices do not offer app connectivity. No trends are observed regarding the use of a pump, type of plant, or the use of a specific growth medium. This data will be useful in determining the key criteria to include and improve on in our automated hydroponics system for home use.

Now that we have the key features that is present in every competitor, we will look at the market needs in the next chapter. This is because the competitors do not have perfect products, and there will always be comments and modifications by the consumer. To better understand what the potential buyers want in a hydroponic system so that we would have a competitive advantage and not just another standard product in the market, we conducted a survey for potential users.

Chapter 5: Problem Decomposition

5.1 Survey

Even though analyzing competitors and their features is a prominent part of determining the features of the project, gathering market research is also a key identifier. To better understand the needs and wants of the hydroponics consumer, we distributed a survey to potential customers. In this survey, we wanted to understand the demographic and preferences of the users. We got 143 responses and analyzed them using the automatic tool on google as well as Python. The questions asked are summarized below:

1) The first question we asked was their age. This was to understand which age group we should focus on while designing and marketing the product. We had a wide range of responses (14-50 years old, see figure 13). We mostly got responses from teenagers to mid-twenties. The second highest age group present was early thirties. This could be a bias in the data due to the fact that we distributed the survey mostly between our colleagues in our university. However, it should be noted that early adults are the most interested in owning indoor plants.

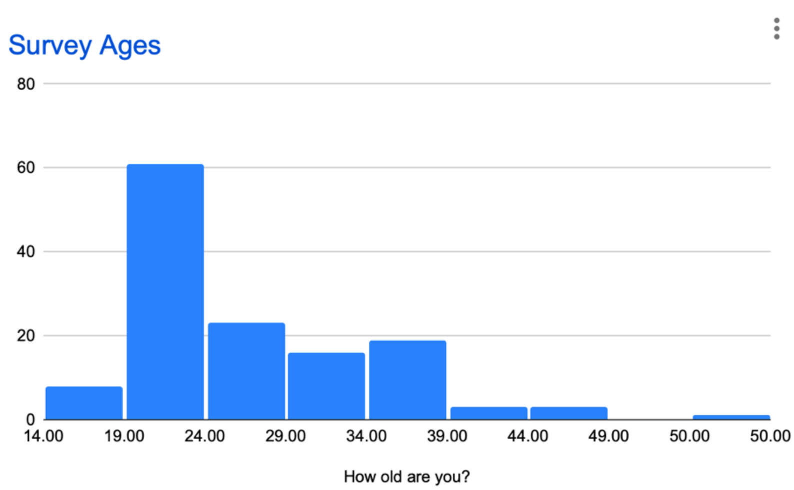


Figure 13- Age Distribution in Survey

2) The second question we asked is the country of origin. The purpose of this question is to understand if the popularity of hydroponics across different nationalities. Our survey received responses from multiple different countries. We believe that this also could be a bias based on the fact that we distributed the survey in our close community hence 55.2% of the respondents were Lebanese (Figure 14).

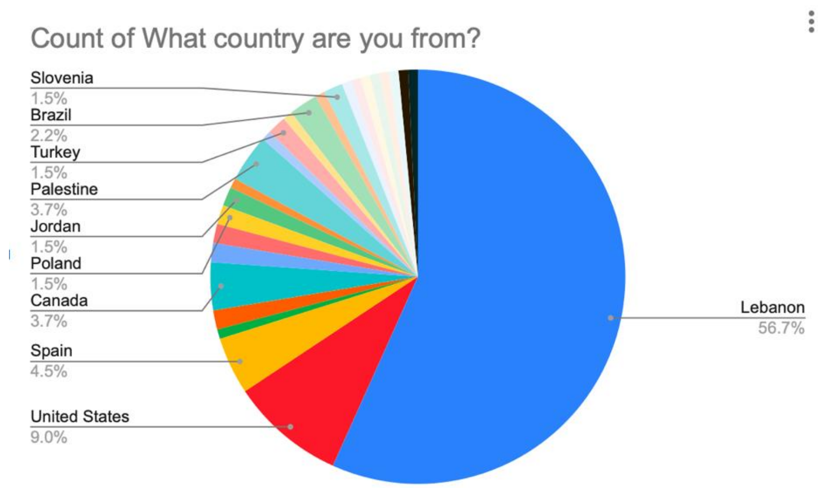


Figure 14- Country Distribution in Survey

3) The third question is directly related to understanding home-planting behavior. We asked the respondents if they own plants at home where 79.7% responded yes and 20.3% responded no.

a. Plant owners:

After that, we asked plant owners to tell us why they owned plants. This allowed us to understand what the consumers are looking for out of our product by understanding the main benefits they value from owning indoor plants. We uploaded the responses to a Pandas data frame using Python. Then, we analyzed their responses by extracting the most common words.

The most frequent words (in random order): Decoration: 15, Cook: 5, Beautiful: 7, Food: 4, Relax: 3, Smell: 1, Veggies: 2, Care: 7, Grow: 6, and Positive: 4. (See figure 15 where size of the word depends on its frequency)

Figure 15- Plant Owners Word Bubble

This allowed us to understand that the most important feature for the plant owners is aesthetic setup for decoration. They also use the plants for positive influence and care. Since we are planning on growing fruitful plants, it is important that the "food" element was notable.

Finally, we asked plant owners what category of plants they own, and 62.2% of respondents own decorative plants and 37.8% of them own edible plants.

This allowed us to have a deeper understanding of why aesthetics was important to the owners.

b. Non-owners:

We also asked non-owners why they do not own plants. We used the same procedure to extract the words repeated the most.

The most common words: Care: 5, Time: 3, Had: 1, Space: 1, and Dying: 1.(See figure 16).

Figure 16- Non-Plant Owners Word Bubble

It is important to note that since the follow-up questions were optional, and thus we received little responses on them compared to the total amount of responses.
However, we were able to gather that the main reasons the respondents do not own plants is that they take a lot of efforts to maintain, they need to much space, and they are not very portable.

Thus, we will be trying to solve those issues in our product to make it appealing for everyone.

4) Then, we asked the respondents how interested they are in growing edible plants where the majority answered 3 out of 5 and above (See figure 17 where 1 is very interested and 5 is not interested).

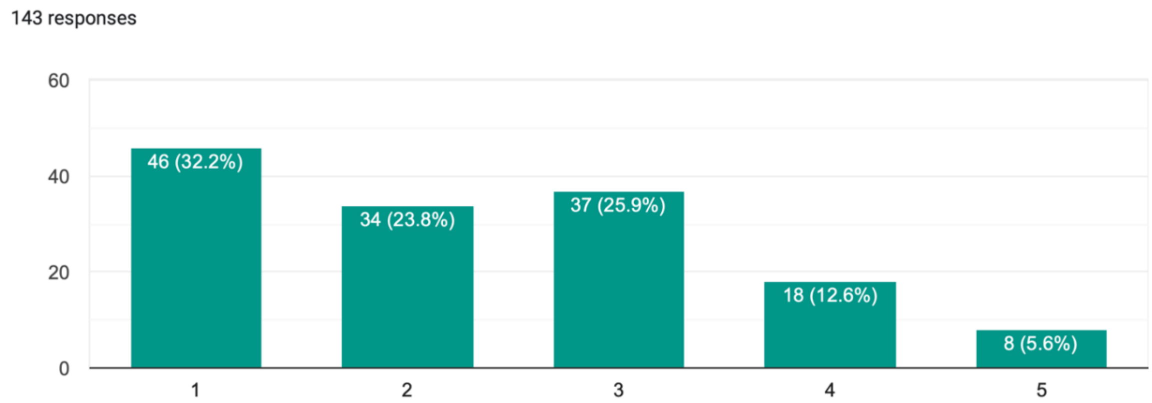


Figure 17- Survey Answers for Interest in Planting Edible Plants

5) We also asked the respondents if they think maintaining a plant is hard work. This will allow us to understand how much of the process needs to be automated. The majority of respondents answered in the middle region, between difficult and easy. From our analysis, the difficulty is depending on the type of plant. However, the majority leaned towards "a lot of effort" option. (See figure 18 where 1 is a lot of effort and 5 is no effort at all.)

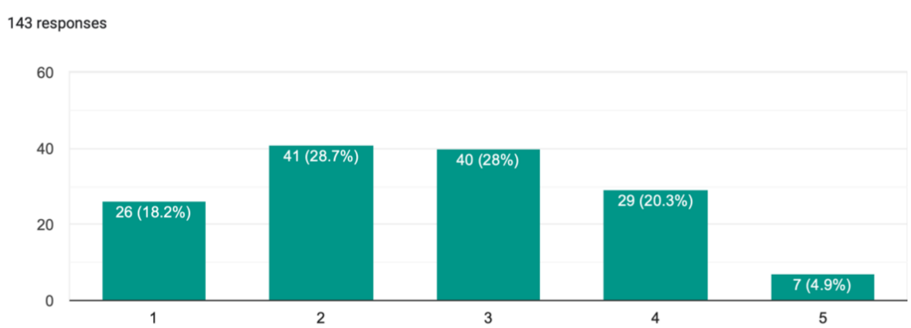


Figure 18- Survey Answers to Ranking Plant Maintaining Effort

6) To better understand which part needs to be automated the most, we asked the respondents which part of planning was the most difficult: Germination, Seeding, Planting, Maintaining the plant's health, fruiting, or harvesting. We split this question into plant owners and non-owners to understand if planting experience will cause a bias in this question. (See figure 19 for general answer).

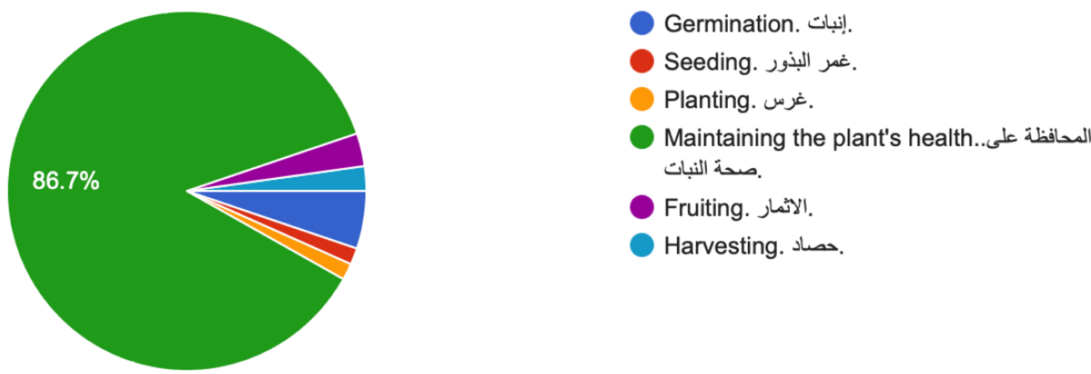


Figure 19- Survey Answers to Hardest Part of Plant-Keeping

a. Plant Owners:

Most owners (around 90%) said that maintaining the plant was the hardest part. This shows that the long-term maintenance is the part that requires the most effort for people who are experienced in owning plants.

b. Non-Owners:

The results from this analysis were interesting as germination was a much more prominent problem amongst non-owners.

7) Diving into core of the survey, we asked the respondents if they know about hydroponic systems. 51% responded yes and 49% responded no.

8) Then, we added a definition of hydroponics and asked how interested they are in owning a hydroponics plant. The majority answered leaning towards interested. (See figure 20 where 1 is very interested and 5 is not interested at all)

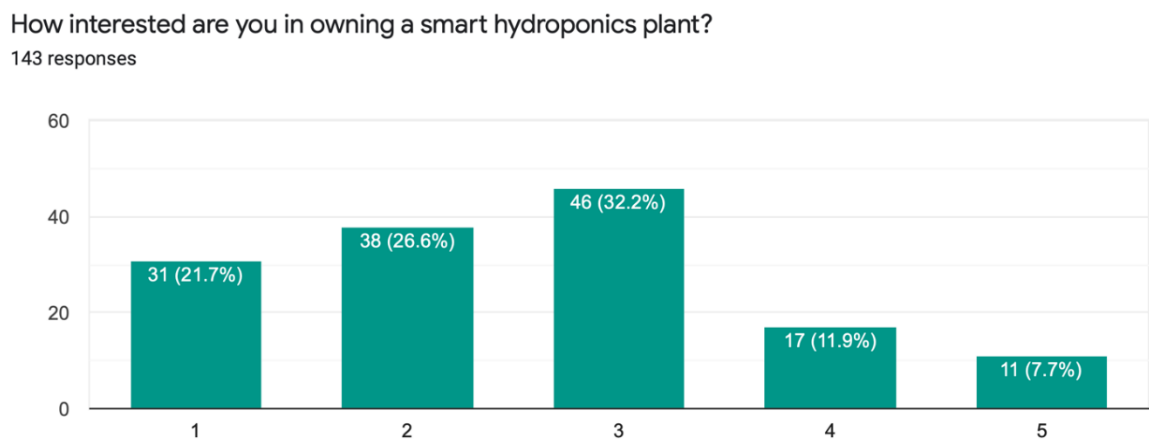


Figure 20- Survey Answers to Hydroponics Plants Interest

9) Finally, we asked the respondents if they are willing to give us their contact information for a second round of surveys when we are going to develop product features.

5.2 Expert Interview

5.2.1 Agricultural Engineer

An expert interview is essential to identify the main environmental variables which will allow the hydroponic plant to properly grow indoors. We interviewed the agricultural expert Eng. Zaher Ayoub who offered a great insight on what is important when growing plants and what to focus on. We found out that hydroponics is currently rising in popularity, especially for home use. Regarding the system, a circulation is essential to have control over the flow rate and level of nutrients, which reduces the risk of pests and diseases. The main sensors to monitor the system are the electrical conductivity sensor, pH sensor, and temperature sensor at root level. A light source will provide the plant with light and some heat, and plants of similar needs can be planted together with the same concentration of nutrients and watering cycles. The following questions were asked with their respective answers:

Q: Have you heard of Hydroponics Systems for home use?

A: Yes, hydroponics is the latest trend in the agricultural sector, and it is a great research prospect.

Q: Which system do you recommend?

A: You need a system with a circulation for the solution to be sterilized and to control the flow and level of nutrients. This would reduce the risk of pests and diseases.

Q: What type of sensors we should use?

A: TDS (EC) sensor to monitor what is inside the solution, pH sensor, and a temperature sensor.

Q: What features should we include?

A: A light as a source of heat so that the plant can be placed anywhere in the house. A camera on the top of the system to monitor leaf color.

Q: What type of plants should we offer?

A: You should include plants that are not complicated to grow like herbs. You should plant similar plants (having same needs) in the same row.

Q: Is there anything else you want to add?

A: It would be a good idea to make different kits with different prices to cover all the market. You should try to decrease the cost without compromising the quality.

Eng. Zaher Ayoub offered a great insight on what is important when growing
plants and what to focus on. To summarize, we found out that hydroponics is currently rising in popularity, especially for home use. Regarding the system, a circulation is essential to have control over the flow rate and level of nutrients, which reduces the risk of pests and diseases. The main sensors to monitor the system are the electrical conductivity sensor, pH sensor, and temperature sensor at root level. A light source will provide the plant with light and some heat, and plants of similar needs can be planted together with the same concentration of nutrients and watering cycles.

5.2.2 Hydroponics Hobbyist/Retailer

Now that we have met with an agricultural engineer, we wanted to meet with someone who had a specialization in hydroponics. Thus, we met with a hydroponics retailer that makes his own systems from scratch. He has been making hydroponics systems for home use for the last 5 years and has tested almost every plant that grows in Lebanese climate and every type of system. By then, we did not have a specific plant in mind, but we wanted to tailor our product to be able to handle a fruiting plant.

Since he did not have a formal education in agriculture, but rather has his knowledge from trial and error, we fact-checked everything he said after the interview.

First, he said that aeroponics is the best choice of system for its low maintenance and high yield, and if we had to stick to hydroponics, we should use the Drip System.

He also said that we do not need any nutrients for the germination phase, which is correct. He told us that the nutrient solutions come either liquid or powder. We can use the powder for initial solutions in the small system, but we always have to use the liquid for bigger system since powder does not come in big-enough sachets. For the powder nutrients, we should use double the amounts of nutrient A than nutrient B. The usual starting point for a 7L system is 30g and 15g respectfully. He said that we need 17 nutrients for tomatoes to grow and 3 of them are in the atmosphere. After checking this fact, we found out that tomatoes actually needed 11 nutrients in total. For TDS measurement, he said that drinking water usually has a TDS of 120 which we should take as a reference when measuring the rest of the TDS in our system.

He then went on to specify the exact measurements for tomatoes. He said that in the first week, they need 300 TDS, second week 700 TDS, and after a month, 1000 TDS as well as manual pollination. He said that the maximum TDS it can reach is 1300-1500 TDS. However, scientific reports mentioned that it will survive until the maximum of 2100-2450 TDS.

He mentioned that we should wash the plants for two days after harvest so that the bitter taste of the nutrients are not prominent. This was correct and confirmed by multiple sources [4].

He mentioned that the pH levels of tomatoes should stay between 5.5 and 6.5, which is also correct. When we see that the pH has increased, we should spray the leaves with white vinegar. If the pH has decreased, we should use a proper basic solution and no alternatives. These are both correct and have sources [5].

For germination pods, he said that oasis cubes are the best option. After checking this, we found that they are recommended for small systems, but not necessarily the best option.

Finally, he mentioned that for every 7L system, we should turn on the water pump for 10 minutes every hour.

Now that we have gathered information from competitors, potential users, and an expert, we can connect them together so that we choose the most suitable system for our project as well as the features we have from them.

Chapter 6: System and Feature Selection

6.1 System Selection

Our system has a set of objectives to meet which affects the type of hydroponic system we'll be using and the different sensors, actuators, and solutions. The objectives can be narrowed to automation, effectiveness, ease of use, and the ability to grow a variety of plants including flowering plants and fruits.

Based on the indoor systems used by competitors, the most prominent types are Deep Water Culture (DWC) System, Wick System, or a custom system that can be considered a hybrid of the two by submersing half the grow medium in the nutrient solution, eliminating the need of an air stone to oxygenate the roots of the plants. While these systems can be much lower in cost due to the lack of automation, however, they are passive and don't have a proper way to adjust the nutrient concentration and pH of the solution. Thus, Deep Water Culture and Wick Systems are not the best choice to grow flowering plants and fruits, since such plants require a very precise solution at specific watering cycles to properly grow, instead of always being subjected to the nutrient solution. They're more suitable for leafy vegetables. Moreover, passive systems require more manual work by the user since they require cleaning and are more prone to root rot, and the germination period requires the user to water the seeds instead of being completely automated.

The other two less prominent types used indoors by competitors are Drip System and Ebb and Flow (Flood and Drain) System. Other types of hydroponic systems are not feasible at a small scale for indoor use. Even though Drip Systems and Ebb and Flow Systems are both automated and have the ability to adjust watering cycles and the concentration and pH of the nutrient solution, however, they are fundamentally different as Drip Systems water the plant from the top of the growing medium, while Ebb and Flow Systems temporarily submerse the roots in the nutrient solution for a certain period of time. These two systems are extremely effective for growing almost any type of plant paired with the proper sensors to monitor the environment and solution then adjust them accordingly. Moreover, they require less user input compared to other systems since it is possible to completely automate the germination, watering cycles, nutrient concentration, and pH if necessary. Both systems can be medium to high in cost depending on the number of sensors, actuators, and solutions used.

The systems we'll be testing are both Drip System (See figure 5) and Ebb and Flow System (See Figure 4) to check the feasibility of both systems indoors at a small scale. Both systems are capable of meeting the required objectives when paired with the right grow medium. The best growing medium for growing flowering plants and fruits among other types of plants is Rockwool. This grow medium is aerated which ensures the roots are properly oxygenated and can deliver the nutrient solution effectively, maintaining an ideal moisture level for the roots which helps prevent over watering and root suffocation.

Now that we have selected our system, we will look at the specifications and features that we want to include in our system. These features are mainly a collection of user needs and competitor features to make sure that we cover everything.

6.2 Features

In this section, we will be listing and explaining all of the specifications and features that we deducted from both previous and current plant owners and non-owners according to the problems they faced. These features will be included in our final product to solve these issues and will be stated below as the following:

6.2.1 Non-Plant Owners

Problems that non-owners were facing with plants were that they had to constantly maintain the plant's health and keep it alive. As a solution to this problem, our product has the ability to maintain and take care of the plants, mostly on its own due to the help of many sensors built in the system that automatically detect and adjust changes like in water or pH levels.

Another problem they were struggling with was the germination process and that plants take up way too much space. Therefore, our product comes with growing medium capsules that do not require germination and has the ability to be easily moved throughout the household, it is compact, easy to assemble and maintain.

6.2.2 Plant Owners:

The most repeated issues of plant owners that the plant needed too much effort in maintaining its health. They also suffered from many different problems with their plants, which made them require a variety of solutions from our product such as the product having an aesthetic setup. This means that the product will be available in different colors, be compact, have soft round edges, and dimmable red and blue lights. The product should be able to grow many types of leafy plants that could be used as a decoration or for cooking purposes.

Moreover, the product is not noisy meaning that it is silent and will not annoy anyone in its surrounding. It will also include a calm lighting system which will also have a positive aesthetic look and an eye-pleasing view.

A crucial feature that our product will also have, is that it will be made from sustainable and recyclable material, also the nutrient solution that is added to help the plants grow, is safe to consume and is eco-friendly.

A common feature that was needed from both owners and non-owners was that for our product to monitor and maintain the plant's health and for it to be easy to assemble, maintain and use.

This is a summary of all the features our product will include:

1. Aesthetic setup.
2. Calm lighting system.
3. Includes red and blue light.
4. Silent product.
5. Can grow multiple types of leafy plants. (Decorative and consumable)
6. Monitors plant growth.
7. Made from sustainable and recyclable material.
8. Nutrient solution is eco-friendly and safe to consume.
9. Easy to assemble, maintain and use.
10. Does not need constant effort and care.
11. Compact and movable.
12. Growing medium capsules. (No germination needed)
13. Automatic adjusting of pH and water levels.

14. Automatic timer.

15. Mold/fungus proof.

6.3 Component Selection

The components used in the indoor hydroponic system consist of the different sensors, actuators, mechanisms, and lights. For the lights, two types of LED strips will be tested, white LED strips and RGB LED strips in grid formation for experimentation.

The actuators consist mainly of two motors that will act as pumps, one of the pumps is a peristaltic submersible pump while the other isn’t. The pumps require a motor drive to be able to be controlled using a microcontroller. Moreover, normally closed solenoid valves are used to control which solution (acid, base, or concentrated nutrients) is pumped into the main reservoir using pipes.

The microcontroller used for this system is a Raspberry Pi, it allows the collection of the data, automation of the system, and visualizes the data in a readable form using a web server. Moreover, an Arduino Uno will be used to set up multiple experiments and test the different sensors and actuators. An LCD display is used to display essential information to the user incase the reservoir needs to be refilled with water, different watering cycles, nutrient concentration, pH level, and temperature.

The sensors used to monitor the environment and the nutrient solution are:

1) pH Sensor: used to measure the pH of the nutrient solution.

   The analog pH sensor is designed to measure the pH value of a solution with high accuracy and show the acidity or alkalinity of the substance. The module has an on-board voltage regulator chip which supports the wide voltage supply of 3.3-5.5V

DC, which is compatible with 5V and 3.3V of any control board. The output signal is being filtered by hardware low jitter. The pH sensor is essential for monitoring the acidity of the nutrient solution since each type of plant has a specific pH for optimal growth. Figure 21 shows the pH sensor we will use.

Figure 21- pH sensor

2) Water Level Sensor (Figure 22): used to measure the level of nutrient solution in the reservoir.

   The water level sensor is an analog sensor that measures the level of the water due to the change in resistivity. This sensor uses three pins: 5V, ground, and signal pin and will be used to monitor the amount of nutrient solution left in the water reservoir.

Figure 22- Water Level Sensor

3) Water Temperature Sensor: used to measure the temperature of the solution.
   The DS18B20 is a waterproof resistivity temperature sensor that precisely measures temperatures in wet environments with a wide range of -55°C to 125°C. Measuring the temperature at root level is essential to monitor the plant's health, data collection, and visualization.

Figure 23- Temperature Sensor

4) Electrical Conductivity (EC/TDS) Sensor (Figure 24): used to measure the electrical conductivity of the nutrient solution, which allows us to measure the concentration of nutrients.
   The electrical conductivity sensor is used to measure the TDS value of water, to reflect the concentration of substances dissolved. TDS (Total Dissolved Solids) indicates how many milligrams of soluble solids dissolved in one liter of water. In general, the higher the TDS value, the more soluble solids dissolved in water. For this project, measuring the TDS value in the water is used to measure the total amount and concentration of nutrients dissolved, in the unit of ppm or milligrams per liter (mg/l). Its Electrode can measure conductive materials, such as

suspended solids, heavy metals, and conductive ions in water which in the case of plant nutrients are mainly nitrogen (N), phosphorus (P) and potassium (K).

Figure 24- Electrical Conductivity Sensor

5) Light Sensor: used to measure the intensity of light on the plant.

   The light sensor is based on the principle of semiconductor photoelectric effect. The sensor can be used to detect the intensity of ambient light. The resistivity of the sensor changes depending on the intensity of light which can realize light measurement, light control, and photoelectric conversion. The intensity of light is measured to gather data regarding the speed of growth of the plant and how it is affected by it for further understanding.

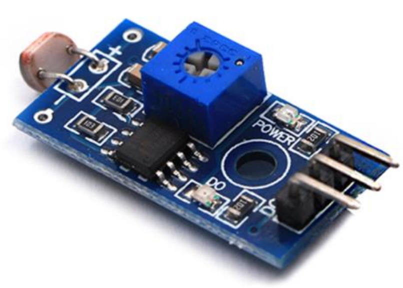


Figure 25- Light Sensor

6) Temperature and Humidity Sensor: used to measure the environment's humidity and temperature around the plant.

The DHT22 is a relative humidity and temperature sensor. It uses a capacitive humidity sensor and a thermistor to measure the surrounding air with a range of -40°C to 80°C. Measuring the temperature and humidity surrounding the plant is essential to monitor the plant's health, data collection, and visualization.

Figure 26- Temperature and Humidity Sensor

Now that we know the exact components that will be used in the experiments, we can sketch the experiments and plan them out to make sure that there is a place for each component and that each feature will work properly, especially with data gathering.

Chapter 7: Design and Implementation of Experimentation

Our hydroponic system requires a set of experiments that must be completed to find the optimal conditions for the plants to grow. For that, we must pick a fruiting plant to ensure that these conditions remain constant, since each type of plant has its ideal watering cycle, nutrient concentration, and pH of the solution. Once a plant is picked, the experiment can be divided into six steps:

7.1 Germination

This experiment includes planting the seeds and testing the capsules and germination caps with Rockwool as a growing medium. The capsules will either be designed, and 3D printed separately so they can be inserted into the system, or will be one undetachable part of the system.

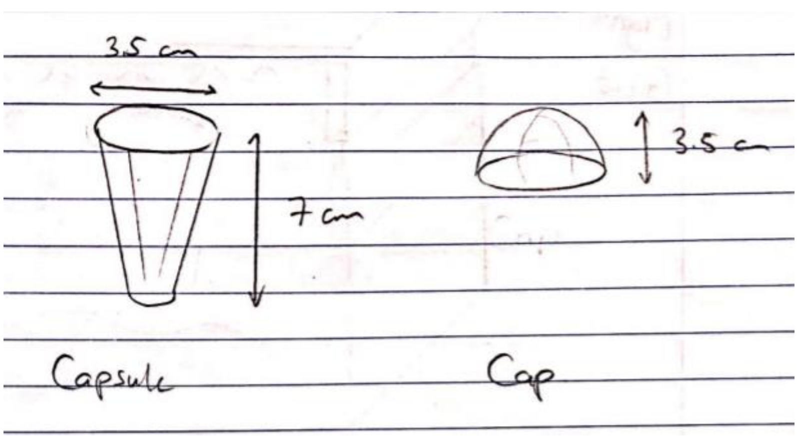


Figure 27- Germination Capsule Design

After attaining the rockwool, turns out that they are rectangular, so we redid our design for them to fit the rockwool. We modeled them on SolidWorks and 3D printed them.

Figure 28- Germination Pods

7.2 pH Sensor

The analog pH sensor is designed to measure the pH value of a solution with high accuracy and show the acidity or alkalinity of the substance. The module has an on-board voltage regulator chip which supports the wide voltage supply of 3.3-5.5V DC, which is compatible with 5V and 3.3V of any control board. The output signal is being filtered by hardware low jitter. The pH sensor is essential for monitoring the acidity of the nutrient solution since each type of plant has a specific pH for optimal growth.

Figure 29- pH sensor Hardware

The pH sensor requires calibration, which was done using distilled water with a pH of 7 that the probe already comes submerged in. This sensor is connected to the Arduino through an analog pin, and it requires no specific library to function.

The Arduino is responsible for measuring 10 consecutive readings from the pH sensor then averaging them out to ensure an accurate pH value of the nutrient solution. An experiment was done to ensure the sensor was working properly in which the pH of bottled water is measured to be around 7.9 as seen below.

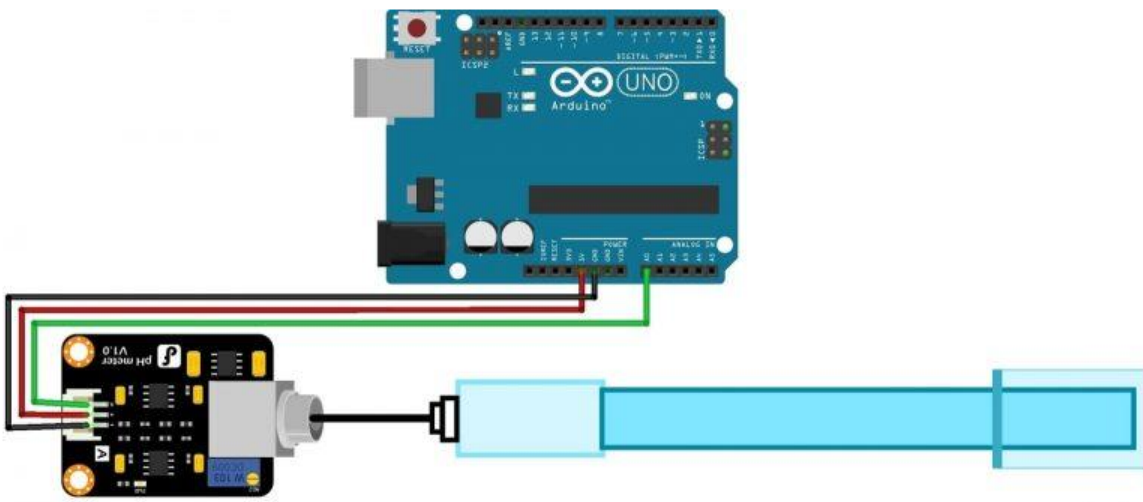


Figure 30- pH sensor Schematic

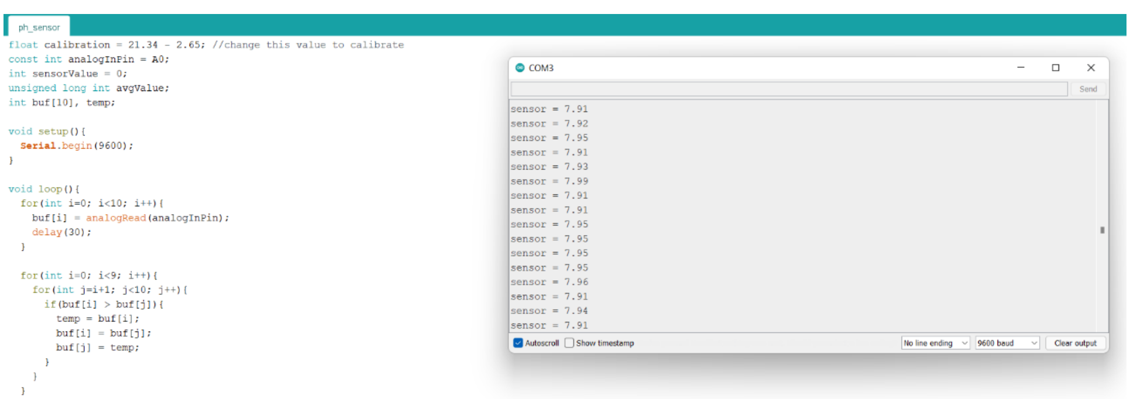


Figure 31- pH Sensor Output

7.3 Water Temperature Sensor

The DS18B20 is a waterproof resistivity temperature sensor that precisely measures temperatures in wet environments with a wide range of -55°C to 125°C. Measuring the temperature at root level is essential to monitor the plant's health, data collection, and visualization.

7.4 Lighting

Figure 32- Water Temperature Sensor Hardware

This sensor requires a 4.7kΩ resistor between the data pin and the VCC pin to function and return proper readings. The sensor requires 5V to function and is connected to a digital pin.

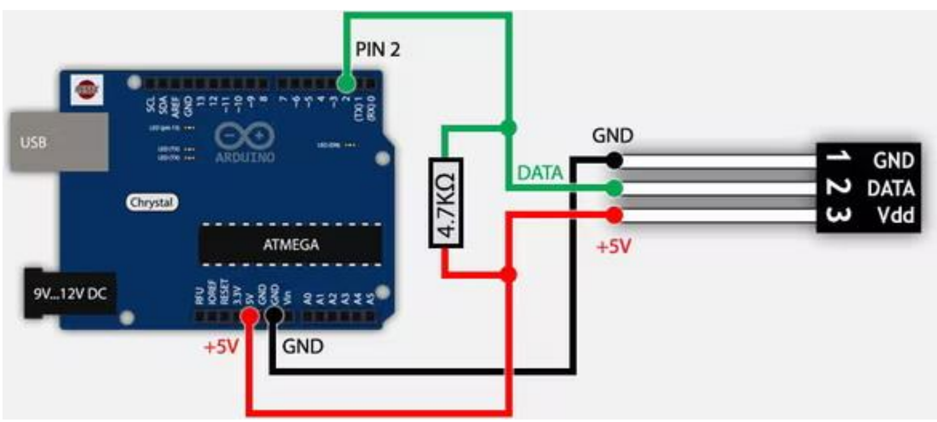


Figure 33- Water Temperature Sensor Schematic

As for the Arduino code, two libraries are necessary to communicate with the sensor through a digital pin. This sensor uses the OneWire library to communicate its readings with the Arduino as well as the DallasTemperature library which returns the temperature in degrees Celsius.

In this experiment, the temperature reading of the sensor is increasing due to friction that is done at the tip of sensor, thus increasing the temperature from around 22 to 27 degrees Celsius at the time of testing.

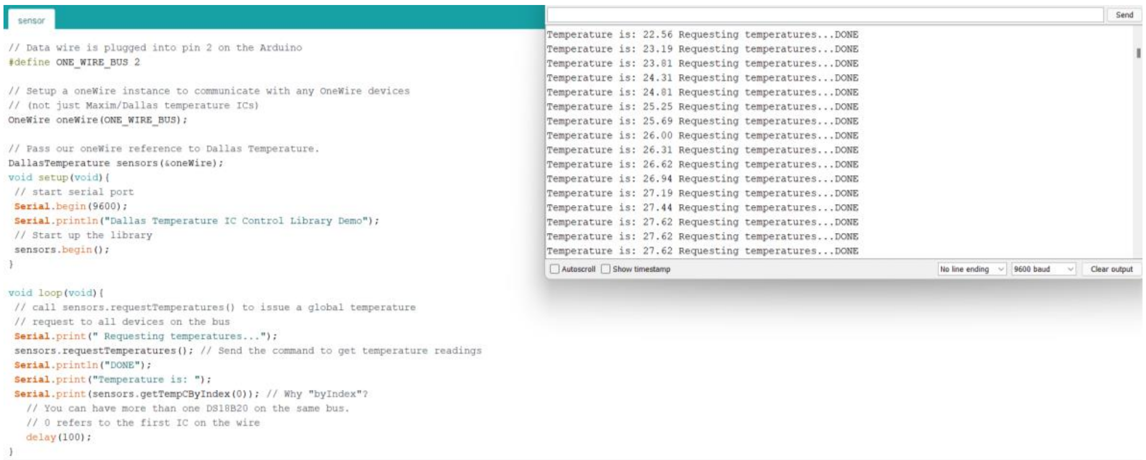


Figure 34- Water Temperature Sensor Output

7.5 Temperature and Humidity Sensor

The DHT22 is a relative humidity and temperature sensor. It uses a capacitive humidity sensor and a thermistor to measure the surrounding air with a range of -40°C to 80°C and humidity in percentage. Measuring the temperature and humidity surrounding the plant is essential to monitor the plant’s health, data collection, and visualization.

Figure 35- Temperature and Humidity Sensor Hardware

This sensor requires 5V to function properly and is connected to a digital pin. The sensor requires the DHT library to function and is able to return both the humidity and the temperature of the air around the sensor.

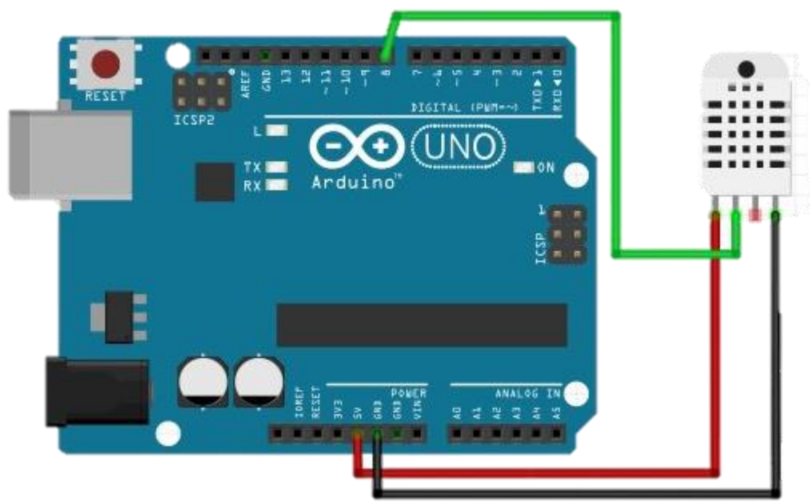


Figure 36- Temperature and Humidity Sensor Schematic

In this experiment, the humidity and the temperature of the air is measured to be 77% and around 25 degrees Celsius respectively as seen below at the time of testing.

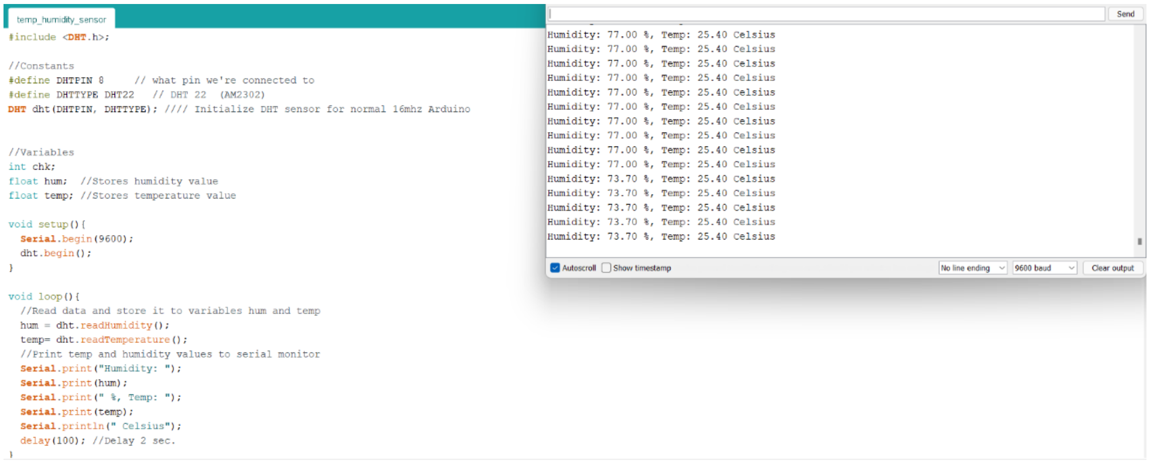


Figure 37- Temperature and Humidity Sensor Output

7.6 Electrical Conductivity (TDS) Sensor

The electrical conductivity sensor is used to measure the TDS value of water, to reflect the concentration of substances dissolved. TDS (Total Dissolved Solids) indicates how many milligrams of soluble solids dissolved in one liter of water. In general, the higher the TDS value, the more soluble solids dissolved in water. For this project, measuring the TDS value in the water is used to measure the total amount and concentration of nutrients dissolved in the unit of ppm (parts per million) or milligrams per liter (mg/l). Its Electrode can measure conductive materials, such as suspended solids, heavy metals, and conductive ions in water which in the case of plant nutrients are mainly nitrogen (N), phosphorus (P) and potassium (K).

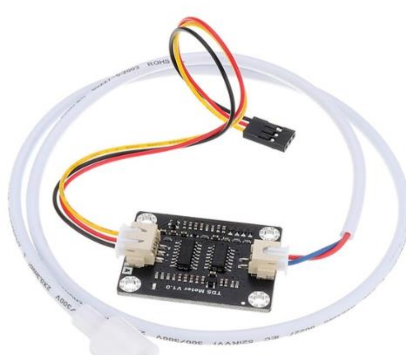


Figure 38- TDS Sensor Hardware

Similar to the pH sensor, this sensor requires a module to function which the sensor probe connects to. The module is then connected to an analog pin and requires 5V.

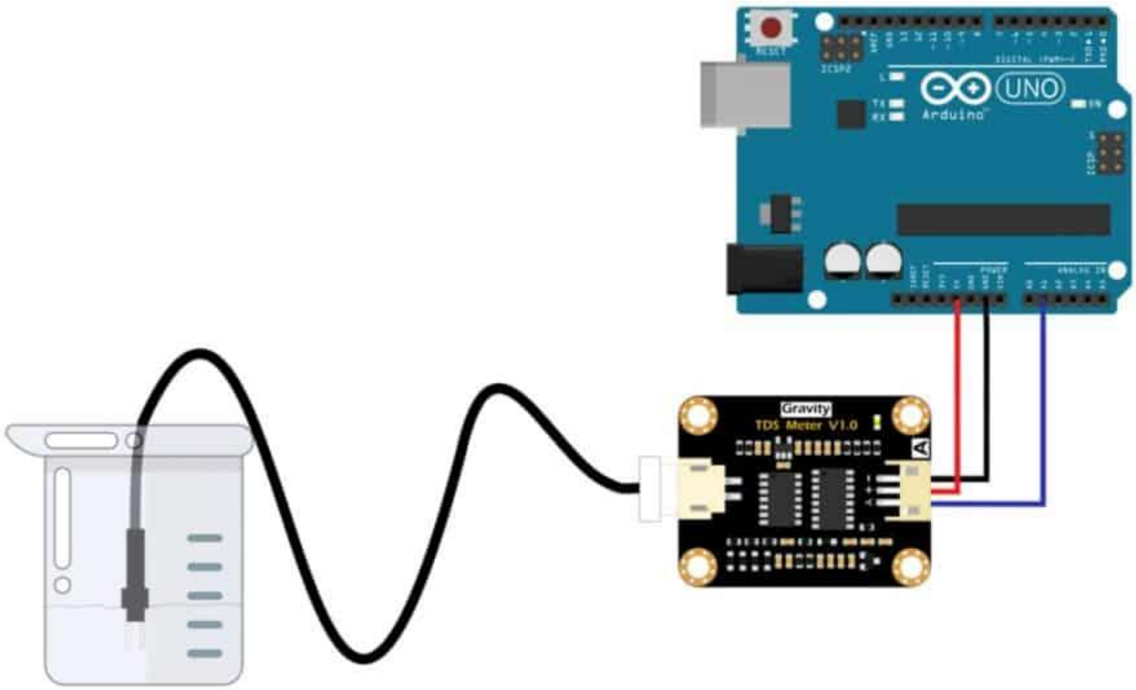


Figure 39- TDS Sensor Schematic

The sensor requires two libraries, the GravityTDS and EEPROM library to communicate with the Arduino. In this experiment, the TDS of bottled water is measured to be around 235 ppm, which will be taken as a reference when adjusting the TDS of the nutrient solution.

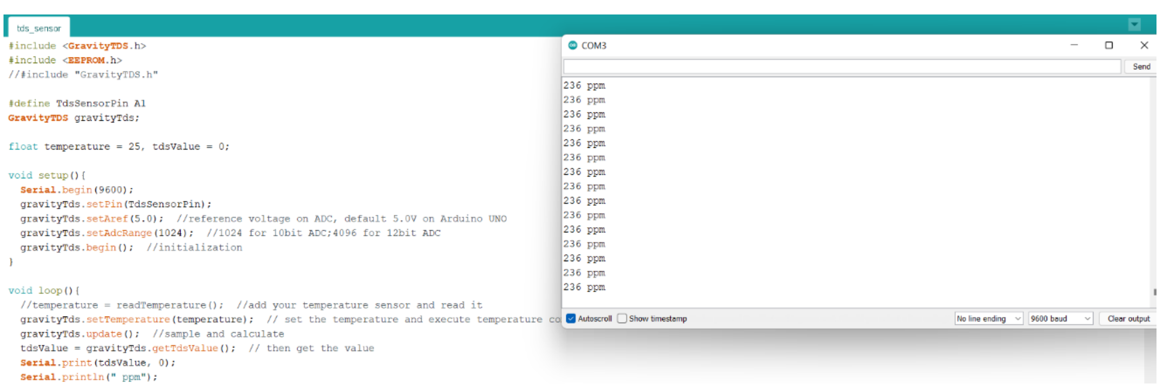


Figure 40- TDS Sensor Output

7.7 Water Level Sensor

Figure 41- Water Level Sensor Hardware

The water level sensor is an analog sensor that measures the level of the water due to the change in resistivity. This sensor uses three pins: 5V, ground, and signal pin and will be used to monitor the amount of nutrient solution left in the water reservoir.

7.8 Outputs

All the outputs which consist of the nutrient pump, four solenoid valves, and LED strip were tested separately to ensure their proper function, then tested together to check for power consumption and the proper control using motor drives. We tested them using delay script to see if they would turn on in a difference of sensor reading, and it worked.

Figure 42-LED Lights used

Figure 43- Solenoid

Figure 44- Water Pump

The results of the output testing can be shown [in this video.]

7.9 Serial Communication between Arduino and Raspberry Pi

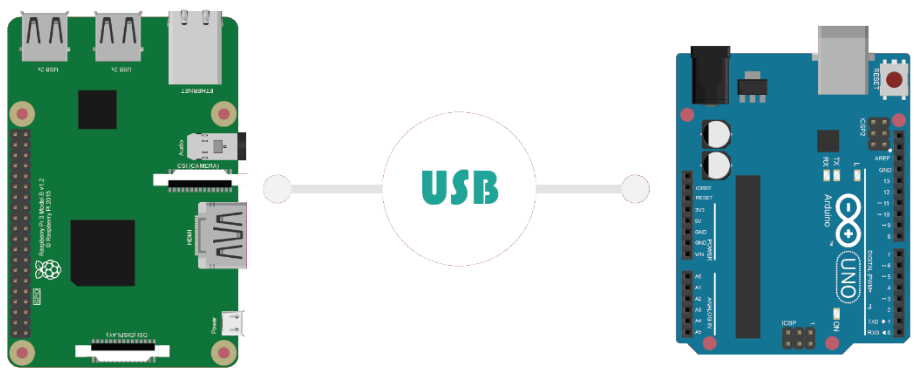


Figure 45- Arduino and Raspberry Pi Connection

Serial communication is the method we'll be using to send the sensor readings from the Arduino to the Raspberry Pi, and this is done through connecting a USB cable between the two microcontrollers.

The Arduino can send data in string format using serial communication and can only communicate with one master at a time. Thus, we'll be sending all the sensor readings by printing them as one string of values separate by white spaces. This will allow the Raspberry Pi to receive all values per one string.

A python script is written on the Raspberry Pi to decode the string of values. First, the serial library is used to communicate with the Arduino UNO of address USB0. After initiating serial communication, the python script reads every new line and separates the received data using the built-in split function which creates an array of data so that every sensor has its unique index.

startup.py

```python
#!/usr/bin/env python3
import serial
import csv

if __name__ == '__main__':
    ser = serial.Serial('/dev/ttyUSB0', 9600, timeout=1)
    while True:
        ser.reset_input_buffer()
        reading = ''
        while reading == '':
            #ser.write(str('1').encode('utf-8'))
            reading = ser.readline().decode('utf-8')
        data = reading.split()
        f = open('/home/pi/Desktop/sensor_data.csv', 'w')
        writer = csv.writer(f)
        writer.writerow(data)
        f.close()

```

Figure 46- CSV Writing Python Script

Then, using the csv library, the array of sensor data is written onto a csv file for data gathering and for Mycodo to be able to read this data for visualization. This python script is set to run on every startup of the Raspberry Pi and continues looping as long as the Arduino is sending sensor data.

As for reading from the csv file, a python script is written for each sensor that fetches the latest reading from its respective index from the csv file. For example, the water temperature sensor readings are stored in the first column , thus it reads the first value of the latest row and prints it. The reason to print it is that Mycodo will be running each script individually whenever it needs to get the latest value for visualization which will be done at time intervals of our choice.

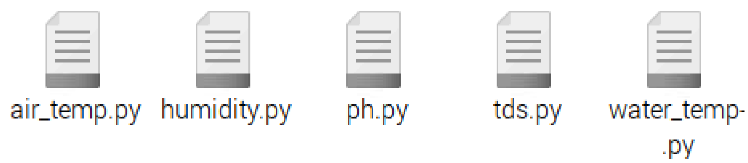


Figure 47- Python Scripts For Sensors

water_temp.py

```
import csv

with open('/home/pi/Desktop/sensor_data.csv') as csv_file:
    csv_reader = csv.reader(csv_file)
    for row in csv_reader:
        water_temp = row[0]
        print(float(water_temp))

```

Figure 48- Reading Script from Sensor

7.10 Mycodo Setup

A local server is hosted by the Raspberry Pi to access Mycodo through the web browser from any device. Entering the IP Address of the Raspberry Pi in the browser using a device connected to the same network shows the Mycodo sign up page for first time users. An admin user is created at this step and will be used to sign in.

In this setup tab under Inputs, each sensor is added separately for Water Temperature, Air Temperature, Humidity, pH, and TDS as type Bash Command. The reason is that Mycodo will run a specific bash command through terminal whenever it requires the latest reading.

The bash command is in following format "*python /PATH/SENSOR.py*" which will run the specific python file for each sensor whenever needed.

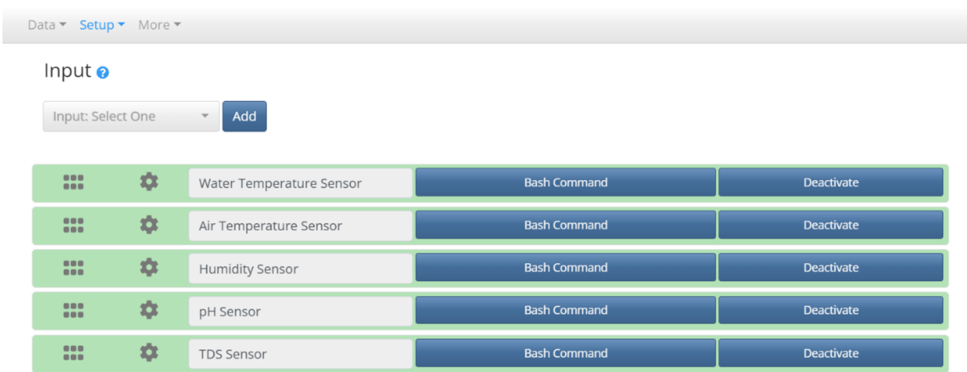


Figure 49- Mycodo Inputs

7.11 Visualization

In the Mycodo Dashboard, a graph was added for each sensor with a time interval of 4 seconds. This will run the bash command of each sensor every 4 seconds and fetches the respective readings from the csv file to properly plot them with respect to time. The following graphs can be accessed from any device connected on the same network as the

Raspberry Pi using the browser.

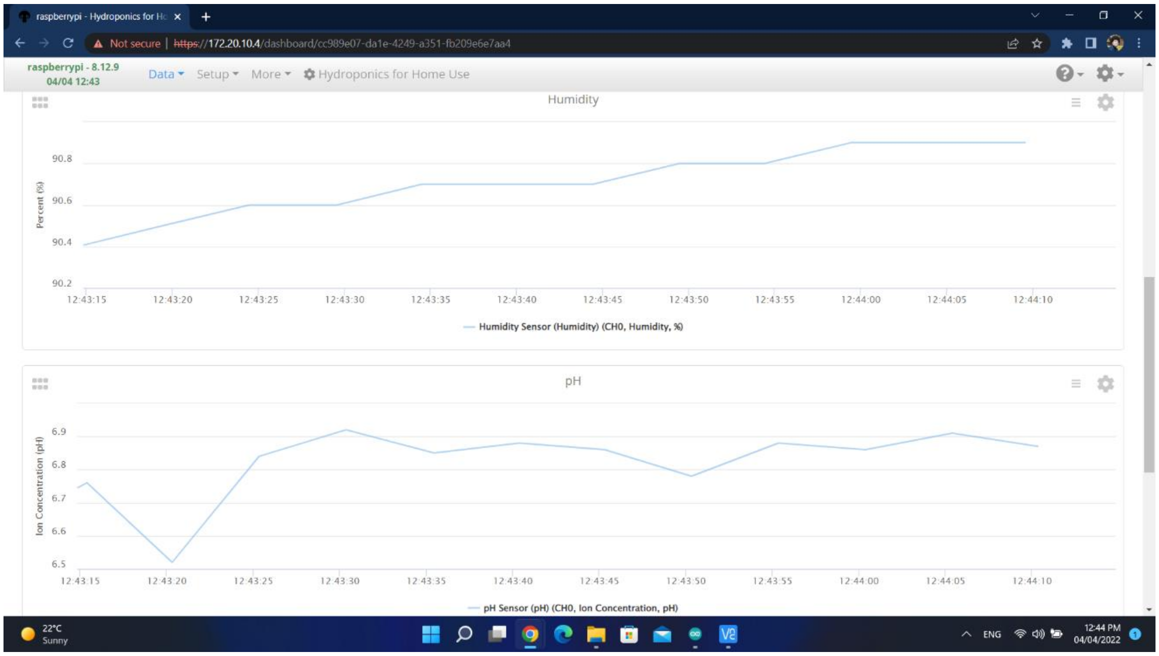


Figure 50- Sensor Reading Visualization

Chapter 8: Choice of Plant

Before designing a hydroponics system, it is essential to determine the type of plant(s) it will accommodate. Each plant has its own nutritional and environmental needs, and satisfying these needs is necessary for efficient and consistent growth. With hydroponics, almost any kind of plant can be grown; however, this is not always a good idea. The goal of our automated hydroponics system for home use is to provide homeowners with easy, fast, and efficient plant growth in small spaces, and it was established in an earlier section that the plan is for the hydroponics system to grow fruitful plants.

While it is possible to grow any type of plant in a hydroponics system, it is nearly impossible to do so in the same harvest. For this reason, our team will design a system to accommodate different types of plants, such as:

- Fruitful plants. These include:
    - Tomatoes
    - Cherry tomatoes
    - Strawberries
    - Bell pepper
    - Chili pepper
    - Leafy plants:
    - Lettuce
    - Arugula
    - Mint
    - Basil
    - Spinach

- Swiss chard
- Watercress
- Chives

When deciding which plant to use to test the efficiency and accuracy of the automated hydroponics system, several criteria were taken into consideration:

Harvest time: this is the time taken from germination to harvest. The aim is to choose a plant with fast harvest time compared to other available plants, as it is important to respect the time restraints provided for this project.

Nutrient needs: some plants require more nutrients and TDS monitoring than other plants. While the designed system should be able to track these no matter how accurate the nutrient needs are, choosing a plant with less nutrient needs is best as it will avoid complications in case an error occurs.

Environmental needs: temperature and humidity play a key role in the growth of a plant. The designed system should have the feature of being used anywhere in the world and at any time of the year, so it should be able to cover environmental needs for the plant. However, it is best to choose a plant that can grow easily in the available temperature and humidity levels in Lebanon during March and April.

Given these restraints, our team decided to plant a leafy plants, as those are known to take considerably less amount of time to harvest. Table 2 shows the comparison between different types of leafy plants.

Table 3- Plant Comparison

		Spinach	Lettuce	Swiss Chard	Basil	Chives	Watercress
Nutrients	Necessary	Calcium, Magnesium	Calcium, Potassium, Magnesium	NPK + calcium magnesium.	Calcium, potassium, nitrogen, magnesium	Basic Nutrient Solution (NPK); no great need for fertilizers	SP All Purpose 20-20-20 with UMAXX and micronutrients
	Other	Phosphorus, Potassium, Sulfur, Iron, Manganese, Zinc, Boron, Molybdenum, Nitrogen	Phosphorus, Sulfur, Iron, Manganese, Zinc, Boron, Molybdenum, Nitrogen	Sulfur, Iron, Manganese, Zinc, Boron, Molybdenum			
Harvest Time		3-4 weeks	3-4 weeks	5 weeks	3-4 weeks	6-8 weeks	2-3 weeks
Temperature needs		10˚C-15˚C	15˚C-18˚C	5˚C-38˚C (Optimal: 30˚C)	15˚C-27˚C	15˚C-35˚C	15˚C-22˚C

Table 2 compares nutrient needs, harvest time, and temperature needs of spinach, lettuce, Swiss chard, chives, basil and watercress. Watercress has the least harvest time and the temperature needs that are readily available in Lebanon during March and April. It also does not require much nutrient monitoring. As a result, our team decided to be planting watercress for this phase of the product testing.

Chapter 9: Workflows

9.1 Code Flow Chart

The Arduino is responsible for gathering all the data from the different sensors regarding pH, water level, water temperature, humidity, air temperature, and electrical conductivity to control the environment and keep it in optimal conditions to ensure growth of a healthy plant. The Raspberry Pi would monitor the hydroponic and graph the readings to properly visualize the conditions of the environment. This will be done by monitoring the values from the sensors to adjust the nutrient solution as necessary by adding acid or base using the respective valve to alter the pH or adding water or condensed nutrients to alter the TDS of the solution, and by changing the watering cycles by pumping the nutrient solution. All the gathered data will be saved using the Raspberry Pi on a local server to be properly visualized using Mycodo.

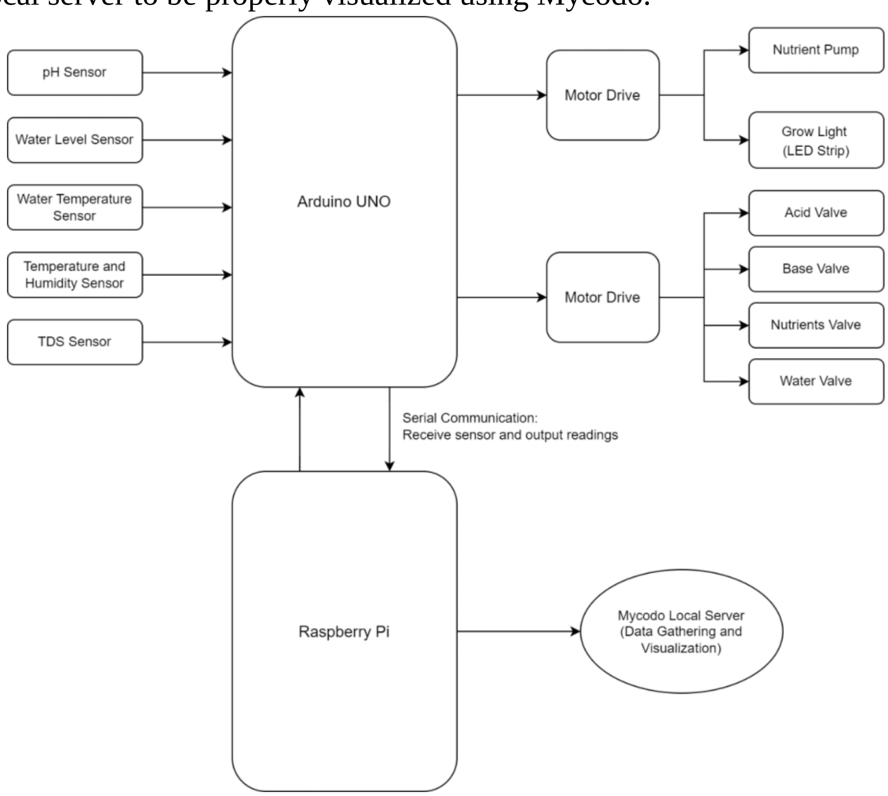


Figure 51- Code Flow Chart

9.2 System Schematic

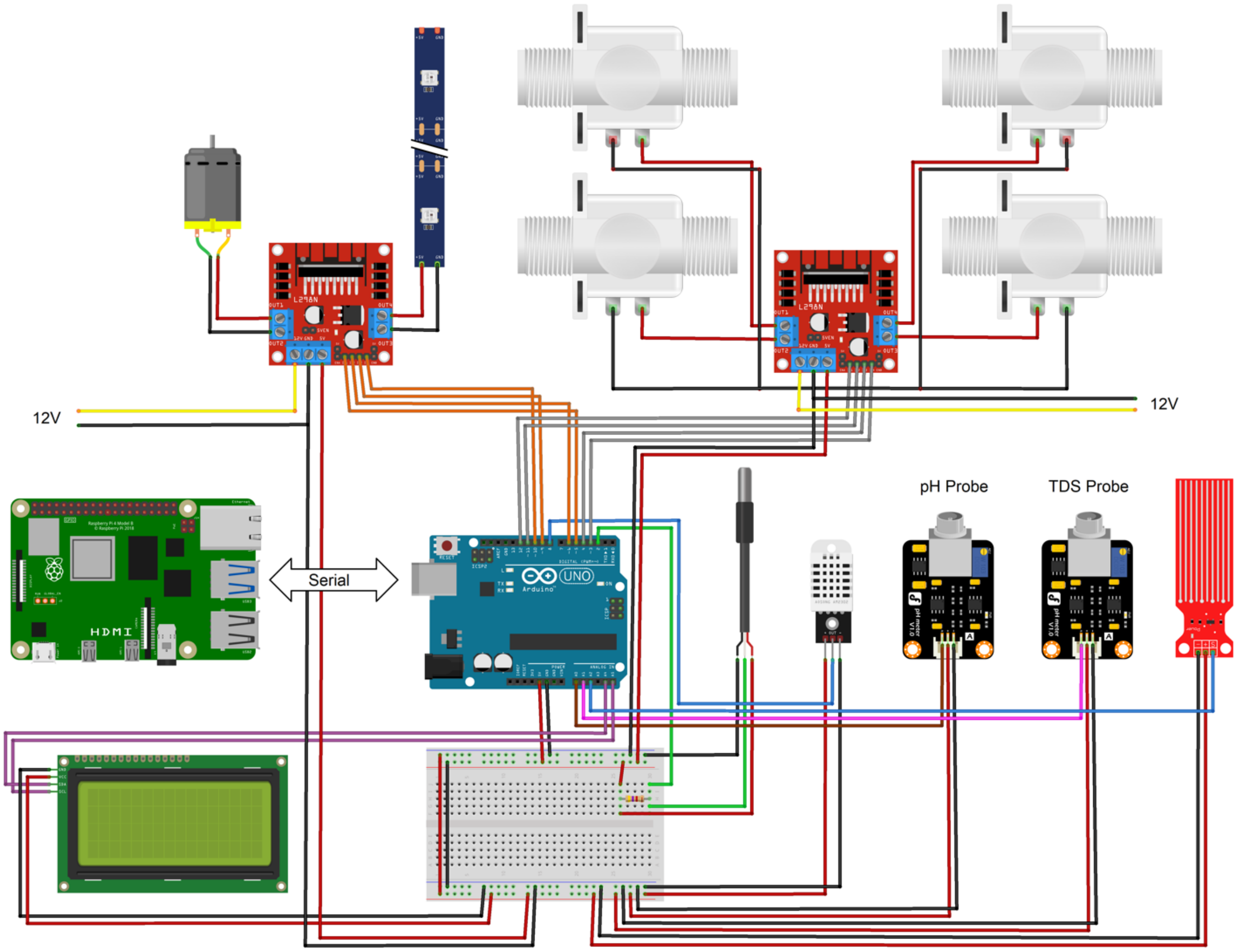


Figure 52- Full Circuit Schematic

As soon as the experimentation and software part were done, our team began the system design. This includes electronic circuit connections and the 3D model of the product and prototype.

As was previously mentioned, serial communication between the Arduino and the raspberry pie was established. The temperature and humidity, water temperature, pH, TDS, and water level sensors are connected to the analog pins of the Arduino as inputs.

The 4 solenoids are controlled by a motor drive connected the Arduino as an output.

The LED lights and the pump are also controlled by a motor drive connected to the Arduino as output.

The I2C LCD is connected to the Arduino as an output. The circuit is supplied with 12V.

Chapter 10: Prototype Design and Assembly

10.1 Specifications Followed

After planning and determining the concept level design and the software and electronics part comes the product design. Product detail design is the most important step in bringing the automated hydroponics system for home use to life. The product should be designed to combine the electric and mechanical part in an aesthetically pleasing and efficient and robust way. A robust product performs correctly, even in the presence of noise factors such as parameter variations, environmental changes, operating conditions, and manufacturing variations.

Understanding the relationships between the design parameters and noise performance is of utmost importance. For this reason, our team has set restraints on the general dimensions of the product:

- Weight should not exceed 7kg, as it should be easily lifted and carried and moved around.
- Length should not be too long as to maintain easy mobility but should also be long enough to accommodate plants with stems.
- This product is intended for small-scale, home use planting, so should be able to fit in a regular space.

10.2 Primary Design and Iterations

The team came up with a primary model shown below. This model is a one-level design where the bottles that should contain the acid, base, and nutrients are situated to the side of the system, and the grow pods are placed over the tank through the lid. However, we later realized this was not very practical as for the lid to be removed and the tank filled with water, the bottles also had to be removed. Also, holes would have to be drilled into the nutrients tank to be supplied with the nutrients and acid and base, which would risk a leak.

Therefore, we came up with a much more practical, safe, and spacious design.

Figure 53- Primary Design

10.3 CAD Model

The main model is made up of 2 containers, and has the following dimensions:

- Nutrients Tank:
  - Outer length 16.8
  - Inner length 14.8
  - Extreme outer width 25
  - Outer width 23.8
  - Inner width 21.7
  - Height 10.4
- Container:
  - Length 25.2
  - Width 34.5
  - Height 15
- Grow Pods:
  - Width 3.3
  - Length 3.3
  - Height 4

- Outer edge 0.5cm each side

The handles on each side are adjustable in height, and the system can reach a maximum height of 61 cm.

These dimensions were modelled and simulated on SolidWorks, and the 3D model is shown in figure 2.

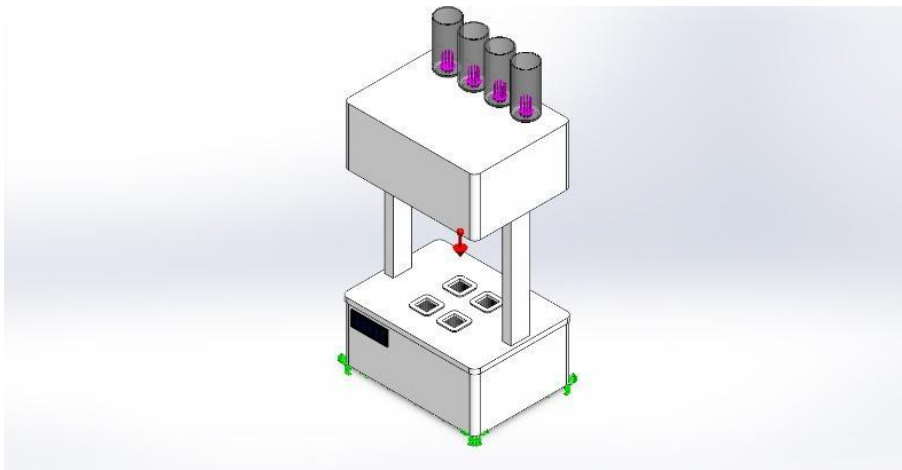


Figure 54- Final CAD Design

The lower container is where the nutrients tank will be found. It can fit up to 4.8 liters of water.

- The plants are placed in grow pods right above the tank, through the lid. The lid just above the tank can slide and open.

- The electronic components are placed in the same container and are separated from the tank with a lid covering them, achieving water resistance by separation.

- The sensors are placed inside the tank through small, tightly enclosed holes to the side of it.

- This container also has the LCD which will display messages to the users.

The upper container will contain the bottles of the acid, base, nutrients, and water.

- These bottles are connected to the solenoids, and when any amount of these is needed, the solenoids will open, and the liquid will flow through pipes down to the tanks.
- This container also has LED Grow Lights to provide light for the plant.

10.4 Materials Used

To determine the materials to be used our automated hydroponics systems, we conducted a thorough research to find the materials that competitors mostly used. Interestingly, in all the competitors, either ABS or PP plastics are used for the outer tanks. Both plastics are very sturdy, have high electrical and heat resistance, and are safe to be used with plants.

To make the decision, it came down to which material will create the most robust design. To determine the best materials to use, we performed stress and displacement analysis of the ABS and PP plastics, which are most used in hydroponics products due to their rigidity and safe qualities. ABS was shown to be stronger than PP, with only 0.3 mm displacement. Therefore, we decided to use ABS, which is also known to be heat and electrically resistant.

The stress analysis performed can be shown in below.

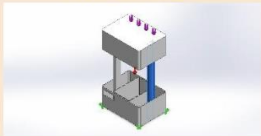
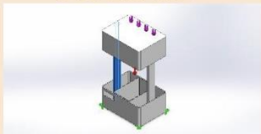
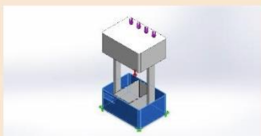
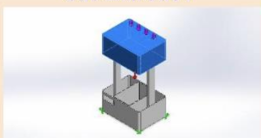
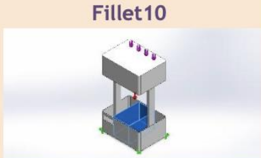
Boss-Extrude1 	Solid Body	Mass:0.6885 kg Volume:0.000675 m^3 Density:1,020 kg/m^3 Weight:6.7473 N
Boss-Extrude1 	Solid Body	Mass:0.6885 kg Volume:0.000675 m^3 Density:1,020 kg/m^3 Weight:6.7473 N
Cut-Extrude1 	Solid Body	Mass:1.17922 kg Volume:0.0011561 m^3 Density:1,020 kg/m^3 Weight:11.5564 N
Cut-Extrude1 	Solid Body	Mass:1.18872 kg Volume:0.00116541 m^3 Density:1,020 kg/m^3 Weight:11.6495 N
Fillet10 	Solid Body	Mass:0.668506 kg Volume:0.000514236 m^3 Density:1,300 kg/m^3 Weight:6.55136 N

Figure 55- Specifications of each part of the design

Study Properties	
Study name	Static
Analysis type	Static
Mesh type	Solid Mesh
Thermal Effect:	On
Thermal option	Include temperature loads
Zero strain temperature	298 Kelvin
Include fluid pressure effects from SOLIDWORKS Flow Simulation	Off
Solver type	FFEPlus
Inplane Effect:	Off
Soft Spring:	Off
Inertial Relief:	Off
Incompatible bonding options	Automatic
Large displacement	Off
Compute free body forces	On
Friction	Off
Use Adaptive Method:	Off
Result folder	SOLIDWORKS document (D:\University\BE Summative Learning Project (MECA595)\Hydroponic System Solidworks Model)

Figure 56- Mesh Study Properties

Material Properties

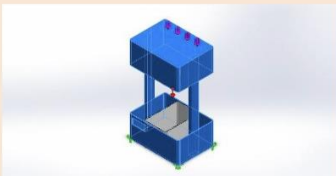
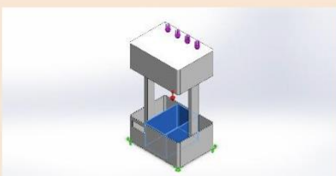
Model Reference	Properties	Components
	Name: ABS Model type: Linear Elastic Isotropic Default failure criterion: Unknown Tensile strength: 3e+07 N/m^2 Elastic modulus: 2e+09 N/m^2 Poisson's ratio: 0.394 Mass density: 1,020 kg/m^3 Shear modulus: 3.189e+08 N/m^2	SolidBody 1(Boss-Extrude1)(bracket-1 SolidBody 1(Boss-Extrude1)(bracket-2 SolidBody 1(Cut-Extrude1)(hydroponic_ e-1), SolidBody 1(Cut-Extrude1)(hydroponic_ -1)
Curve Data:N/A		
	Name: PVC Rigid Model type: Linear Elastic Isotropic Default failure criterion: Unknown Tensile strength: 4.07e+07 N/m^2 Elastic modulus: 2.41e+09 N/m^2 Poisson's ratio: 0.3825 Mass density: 1,300 kg/m^3 Shear modulus: 8.667e+08 N/m^2	SolidBody 1(Fillet10)(tank-
Curve Data:N/A		

Figure 57- Martials in tank and container

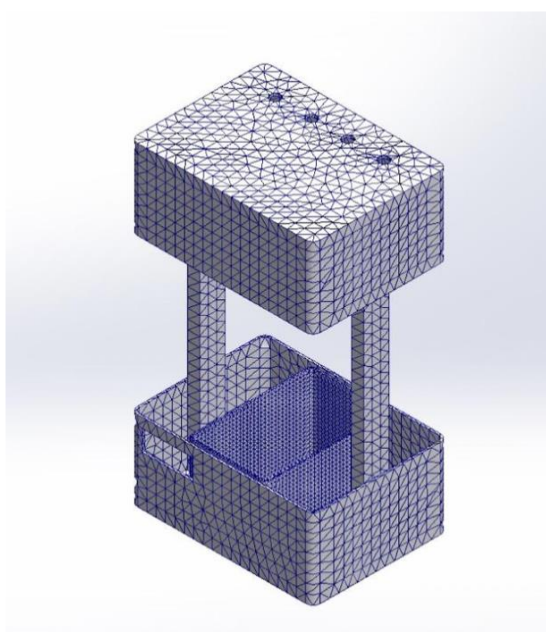


Figure 58- Final Mesh

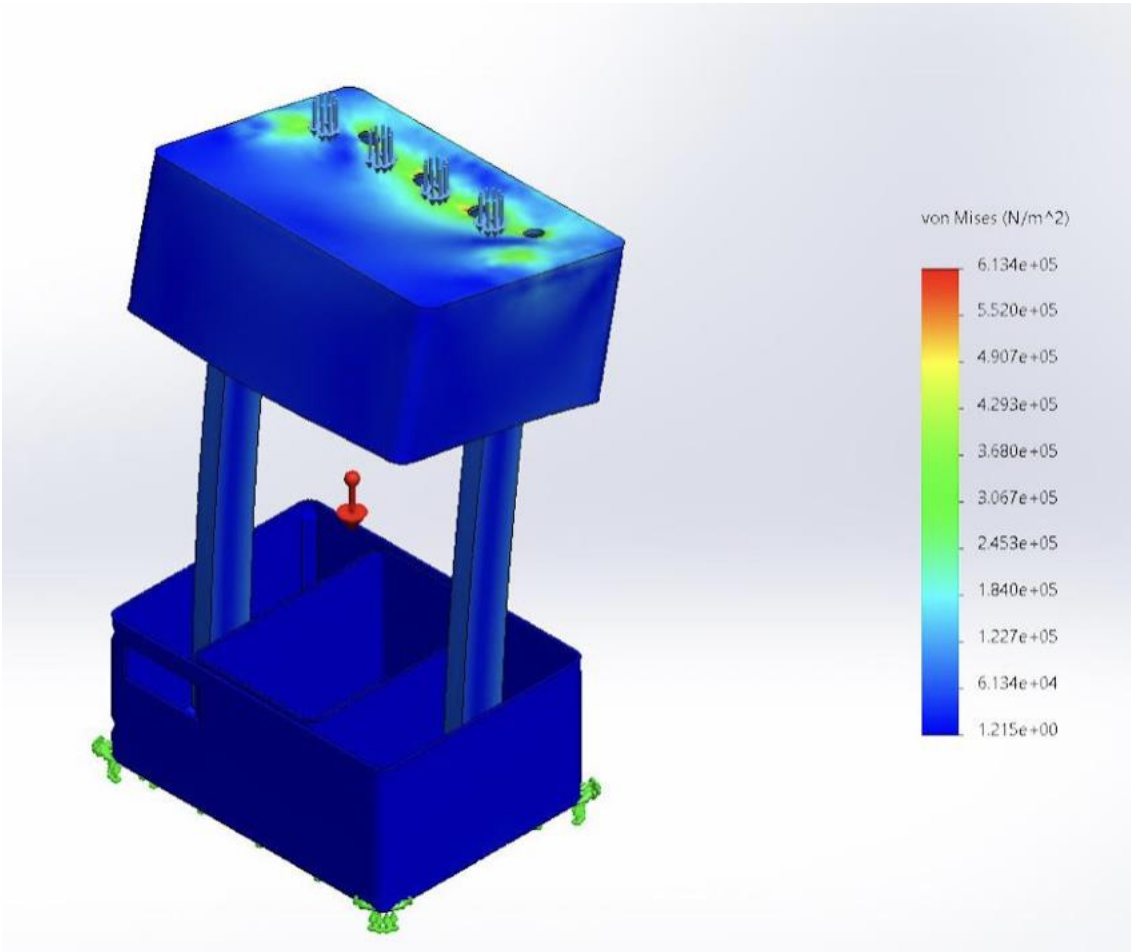


Figure 59- Stress Analysis

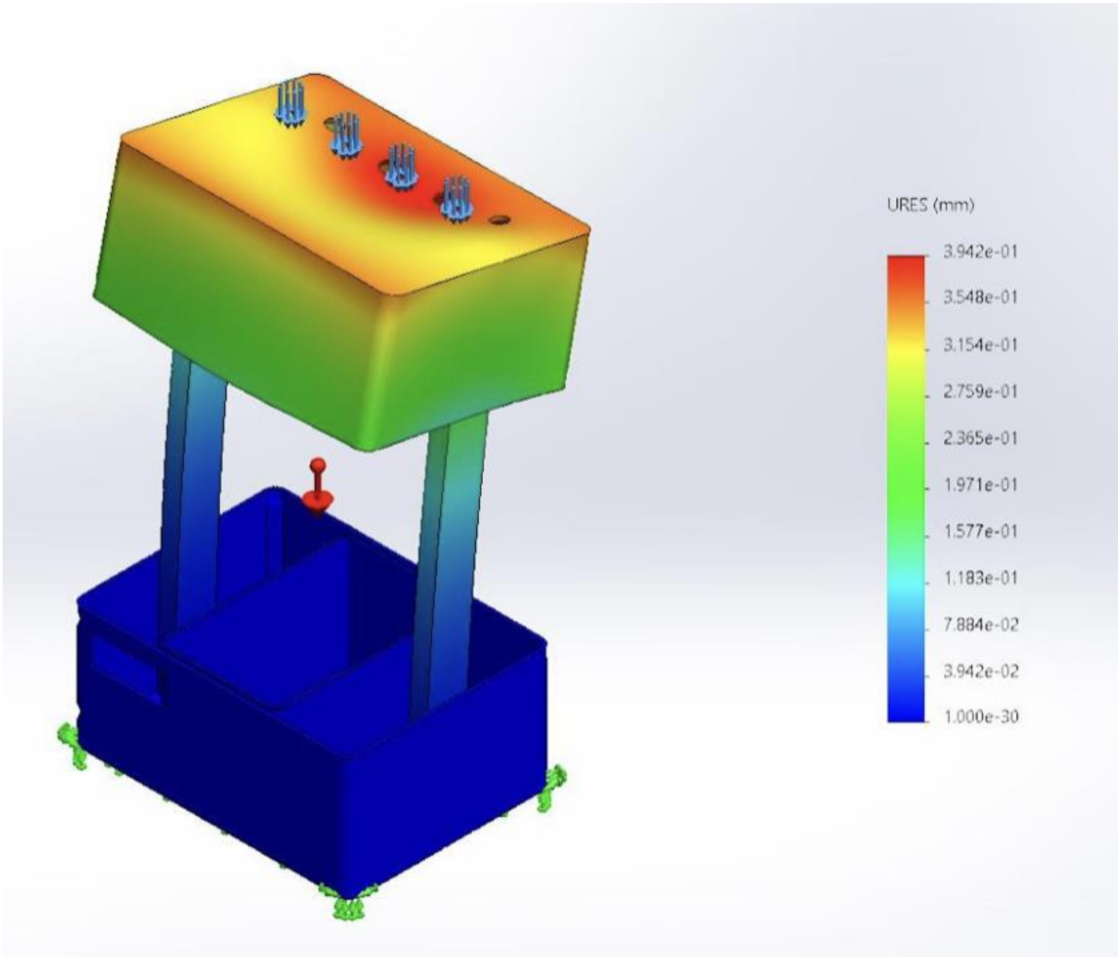


Figure 60- Displacement Analysis

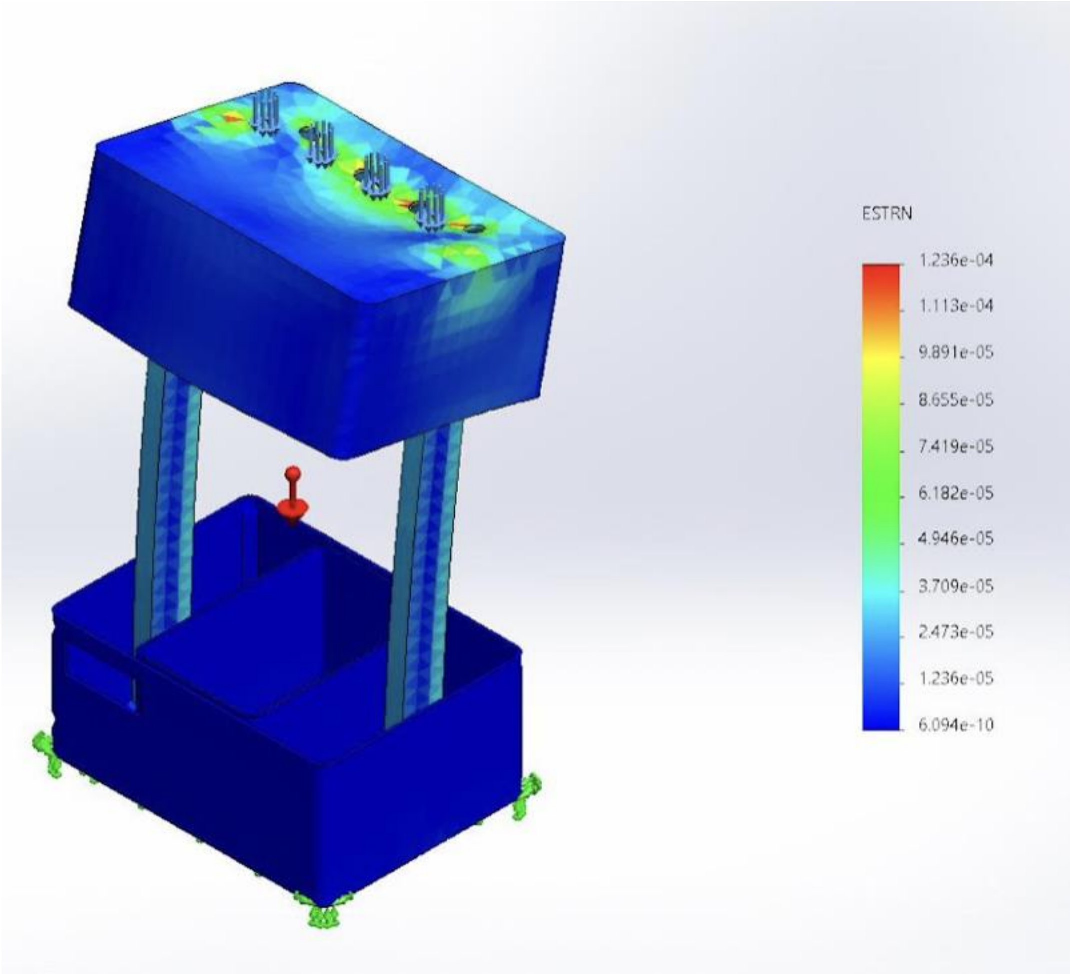


Figure 61- Stress Strain Analysis

10.5 Prototype Assembly

The prototype was chosen according to the designed model. However, not much attention was paid to the type of materials, as this prototype will act as a minimum viable product to provide proof of concept and an understanding of the working principle.

- The grow pods were 3D printed according to the design mentioned in the above section.
- Two plastic containers were purchased in place of the upper and lower containers in the design. Holes were cut in one of the containers, which served as a lower container, where the grow pods were to be placed.

- A separate, smaller container was added as the nutrients tank and was placed inside the lower container.
- For the upper container, the solenoids and rods were attached with screws on the inside. The bottles were placed above the solenoids on the other outer side of the container, and the pipes were added from those to the lower container

The electronics and sensors were finally added in the lower container, separated with a lid from the nutrients tank, to achieve water resistance by separation.

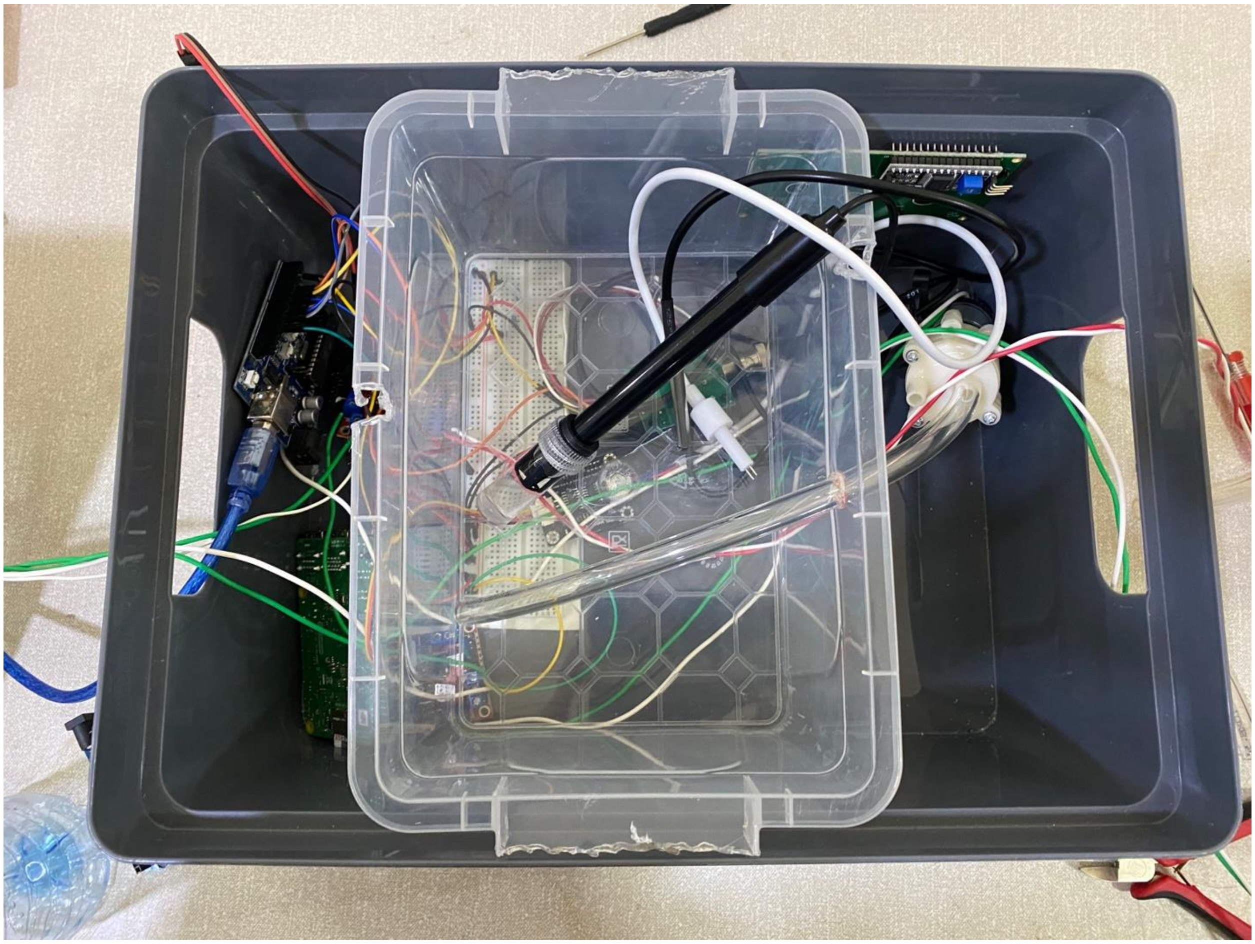


Figure 62- Inside Container

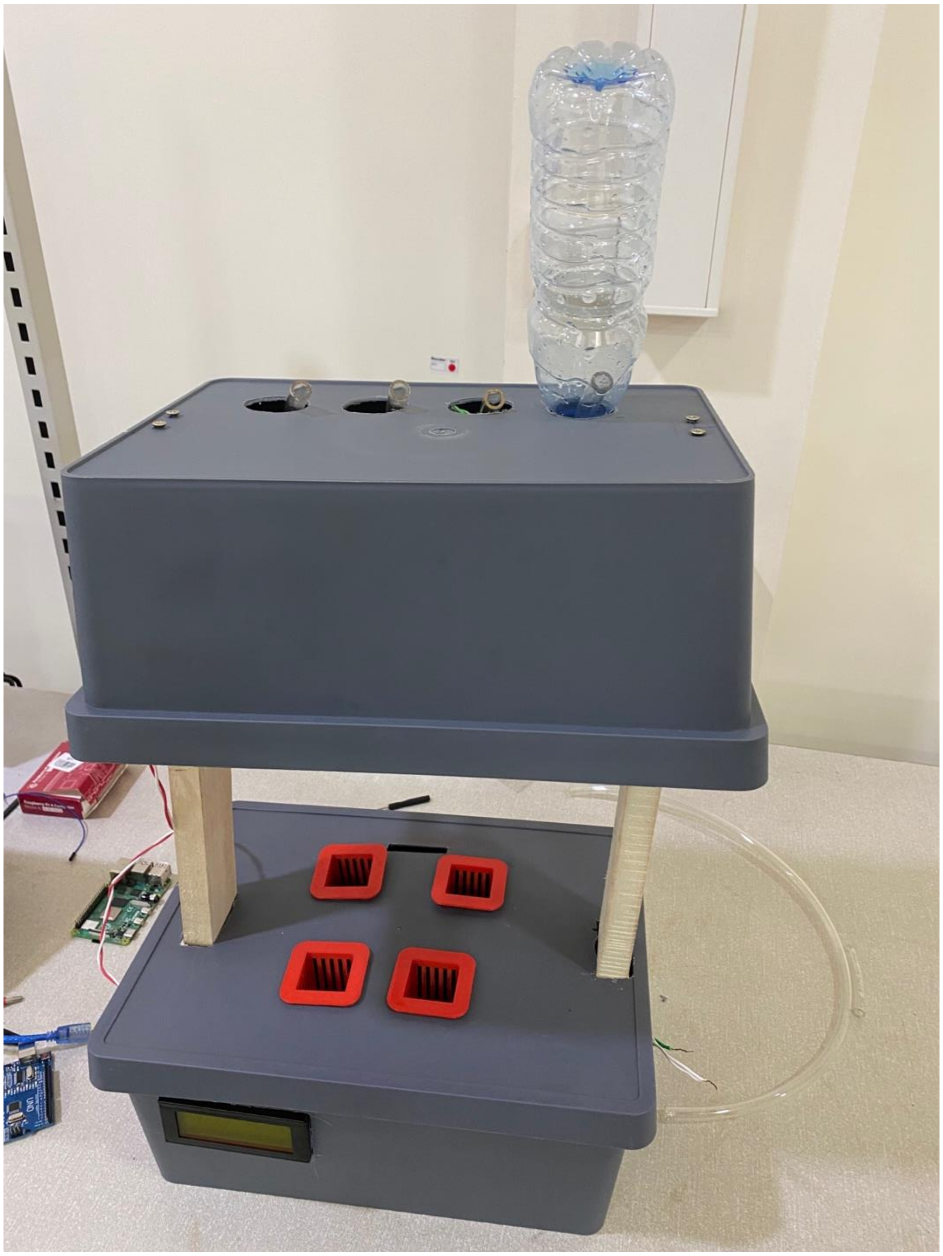


Figure 63- Final Prototype

Chapter 11 Future Plans

11.1 Deep Learning Classification Problems

Now that we have made a model that is able to handle collecting large amounts of sensor data, we can then use this data to fully automate the system using deep learning. There are various ways we can do that, and the most prominent of which is forecasting if the plant will harvest depending on sensor readings and classifying if the plant will live or not based on the specifications and placement.

We created a deep learning model as a baseline to be tested once the sensor readings are ready. The model is sequential, and consists of an input layer whose dimension is the same as the amount of the sensors available, two hidden layers, and an output layer with a sigmoid activation function for binary classification.

```
from tensorflow.keras.models import Sequential
from tensorflow.keras.layers import Dense

model = Sequential()
model.add(Dense(4, input_dim = 2, activation = 'relu'))
model.add(Dense(6, activation = 'relu'))
model.add(Dense(1, activation = "sigmoid"))

# print model
model.summary()
```

```
Model: "sequential_1"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
dense_3 (Dense)              (None, 4)                 12
_________________________________________________________________
dense_4 (Dense)              (None, 6)                 30
_________________________________________________________________
dense_5 (Dense)              (None, 1)                 7
=================================================================
Total params: 49
Trainable params: 49
Non-trainable params: 0
_________________________________________________________________
```

Figure 64- Deep Learning Model Architecture

11.2 Image Classification

One of the most breakthrough data we can collect for hydroponics is image data. We found the one and only open-source image dataset for hydroponics which is the images of plant roots for marijuana plants. We used this dataset, fitted it to a Convolutional Neural Network Model, and was able to attain an accuracy of 97% of classifying which roots are healthy and which ones are not. We can see that classification in the figure below.

	precision	recall	f1-score	support
healthy_root	1.00	0.94	0.97	299
non_healthy_root	0.95	1.00	0.97	311
accuracy			0.97	610
macro avg	0.97	0.97	0.97	610
weighted avg	0.97	0.97	0.97	610

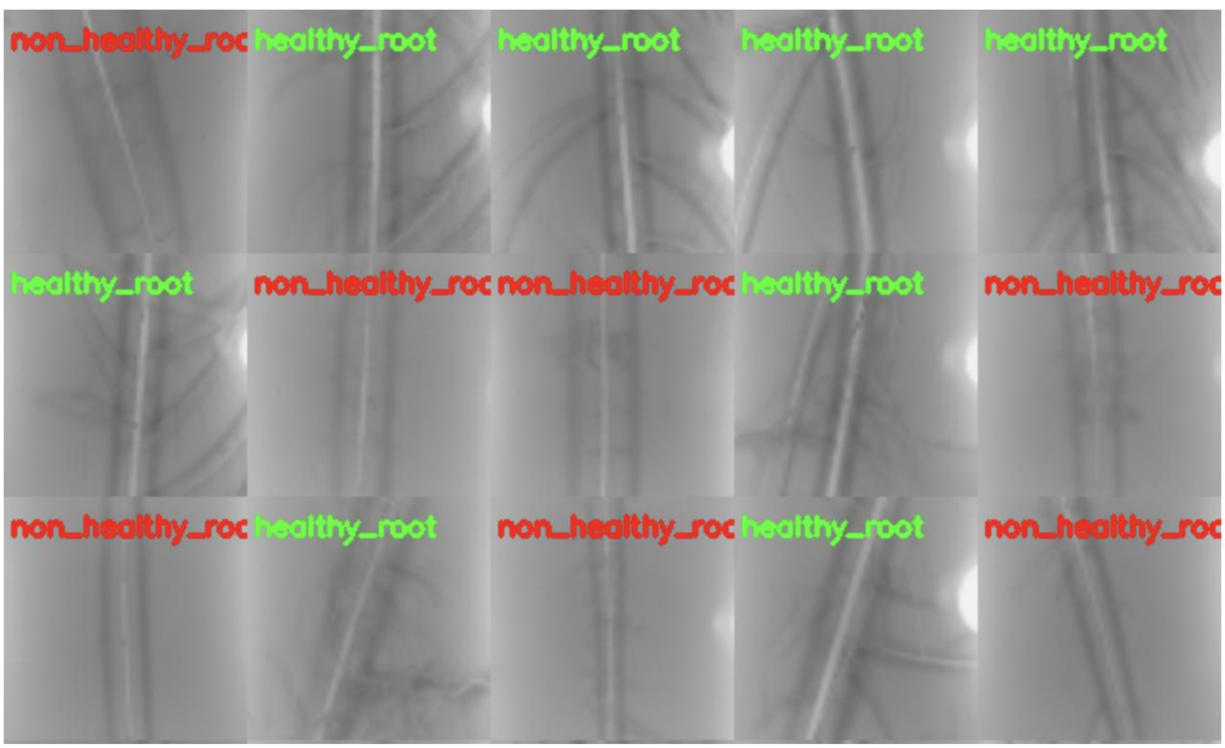


Figure 65- Accuracy Measures of the CNN Model

```
idxs = np.arange(0, testY.shape[0])
idxs = np.random.choice(idxs, size=(1,), replace=False)
images = []

# loop over the testing indexes
for i in idxs:
  # grab the current testing image and classify it
  image = np.expand_dims(testX[i], axis=0)
  preds = model.predict(image)
  j = preds.argmax(axis=1)[0]
  label = le.classes_[j]

  # rescale the image into the range [0, 255] and then resize it so
  # we can more easily visualize it
  output = (image[0] * 255).astype("uint8")
  output = np.dstack([output] * 3)
  output = cv2.resize(output, (128, 128))
  # draw the colored class label on the output image and add it to
  # the set of output images
  color = (0, 0, 255) if "non" in label else (0, 255, 0)
  print("Looks unhealthy, the plant needs more nutrients!") if "non" in label else print("Looks healthy! Keep it up.")
  cv2.putText(output, label, (3, 20), cv2.FONT_HERSHEY_SIMPLEX, 0.4, color, 1)
  images.append(output)

# create a montage using 128x128 "tiles" with 5 rows and 5 columns
montage = build_montages(images, (256, 256), (1, 1))[0]

# show the output montage
cv2_imshow(montage)
```

```
Looks healthy! Keep it up.
```

Figure 66- Result of Classification

Chapter 12: Results and Conclusion

The purpose of this project is to build a fully automated hydroponics system for home use. This product was tested and is proven to simulate a healthy environment to promote almost any plant growth in a fully automated manner, with minimal user intervention. This is a unique product, as none of the major competitors offer the automation and data collection that our product offers. This product will allow real-time tracking and data collection, enabling users to interact and learn in the process.

To design and build our automated hydroponics system for home use, our team not only applied engineering methods that we learned throughout the years we studied at Rafik Hariri University, but we also thoroughly learned the process of how to create a user-oriented product. As this is a complex engineering problem, each one of us learned the importance of research, time management, and teamwork. Our team also acquired good experience in calibration, testing, and simulation, which are all extremely necessary skills to have in the workplace to satisfy international standards.

APPENDIX A: ADDRESSING STUDENT OUTCOMES' KPIs

	How was it addressed in the SLP	**Where was it addressed in the SLP**
a. An ability to apply knowledge of mathematics, science, and engineering.		
a.1 An ability to apply knowledge of Mathematics	Power Consumption and volume calculations	Chapter 10
a.2 An ability to apply knowledge of Science	Stress Analysis and Simulations	Chapter 10
a.3 An ability to apply knowledge of Engineering	CAD drawing	Chapter 10
b. An ability to design and conduct experiments, as well as to analyze and interpret data		
b.1 An ability to design experiments	Experiment design	Chapter 7

b.2 An ability to conduct experiments	Experiment Implementation	Chapter 7
b.3 An ability to analyze and interpret data	Automation	Chapter 7
c. An ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability		
c.1 Design a system/component of a system or a process to meet specific engineering constraints	Assembly and components	Chapter 10
c.2 Modify a system/component of a system or a process to adhere to applicable economic, environmental, safety and sustainability constrains	Safety Measures and Standards	Chapter 10 and Appendix D
d. An ability to function on multidisciplinary teams		
d.1 Ability to plan and organize multidisciplinary team tasks collectively	All team members cooperate to reach the project success by dividing the tasks respectively.	Meeting Minutes Appendix E
d.2 Ability to carry out tasks assigned by a team	Meeting Minutes	Appendix E
e. An ability to identify, formulate, and solve engineering problems		
e.1 Pinpoint the existence of an engineering problem	Problem Statement	Chapter 1
e.2 Ability to model an engineering problem	Attaining Specifications	Chapter 4,5,6
e.3 Ability to justify a solution to an engineering problem	List of specifications	Chapter 4,5,6
f. An understanding of professional and ethical responsibility		
f.1 Differentiate between ethical/unethical behaviors using applicable engineering code of ethics	Through meeting with sponsor and communication with advisor	Appendix E
f.2 Differentiate between professional and unprofessional behaviors	Through meeting with sponsor and communication with advisor	Appendix E

g. An ability to communicate effectively		
g.1 Ability to write a well-structured formal report/technical document that addresses an assigned task	Submitting several technical reports, progress reports, and meetings' minutes to the advisers and jury	Appendix E
g.2 Ability to deliver a well-structured formal presentation that addresses an assigned task	Delivering several formal presentations throughout the SLP Project in front of the advisors and the assigned jury.	Presentation Deliverable
h. The broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context		
h.1 Identify global, economic, environmental, and societal impact of implementing engineering solutions	The robot can be applied and used in different applications related to monitoring, inspection.	CHAPTER 1
h.2 Explain global, economic, environmental, and societal impact of implementing engineering solutions	The robot can be used for surveillance application and reduce the power consumption and last long in the field	CHAPTER 1
i. A recognition of the need for, and an ability to engage in life-long learning		
i.1 Recognize the need to engage in life-long learning	Attending the workshops and Career guidance seminars organized by the MME department; Recognizing the need of learning Arduino language and adhesions types	Future Plans Chapter 11

i.2 Ability to engage in life-long learning through participation in workshops, seminars, and extracurricular activities	Talking with experts and future plans	Chapters 6 and 11
j. A knowledge of contemporary issues		
j.1 Ability to identify and discuss contemporary issues	Problem Decomposition	Chapter 5
k. An ability to use the techniques, skills, and modern engineering tools necessary for engineering practice		
k.1 Identify necessary techniques, skills, tools of modern engineering practice to solve a problem at hand	Design of Experiments	Chapter 7
k.2 Apply appropriate techniques, skills, tools of modern engineering practice to a problem at hand	Design of experiments	Chapter 7

APPENDIX B:BILL OF MATERIALS

1) From Lebanon

	Component	Option 1	Option 2	Price 1	Price 2
Lights	LED Strip/Matrix (RGB)	Katranji	Katranji	$ 6.50	$ 4.00
	LED Light (White)	Katranji		$ 8.00	
	Incandescent Light (Bulb)				
Water Control	Peristaltic Submersible Pump	Katranji		$ 6.25	
	Water Pump	Katranji	Katranji	$ 5.50	$ 4.00
	Water Reservoir				
	Pipe (6mm)	Katranji		$ 0.30	
	Pipe (8mm)	Katranji		$ 0.50	
	Pipe (10mm)	Katranji		$ 0.80	
	Pipe (12mm)	Katranji		$ 1.00	
	Solenoid Valve (x4)	Katranji	Katranji	$ 45.00	$ 25.00
Hydroponic base	Rockwool				
	Seed Capsules				
	Seeds				
Solutions	Plant Growth Nutrient Solution				
	pH Adjustment Solution (Base)				
	pH Adjustment Solution (Acid)				
Microcontrollers	Raspberry Pi v4	Katranji		$ 58.00	
	Arduino Nano/Uno	Katranji	Katranji	$ 7.00	$ 6.75
Sensors	pH Sensor	Katranji		$ 32.00	
	Water Level Sensor	Katranji	Katranji	$ 0.50	$ 15.00
	Water Temperature Sensor	Katranji		$ 2.00	
	Electrical Conductivity Sensor	Katranji		$ 21.00	
	Light Sensor	Katranji		$ 0.65	
	Water Flow Sensor	Katranji		$ 5.00	
	Temperature & Humidity Sensor	Katranji	Katranji	$ 4.50	$ 2.00
Electrical Components	L298N Motor drive	Katranji		$ 2.75	
	LCD (20 characters, 4 lines)	Katranji	Katranji	$ 5.00	$ 4.00
	I2C Adapter	Katranji		$ 1.00	
	Breadboard	Katranji	Katranji	$ 0.90	$ 0.50
	Battery holder	Katranji	Katranji	$ 0.60	$ 0.15
	Jumper Wires	Katranji	Katranji	$ 2.50	$ 1.35
	Push Button	Katranji			
	Switch	Katranji			
Other	microSD Card (16 GB)	Katranji		$ 5.50	
	Heat Plate/Mat				
Optional	LED Plant Growth Light	Katranji		$ 26.00	
	Hydroponic Plant Growth System	Katranji		$ 48.00	
	Raspberry Pi Camera Module	Katranji		$ 5.50	

Total	**$ 222.75**
Optional	$ 79.50

2) From UAE

Component	Link	Price	
Rockwool	Amazon UAE	AED	39.95
pH Control Kit	Amazon UAE	AED	124.00
Nutrient Solution Part 1	Amazon UAE	AED	154.00
Nutrient Solution Part 2	Amazon UAE	AED	159.00
Raspberry Pi v4	Amazon UAE	AED	690.00
32GB microSD	Amazon UAE	AED	20.00
	Total (AED)	AED	1,186.95
	Total (USD)	$	323.16

APPENDIX C: CODES AND STANDARDS

The circuits designed in this project are according to IEC standards, as the VCC and GND wires were red and black respectively. Moreover, a high efficiency pump of 1.8L/min was used.

The system was designed according to the American Society of Mechanical Engineers (ASME) design modelling standards. The ASME Y14 standards guide engineers through the entire product development process, from concept to delivery, enabling the delivery of solutions that meet and exceed performance criteria. Their established language and methodology have served as the foundation for much of today's manufacturing, inspection, and computer-aided design (CAD) software. The system was designed with accurate dimensions and tolerances and was solution-driven. That is, problem statement was taken into consideration when developing our hydroponics product for home use. The design also supports clear & streamlined drawings, models and documentation.

Moreover, according to ASME's code of ethics, the product is highly ethical as it promotes environmental care and is done safely using heat resistance and water resistance due to separation. It is a product that respects ASME's code of ethics for engineers and their standards for design and modelling.

APPENDIX D: MEETINGS' MINUTES

1.

Minutes of Meeting: Progress Presentation

Date: 25/10/21
Time: 11:00 A.M. -12:00 P.M.
Participants:

- Dr. Hassan Hariri
- Dr. Jad Nasreldine
- Mr. Mohammad Chamas
- Jana Kibrit
- Elio Eid
- Oussama Matar
- Riwa Matar

Meeting Minutes:
11:00 – 11:30: Students presented a progress report
11:30 – 12:00: Questions period.

Questions & Answers:

1) Mr. Chamas: Why might the deep-water culture system be the best choice?
   Answer:
   - Most competitors use deep-water culture.
   - It is less likely to have insects and pesticides.
   - Other systems need drainage.

2) Mr. Chamas: What is the expected duration of the project?
   Answer: Expert said that two semesters are enough.

3) Dr. Hariri: Comment on the meeting with engineer.

4) Mr. Chamas: Do other systems use sensors?
   Advice: To find inspiration on how to use different kinds of sensors.

5) Dr. Nasreldine: Commented to add one row about the sensors.

6) Dr. Nasreldine: What do you mean by manual maintenance?
   Answer: Regular manual maintenance by the user like changing filters and changing sponges.

7) Dr. Nasreddine: Commented on removing mechanical components from the table.

Meeting concluded.

2.

Minutes of Meeting: Progress Presentation

Date: 10/1/2022

Time: 7:00 PM – 8:00 PM

Participants:

- Dr. Hassan Hariri
- Jana Kibrit
- Elio Eid
- Oussama Matar
- Riwa Matar

Meeting Minutes:

7:00 – 7:40: Students presented more detailed sketches to further explain the rough design and dimensions of the testing prototype, sensor placement, valves, and mechanism used.

7:40 – 7:50: Questions period.

Questions & Answers:

1. Dr. Hariri: Is the temperature something you will control?

Answer:

- Not essential since the system is indoor but can be beneficial.
- Using a heating element.

2. Dr. Hariri: Do you know the pH and nutrients needed for tomatoes for example?

Answer:

- Ask an expert.
- Further research.

3. Dr. Hariri: Can the sensors read wrong values due to placement and high concentrated areas?

Answer:

- The solution is always circulating and mixing well.
- Requires further testing of pump speeds.

4. Dr. Hariri: What are your next steps?

Answer:

- Working on the report and presentation.

Final Notes:

- Contact the nutrients store.
- Use a microcontroller power supply for the prototype instead of building an AC/DC converter from scratch.
- Find an expert in agriculture to contact or recontact the previous expert.

Meeting Concluded.

3.

Minutes of Meeting: Hydroponic System for Home Use

Date: Tuesday 15/2/2022

Time: 8:30 PM – 9:00 PM

Participants:

- Dr. Hassan Hariri
- Mr. Chamas
- Jana Kabrit
- Elio Eid

- Oussama Matar
- Riwa Matar

Meeting Minutes:

8:30 – 8:45: Students presented the sensors tested with their circuit representation, code, and real-life measurements. The sensors tested are light sensor, temperature and humidity sensor, water temperature sensor, and pH sensor.

8:45 – 9:00: Questions period.

Questions & Answers:

5. Mr. Chamas: Can you start testing with water and create a skeleton to make the pumps work?

Answer:

- We'll be working on setting up the system.

6. Dr. Hariri: What kind of actuators do you have?

Answer:

- A water pump and some solenoid valves to control the pump.

7. Dr. Hariri: How many sensors do you have left for testing? Can you test the pH sensors with coke or any acid solution?

Answer:

- pH and TDS sensors, we need the right solutions for accurate measures.
- We could use coke to test.

Final Notes:

- Continue working on the rest of the sensors.

- Set up pumps and pipes.
- Research the method of communication between Raspberry Pi and Arduino.
- Work on the skeleton of the system.

4.

Minutes of Meeting: Hydroponics BE Project

Date: 22/2/2022

Time: 8:30 PM – 9:30 PM

Participants:

- Dr. Hassan Hariri
- Mr. Mohammad Chamas
- Jana Kabrit
- Oussama Matar
- Riwa Matar
- Elio Eid

Meeting Minutes:

8:40 – 8:20: Students presented the pictures of the sensors connected to the Arduino directly. They also discussed the testing of all the components available. The sensors presented were the temperature, water level, and humidity sensor.

8:50 – 8:55: Dr Hariri and Mr chamas asked questions.

8:55-9:00: The students discussed having an interview with the owner of the hydroponics solution shop owner since he has his own project.

Questions & Answers:

8. Mr. Chamas: Can we control the flow of the water through the pipe through the valve?

Answer:

- The datasheet of the motor contains the flow that will be outputted when a given voltage is applied. The flow can be controlled through changing the voltage applied to the motor.

9. Dr Hariri: How will you insure the communication of the data from the raspberry pi and Arduino? Can this communication be replaced with a sp32?

Answer:

- Mycodo is an open-source environmental monitoring and regulation system that was built to run on the Raspberry Pi. This is why the raspberry pi is essential. We will further research how we will make the Arduino and raspberry pi communication robust.

10. Jana: Do we have any size constrains?

Answer:

- Mr. Chamas: 70x70cm ideally should not be exceeded. The smaller the better, but quality is of higher priority.

Final Notes:

- The students will prepare a report that will contain all the components tested and a short documentation of the testing. This will also include the codes the students used in the testing for reference.
- The students will also research how to have communication between Arduino and raspberry pi.
- The students will have an extensive meeting with the expert to finalize the understanding of our constrains and what we should focus on.

5.

Minutes of Meeting: Hydroponics BE Project

Date: 10/3/2022

Time: 8:30 PM – 9:30 PM

Participants:

- Dr. Hassan Hariri
- Mr. Mohammad Chamas
- Jana Kabrit
- Oussama Matar
- Riwa Matar
- Elio Eid

Meeting Minutes:

8:00 – 8:30: Students presented the summary of the interview with the expert where they showcased him recommendation and instructions. The most important notes is that the tomatoes are the hardest to make, drip system has the best results, and the TDS values that we should monitor during the cycle.

8:30 – 8:40: Dr Hariri and Mr chamas asked questions.

8:50-9:00: Final notes and next steps.

Questions & Answers:

11. Dr. Hariri: Did you research the information the expert gave you?

Answer:

- All the values and information the expert gave us was from his own experience and through trial and error in his own experience.

12. Mr. Chamas: Due to time constraints, will you be able to grow tomatoes?

Answer:

- We can test the system multiple times on an easier plant with a shorter lifetime for proof of concept.

13. Students: Do we design the system for the fruiting plants still?

Answer:

- Mr. Chamas: Yes.

Final Notes:

- The students will research the information given by the expert.
- We will make a design of the system on cad by next meeting as well.
- We will test with a short cycle leafy plant multiple times and try to add a fruiting plant until whatever phase it reaches before April 20th.

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Table of Figures