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"Integrated Smart System for Hydroponic Cultivation in Egypt"

A Graduation Project
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Part II

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Abstract

Water scarcity has become the main problem all over the world. Due to climate change, lack of freshwater, and clean water resources, there are not enough resources to meet the demand that leads to an unstable Ecosystem. The recycling of water will help to reduce the problem severity. Hydroponic farming has many benefits over traditional, soil-based farming. Increased water conservation and reduced fertilizer usage.

Many farmers do not work on hydroponic farms due to lack of disease control and that will result in low crops production and lack of crop quality. In this thesis, the hydroponic cultivation process is presented through a smart integrated system covering the monitoring of plant watering and recirculating of water, keeping the required percentage of nutrients for healthy planting and producing organic crops. This will make the hydroponic systems attractive, recirculating integrated systems requires very specific algorithms using Machine Learning (ML).

The ML algorithm is applied to control plant growth, optimize the Electrical Conductivity (EC) values of the nutrient solution, predict plant maturity and crop quality, make smarter decisions, and take appropriate action in real-world scenarios without (or with limited) human participation. It provides a comprehensive and adaptable framework for data-driven decision-making that may be utilized in a variety of agricultural settings.

On the other hand, our project plays an important role in reducing the pollution caused by the drainage water discharge as it re-uses the drained water after nutrients injection process in planting. In addition, there is no need to use herbicides, or any chemical fertilizers as weed growth will be eliminated with hydroponic systems. Herbicides or chemical fertilizers in traditional farming cause air pollution and soil contamination. All of that is covered and resolved throughout this project.

Table of Contents

List of Figures

List of Tables

Chapter 1
INTRODUCTION

1.1 problem definition

1.1.1 land degradation

Degradation is the short- or long-term loss of soil productive ability, and it is one of Egypt's major issues which caused by Droughts, Environmental pollution, global warming, extreme heat and other climate impacts. Egypt's total area is approximately one million square kilometers, or 238 million feddans (1 feddan = 4200 m2). The extent of arable land in Egypt is estimated to be roughly 14 million feddans, or around 6% of the country's total land area. Egypt's overall agricultural area is roughly 8.5 million feddans, divided into 5.7 million feddans for irrigated land in the Nile delta and valley, and 2.5 million feddans for reclaimed irrigated land. This indicates that agricultural land in the Nile Delta is dwindling, and the productive capacity of the agricultural patch is much less compared to the population increased [1].

Globally, according to statistical studies on soil deterioration based on data collected over the last two decades, there has been a 40% increase in erosion worldwide, affects 3.2 billion people, primarily rural populations, smallholder farmers, and the impoverished, and approximately 25 percent of overall land area has been degraded which is due to the following factors: population growth of 1.6 percent per year, overgrazing, mechanized agriculture, and urban sprawl. Scientists recently warned that unsustainable agriculture methods were causing the loss of 24 billion tones-of valuable soil each year [2]. According to estimates, by 2050, The world's population is expected to grow by around 35 percent to 9.7 billion people which means increasing in demand 70 percent more food than it does now and 95 percent of the Earth's land areas might be degraded if current trends continue [3].

1.1.2 water crisis

The biggest difficulty facing Egypt's water resources system is the restricted availability of supply resources. The Nile River, effective rainfall on the northern strip of the Mediterranean Sea such as Sinai, non-renewable deep groundwater from the western desert such as Sinai, and shallow groundwater provide 55.5, 1.6, 2.4, and 6.5 BCM/year, respectively which means the total water supply is 66 BCM, while the total current water requirement for different sectors is 79.5 BCM/year. The gap between water demand and supply is approximately 13.5 BCM/year. This void is filled by recycling drainage water, either formally or informally. According to the research, if existing practices are maintained, there will be a 26 BCM/year water shortfall in 2025 [4]. Agriculture is the major water consumer, accounting for around 85 percent of overall water demand. However, the country as a whole is experiencing significant water scarcity as a result of recent population increase and climate change [5].

On a global scale, Water comprises 70% of our world, and it's simple to assume that it will always be abundant. Freshwater, on the other hand, is extremely scarce. We drink it, bathe in it, and use it to irrigate our farm areas. Only 3% of the world's water is fresh, and two-thirds of that is frozen glaciers or otherwise unavailable for human consumption. As a result, 1.1 billion people around the world lack access to water, while 2.7 billion face water scarcity for at least one month of the year [6]. Farming consumes about 70% of all water withdrawals, and in certain poor nations, up to 95%. Water scarcity has become increasingly severe in agricultural regions around the world in recent years. Droughts in Chile and the United States have harmed agricultural output and depleted surface and groundwater supplies. These, as well as other extreme weather events such as floods and tropical storms, are anticipated to become more common. Climate change is expected to increase variability in precipitation and surface water supplies, diminishing snowpack and glaciers and influencing crop water needs. Farmers in many areas will face increased competition from non-agricultural users due to increasing urban population density and water needs from the energy and manufacturing sectors [7].

1.2 Overview on the traditional agriculture

Traditional agriculture can be defined as traditional means of making a living from the land that have been passed down through the generations by word of mouth or experience and hence have endured with the passage of time. As the quality of agricultural production declines, everyone wants nutrient-dense food, yet this need cannot be provided using our old agricultural methods. This approach has a number of flaws. Some of them include land and labor availability; another is increasing fertilizer use, which can alter crop quality and, in turn, soil fertilization ability. The farmer may confront a slew of issues as a result of low soil fertility. He didn't get a lot of production, and the crop we'll get isn't very nutrient-dense. Other issues with conventional agriculture include frequent weather changes, temperature rises, water contamination, and so forth. In this situation, growing a crop that can feed the entire population with traditional agriculture will be extremely challenging in the future [8].

1.3 Introduction to hydroponics

1.3.1 Definition of hydroponics

Based on the problems mentioned above, many solutions were presented, and one of those solutions which have risen, and shine, and show high efficiency is Hydroponic farming which is a result of trying to get-ride of the conventional way of cultivating plants to solve the problem of lack of water and scarcity of suitable soil which depends mainly on that as long as the plants can grow as long as certain criteria are met. It can be simply defined Hydroponics as planting or gardening without soil, is a new popular technique of growing plants by using liquid nutrient solution. In recent years, hydroponics has grown in popularity in a number of countries. Because of a closed system, the number of chemicals used to control growth and guard against pests may be regulated. As a result, the output is of great quality and appears to be palatable [9]. A water-based recirculating system with required nutrients for plant growth is used in the hydroponics system. Conductivity (EC) and pH values are important characteristics that must be kept within the appropriate range for plant growth and type at all times. This necessitates the farmer's expertise and experience in adjusting these factors for crop quality preservation, chemical residue, and resource consumption [10].

1.3.2 History of hydroponics

Many millennia ago, hydroponics was used in Amazon, Babylon, Egypt, China, and India. The "Babylon Hanging Garden" and the Aztecs' floating farms were both hydroponic systems prototypes. Plant physiologists coined the term "nutria-culture" when they began to grow plants with specific nutrients for research objectives. Dr. William F. Gericke of the University of California succeeded in growing 7.5-meter-high tomato vines in nutrient solutions in 1929. Hydroponics kits for home use became popular in the 1990s. During the 1920s, hydroponics evolved into a more organic food producer, free of pollutants and risks [11]. In recent years, hydroponics has gained popularity around the world as a sustainable model for a controlled environment and precision agriculture system. Technology advancements have become increasingly important in automating agriculture systems and maximizing the efficient use of resources such as water and fertilizers. Instead of using traditional farming methods, urban farmers can use pesticide-free, controlled-environment agriculture and genetically modified organism (GMO) approaches [12].

1.3.3 Hydroponics advantages

Hydroponics has a number of advantages over traditional soil-based agriculture. Notably, hydroponic gardening uses less water, has a low risk of contamination, and is suitable for all weather conditions because the controller can control the air, water, light, temperature, and humidity of the plants. Furthermore, hydroponically grown plants grow faster and are healthier than soil-based plants [9]. It can also be done in a small space. Because we are growing plants in a water-based solution, we must manage the electrical conductivity of the solution, pH, humidity, and other factors in order to increase productivity and produce nutrient-rich food. Plants require oxygen, water, sunlight, and nutrients to survive. Soil cannot provide the nutrients necessary for plant growth; it can only act as a framework to hold the plants in place [8].

1.3.4 Applied Hydroponics Systems

Hydroponic systems are extremely adaptable, and many different variations have been employed to maximize growing conditions for certain plants [13]. When it comes to growing plants, there are hundreds of different types of hydroponic systems to choose from [14]. They are classified into two types based on whether the nutritional solution and supporting media are reused or recycled; nutrient solution and supporting media are not reused or recycled in open systems, but are reused or recycled in closed systems [13]. Although open hydroponic systems are less sensitive to water salinity than closed hydroponic systems, closed systems are more cost-effective. All variations, however, are classified into only six types of hydroponic systems. Wick, Ebb and Flow (Flood & Drain), Deep Water Culture (DWC), Drip (Reuse and non-reuse), and Aeroponic, which was newly developed and have several advantages over conventional farming systems, are six regularly used hydroponic systems [12].

Each type of hydroponic system works in a different way, thus each of the six hydroponic systems has its own set of advantages and disadvantages to consider. Aerators, pumps, and electricity are not used in the wick system. An Ebb and flow system which don't require any high-tech, pricey components that could cause their prices to increase, are often extremely modest in compared to many other systems. Even better, if you try to create the system on your own, you'll save a lot of money [13]. DWC and NFT which are defined as supplies water that delivers needed nutrients to the plant's roots on a continuous basis and ensures that the plant's foundations are immersed in water with sufficient oxygen [12]. Aeroponics which characterized as developing plants in an air/fog condition with mist water but no soil. We can call Aeroponics a developed version of hydroponics because it uses nearly 90 percent less water than traditional farming and 40 percent less water than hydroponics [15].

1.4 Technologies used in hydroponics

Technology has been introduced into practically all agricultural applications in recent decades, resulting in highly computerized systems that provide reliable results. Agrarian requests are changing, and so are consumer inclinations from routine needs. These demands should be satisfied by this industry, which is seeing an increase in labor expenses due to a shortage of manual laborers. Agriculturists can now turn to innovation to make their ranches more efficient, mechanized, and financially viable thanks to modern horticulture [16]. Integration of Web of Things, Artificial Insights, Machine Learning, Information Analytics methods, Cloud, Remote Sensor Systems, and many other modern improvements are becoming recognized by growers and organizations to boost and computerize the growing framework. Several modernized techniques have been implemented to design a controlled system which is recognized briefly in the next paragraph and deeply in the literature review chapter [12].

1.5 Thesis Objectives

In order to accomplish our project, we need first to achieve the following objectives which can be summarized in monitoring, controlling, and recirculating. Firstly, monitoring air and water temperature, humidity, water level, and required amount of nutrients which depends on PH and EC of solution in order to produce organic crops. Secondly, controlling the nutrient use in order to control the plant growing, but it's all organic and there are no chemicals. Finally, recirculating water which is very important to fix the problem of the water crisis by injecting the required minerals for reuse in the watering process.

1.6 Thesis Structure

Through this chapter, which represents our entrance to thesis and showed problem definition which consists of land degradation and water crisis, overview on traditional agriculture, introduction to hydroponics that contains definition, history, advantages, and applied systems for hydroponics, Technologies used in hydroponics, and thesis objectives.

Chapter 2
BACKGROUND (Literature Review)

2.1 Introduction

In this chapter, we will discuss the distinction between traditional agriculture and hydroponic systems with showing the disadvantages of traditional agriculture and how we treat these by using hydroponic systems. We will also explain hydroponic systems in depth through the parameters need to be controlled such as PH, EC, temperature…. etc. In addition, different architectures for hydroponic system.

2.2 Traditional agriculture in depth

Agriculture encompasses a significant effect on the country's economy. One of the greatest difficulties which faced humans since ancient times is provision of food and with the increase of population, it required also increasing of food production. Traditional agriculture could be a primitive kind of cultivating that creates broad utilize of inborn information, conventional gear, normal assets, natural manure, and the farmers' social values. It's worth noticing that about half of the world's populace still employments it [22].

In nowadays, traditional agriculture become inefficient and extremely harmful to our health due to many reasons, the most important which is, firstly, inorganic fertilizers (contains chemicals) to speed up the process of plant growth which caused so many health problems and unrecoverable environmental pollution. Secondly, soil erosion which is a process of the removal of topsoil by the natural physical forces of water and wind, deforestation operations for the purpose of raw materials such as wood, or through forces associated with farming activities such as tillage or repeatedly planting the same plant in the same soil. Represented in Figure 2.1 The map is based on the differences in soil erosion between each country and its neighbors (unweighted). Darker green indicates that a country has a greater positive impact on global soil erosion than its neighbors (that is, it has a dampening effect), whereas darker red shows that a country has a greater negative impact (that is, it has higher erosion rates) [25].

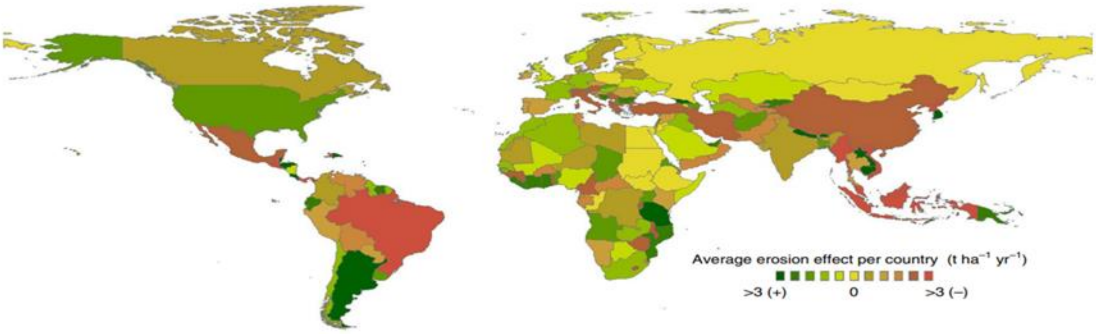


Fig. 2.1 A global map of countries' soil erosion performance.
(Mean erosion rate, based on hectare per year)

2.3 Hydroponics in depth

As a result of the problems specified within the introduction and in this regard, the soilless system cultivation is obviously a reasonable alternative due to surfaces that are not prolific (due to pollution or pathogen issues) and also limiting water consumption (due to the lack of fresh water year after year) [27]. Hydroponic systems are cultivation systems that utilize a mineral nutrient solution in a water solve to allow plants to absorb nutrients more efficiently than soil solutions or soil substrates. Native plants can be cultivated in nutrient solutions with their roots exposed.

As indicated in Figure 2.2, the nutrients supplied to the roots come from a variety of sources [12]. To offer physical support for plants, natural or manufactured media such as peat moss, sawdust, charcoal, rockwool, coco coir, clay granules, gravel, or ceramics are sometimes employed. Hydroponic research could help to sustainably feed fresh crops throughout the year, regardless of season, with higher yields using less land and as shown in figure 2.3 Plant growth in hydroponics compared to traditional soil growth, and it's apparent that hydroponics is far superior than traditional soil, more efficient use of water, Nutrient cycling, no use of chemicals, and a safer culture with lower environmental impacts and specific greenhouse gas emissions [28].

Fig. 2.2 Hydroponics system

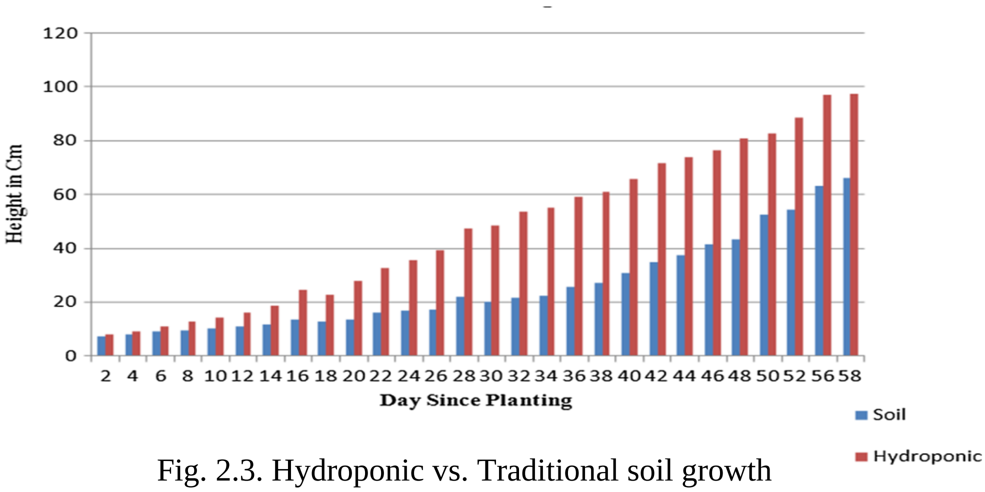


Fig. 2.3. Hydroponic vs. Traditional soil growth

2.3.1 Advantages of hydroponics

Yields improvement

Barbosa et al., (2015) investigated the Land, Water, and Energy Requirements of Lettuce Grown Using Hydroponic vs. Conventional Agricultural Methods in order to enhance hydroponic yields as shown in figure 2.4. While hydroponic lettuce cultivation delivers higher yields and more efficient water use, the regulated environment in which the hydroponic system creates its higher yields has a higher energy demand, according to the findings. This advantage of hydroponic production isn't limited to lettuce; it can apply to any crop depending on the operational settings under which it's cultivated. In the same way, most hydroponic systems will use water more efficiently than traditional farming.

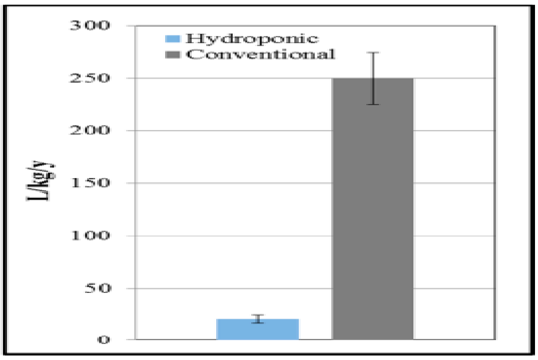


Fig. 2.4 Annual water use in liter per kg of lettuce produced hydroponically vs. conventionally in southwestern Arizona (error bars show one standard deviation).

Nutrient cycling

The second benefit is nutrient cycling, which, according to Springmann et al. (2018), is currently seen as a key component of future sustainable food systems when functioning within the framework of a circular economy. Currently, anthropogenic nutrient cycling relies mostly on nutrient recycling from animal farming, biogas production, and composting of agricultural and home waste [30]. Over the last year, there has been an increase in the number of new technologies that use biological or chemical processes to recover nutrients from organic waste streams in the form of recycling fertilizers (RFs) [28].

For nutrient cycling, hydroponics has two major advantages. First, as Goddek et al. pointed out, combining a recirculating aquaculture system with hydroponic production prevents the discharge of aquaculture effluents enriched in dissolved nitrogen and phosphorus into already polluted groundwater as shown in figure 2.5, and second, it allows for the fertilization of soilless crops with an organic solution rather than mineral fertilizers derived from depleting natural resources, as Yogev et al. noted out [31].

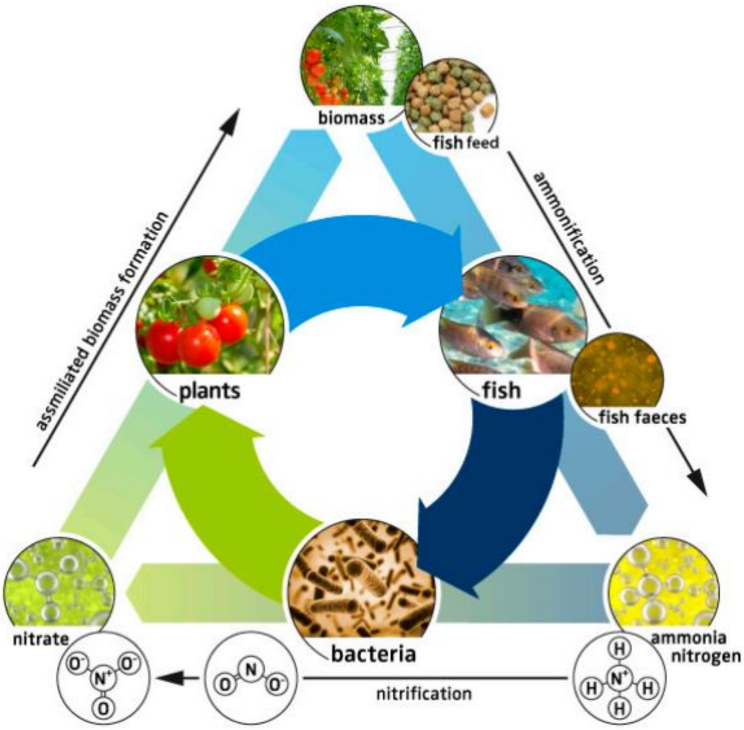


Fig. 2.5. Symbiotic aquaponic

Water saving

The third benefit is water-saving as hydroponics was originally developed for this purpose. Manjula et al. established the Controlled Environment Agriculture (CEA) system, which is distinguished by a higher level of environmental control, technological integration, the use of less precious water resources, and the absence of pesticides for the long-term growth of plants [12]. The drip system is one of the most efficient system in the process of utilizes water, as it mainly depends on the delivery of water in a uniform and at periodic intervals without causing stress on the plant and this system also applies the concept of water recycling as the water in the tank that overflows is returned to the system and is modified to be usable again for the process of providing nutrients [12].

A greywater-fed hydroponics garden was designed for the LEAP 5 campus, which primarily works on implementing hydroponic systems to reduce water consumption and increase yield, as part of a collaboration between Langa Education Assistance

Program 5 (LEAP 5) high school and STEM school in South Africa to address agricultural water scarcity in the Limpopo River Province [32]. As shown in figure 2.6.

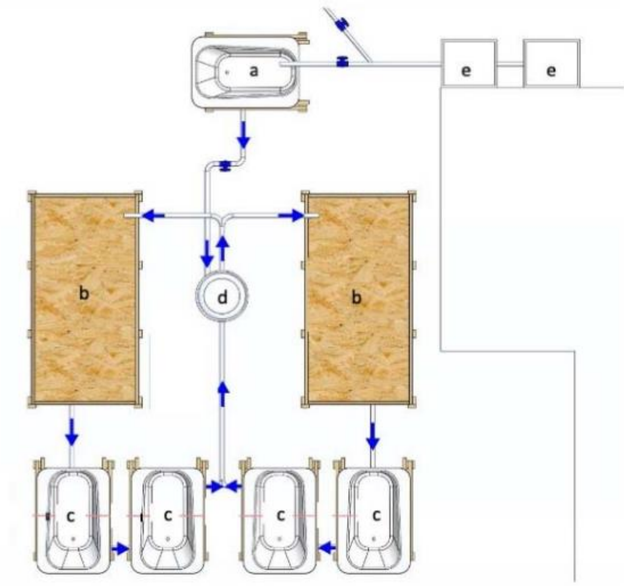


Fig. 2.6. Plan view of the design for LEAP 5 School in

Less environmental impacts

For safer life with less environmental impacts, hydroponic is considered as the useful and one of the most environmentally friendly technologies. hydroponic farming can substantially reduce pollution caused by the drainage water discharge as it does not drain the water after the process of providing nutrients to plants through water, but rather take it back to system which can prepare and treat it to be usable again in providing nutrients to plants as shown in figure 2.7.

Weed growth was eliminated with hydroponic systems, which meant no herbicides were used [28]. Herbicides are used in traditional farming, which pollutes the air and contaminates the soil. There is also no risk of chemical fertilizer contamination because the plants are not in the soil. Moreover, because there is no soil, the crops remain clean and do not need to be washed. Furthermore, when compared to soil cultivation (0.23 kg CO_2 equivalent), hydroponic systems emit significantly less CO_2 (0.11 kg CO_2) [33].

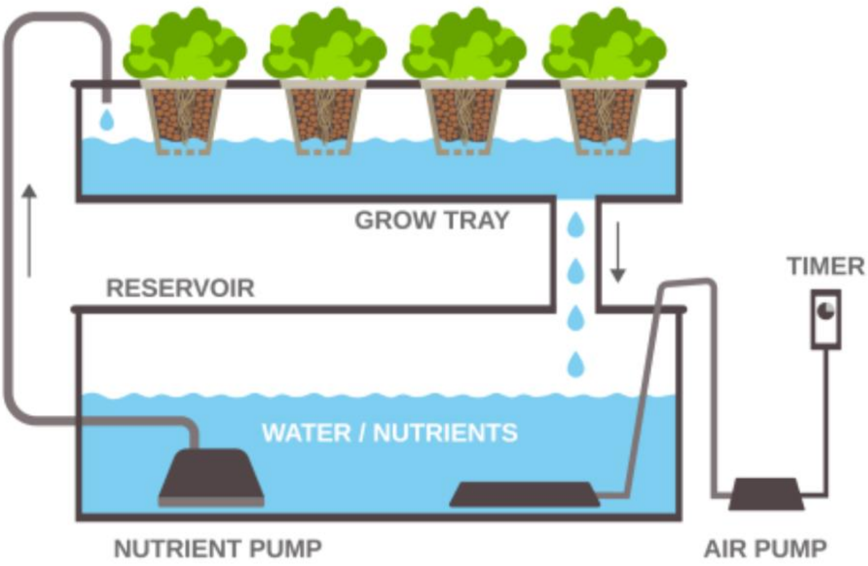


Fig. 2.7 Water cycle in hydroponic

2.3.2 parameters need to be controlled

In order to have a fully control on the system, The main difficulty with hydroponic farming techniques is that optimal plant growth is dependent on a number of parameters. Using a fuzzy logic technique, the authors [34] identified and evaluated twelve crop traits that play a crucial influence in optimal plant growth and from table 2.1 as shows the relative value of twelve crop parameters as determined by the aforementioned four different evaluation methodologies on (a zero-to-ten-point scale). The challenges needed to be controlled are Light intensity, water quality, air quality, water and air temperature, nutrient level, growing media, humidity, air flow, crop layout, crop species and Co2 [12].

It is important to know that every and each of these parameters required its own sensor or actuator in order to calculate all of these parameters precisely so as to make it possible to take decisions for example, The hybrid tomato plant requires lighting conditions of 18:6 (18 hours of light, 6 hours of darkness) or 14:10 (14 hours of light, 10 hours of darkness) [27].

Table 2.1 Summary of twelve crop factors scores by four different evaluation methods

Crop Criteria	Score of relative importance (0 to 10 point scale)			
	Food consumer importance	Expert's importance	Farmer importance	Food dealer importance
Air circulation	4	5	2.5	2.5
Air freshness	2.5	3.5	2	6.5
Crop cultivar	9.5	8.5	7	5.5
Crop spacing	1.5	4.5	4	2
Daylight length	6	6.5	5	4.5
Light intensity	8.5	5.5	7.5	9.5
Relative humidity	8	1.5	1	0.5
Nutrient availability	7	8	9	7
Moisture availability	3	4	6.5	8
Substrate media	5.5	7.5	8	6
Temperature	3.5	6	4.5	4
Water quality	7.5	9.5	9.5	8.5

Nutrient solution

Nutrient solution is a liquid fertilizer solution created in a specific composition to encourage plant growth, so from this perspective, it can be said that Nutrients are the basic materials for hydroponics. The authors [37] confirmed that the soilless nutrition solution became a good replacement for most of the crops grown in a hydroponic system using Deep Water Culture or Nutrient Film Technique.

The balance and concentration of nutrients are the major elements that determine optimal growth and increased yields. The mixture of various nutrients in the nutrition solution is important since their optimal uptake impacts the functioning of plants and, as a result, their growth. Before using water in hydroponics for nutrient solution, it must be tested to obtain reliable information about its qualities [13]. Kumar et al. determined the composition of the nutrient solution used to grow strawberries for a closed type of NFT as shown in table 2.2.

A study made by the authors [38] which is based mainly on analyzing the difference in nutrient concentrations over a four-week period. Week 4 had the biggest nutrition shortage, with 23.81 percent, which hampered plant growth.

Table 2.2 the quantity of every component (ppm) in nutrient solution of strawberry

Nutrient elements	Quantity (ppm)
Nitrogen (nitrate form)	160.0
Nitrogen (ammonium form)	15.0
Phosphorus (PO_4)	50.0
Potassium	210.0
Calcium	190.0
Magnesium	50.0
Iron	6.0

EC& PH levels

The EC and pH values have a significant impact on plant development. It is critical to monitor the nutrient solution using EC and pH sensors on a regular basis and adjust the values for plant growth. In soilless agriculture, pH levels between 5.5 and 6.5 are considered to be the ideal range [10]. Bicarbonates and, to a smaller extent, carbonate are the most important elements of alkalinity in nutritional solution and this acid requirement is based on the intended pH value and dissolved bicarbonate absorption [39].

The EC (dS m-1) value is calculated using a conglomeration of particle concentrations that will be appropriately measured utilizing EC meters and is enormously affected by temperature [12]. The authors [40] thoroughly examined plant growth in a variety of EC treatments ranging from low to high, which altered the dramatic effect of photosynthesis on leaves and biomass. The EC treatment range of 1.8-2.4 resulted in a higher quality crop.

The EC and pH sensors are connected to the microcontroller for detecting plant growth, and they are accurately controlled using artificial intelligence and machine learning technology, which functions as a tool for an automated hydroponic system, according to the authors [41]. To do the cultivation of crops such as vegetables in a hydroponic system, it is important to know the optimum range of electrical conductivity (EC) and pH values which are shown in table 2.3 [42].

Table 2.3 Optimum range of electrical conductivity (EC) and pH values for hydroponic

VEGETABLE	pH	EC	VEGETABLE	pH	EC
ARTICHOKE	6.5-7.5	0.8-1.8	MARROW	6.0	1.8-2.4
ASPARAGUS	6.0-6.8	1.4-1.8	OKRA	6.5	2.0-2.4
BASIL	5.5-6.5	1.0-1.6	ONIONS	6.0-6.7	1.4-1.8
BEAN (COMMON)	6.0	2.0-4.0	PAK CHOI	7.0	1.5-2.0
BEETROOT	6.0-6.5	0.8-5.0	PARSNIP	6.0	1.4-1.8
BOK CHOI	6.0-7.0	1.5-2.5	PEA	6.0-7.0	0.8-1.8
BROAD BEAN	6.0-6.5	1.8-2.2	PEA (SUGAR)	6.0-7.0	0.8-1.8
BROCCOLI	6.0-6.5	2.8-3.5	PEPINO	6.0-6.5	2.0-5.0
BRUSSELL SPROUT	6.5-7.5	2.5-3.0	PEPPERS	5.8-6.3	2.0-3.0
CABBAGE	6.5-7.0	2.5-3.0	PEPPERS (BELL)	6.0-6.5	2.0-3.0
CAPISCUM	6.0-6.5	1.8-2.2	PEPPERS (HOT)	5.0-6.5	3.0-3.5
CARROTS	6.3	1.6-2.0	POTATO	5.0-6.0	2.0-2.5
CAULIFLOWER	6.0-7.0	0.5-2.0	PUMPKIN	5.5-7.5	1.8-2.4
CELERY	6.5	1.8-2.4	RADISH	6.0-7.0	1.6-2.2
CUCUMBER	5.8-6.0	1.7-2.5	SPINACH	6.0-7.0	1.8-2.3
EGGPLANT	5.5-6.5	2.5-3.5	SILVERBEET	6.0-7.0	1.8-2.3
ENDIVE	5.5	2.0-2.4	SWEET CORN	6.0	1.6-2.4
FODDER	6.0	1.8-2.0	SWEET POTATO	5.5-6.0	2.0-2.5
GARLIC	6.0	1.4-1.8	TARO	5.0-5.5	2.5-3.0
KALE	5.5-6.5	1.25-1.5	TOMATO	5.5-6.0	2.0-5.0
LEEK	6.5-7.0	1.4-1.8	TURNIP	6.0-6.5	1.8-2.4
LETTUCE	5.5-6.5	0.8-1.2	ZUCCHINI	6.0	1.8-2.4

Temperature

The temperature of the water/nutrient solution is regarded one of the most critical deciding elements of crop output and quality in hydroponic production systems. The ideal temperature for nutrient solutions varies depending on who you ask and what type of plant you have, but the ideal water temperature for your hydroponic systems is between 68 and 72-degrees Fahrenheit (20 to 22 Celsius). Some people will raise the temperature to between 68 and 75-degrees Fahrenheit (20 to 24 Celsius). There isn't much of a difference in either case [43].

The amount of oxygen absorbed by plants is directly proportional to the temperature of the nutrient solution, while the amount of oxygen dissolved is inversely proportional. Furthermore, the temperature of the nutrient solution is said to affect the crop's uptake of water and nutrients in distinct ways [44]. During 2016/2017 (June-August), the authors [44] conducted an experiment with hydroponic cucumber in cooling treatments T1 (22^{o}C) through cooling nutrient solution versus non-cooled treatment T2 (33^{o}C) and discovered that T2 (141cm and 132cm, respectively) had the lowest plant height with low DO levels (5.1 mg/L and 5.2 mg/L) in both years. T1 plants, on the other hand, are taller than T2 plants (172.4 cm and 157.4 cm) and have higher DO levels (7.9 mg/L and 8.1 mg/L) as shown in table 2.4.

Table 2.4. DO and yield parameters as affected by RZT of cucumber grown in hydroponic system during summer cropping period (June-August) in cooled greenhouse.

RZT	First year 2016/2017			Second year 2017/2018		
	DO mg/L	Fruit. No/m^2	Yield t/gh	DO mg/L	Fruit. No/m2	Yield t/gh
22 °C	7.9 a	180 a	5.0 a	8.1 a	220 a	6.1 a
25 °C	7.3 b	167 a	4.4 a	7.2 b	221 a	6.0 a
28 °C	5.6 c	178 a	4.7 a	5.7 c	143 b	3.8 b
33 °C	5.1 d	101 b	2.8 b	5.2 d	133 b	3.5 b

Humidity

One of the most critical parameters in hydroponics is humidity as it is a perfect indicator to determine plants resilience against mold in addition to how much your plants need to drink as it is known that humidity is the amounts of water in the air. Humidity can be measured in a variety of ways, including relative, specific, and absolute humidity. In reality, we commonly measure "relative humidity" (RH) in hydroponics, which does not indicate how much water is in the air but rather what rate of the accessible capacity we are utilizing [45]. According to one of Nebula and Sirius' case studies for growing cannabis in hydroponic culture, the optimal relative humidity during clones rooted can be 70-80 percent. RH values are 40-60% during the transition from germination to vegetative phase, and 40-50% during the flowering phase [70].

Co_2 levels

It's crucial to remember that plants' photosynthesis is dependent on CO2 concentration, so it's essential to provide it to them. When plants are grown in the soil, they are naturally supplied with necessary levels of carbon dioxide. Plants in indoor hydroponics, on the other hand, aren't normally exposed to the same levels of CO2. This means that C02 will have to be supplied to the hydroponic system in order for the plants to have the greatest growing circumstances possible [46].

The important research undertaken by [47] identified physiological problems at concentrations greater than 1200 ppm. Temperature, light intensity, nutrients, and pH all alter the quantities of CO2 required for optimal plant growth and metabolism in a closed environment, depending on the plant type. With a controlled Co2 concentration within the range, the growth rate rose. The study on tomato species also demonstrates that increasing the ambient CO2 concentration to 400-500 ppm reduces the rate of chlorosis-like physiological disorders and enhances growth rate. Plants respond positively to CO2 levels up to 700 parts per million, as illustrated in figure 2.8, but greater levels of CO2 may cause plant harm.

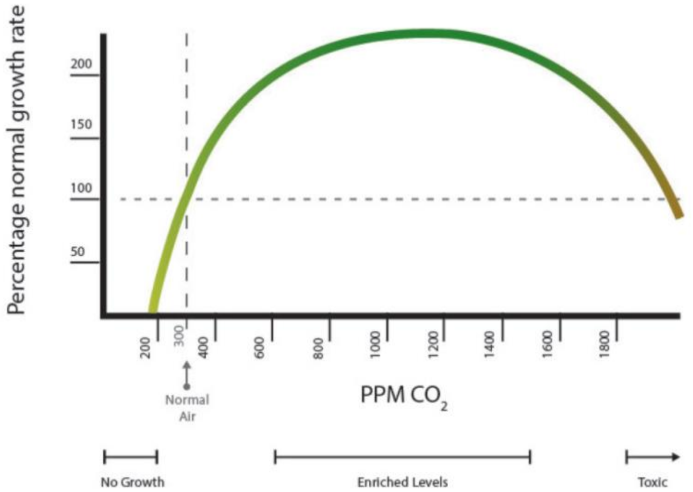


Fig. 2.8. Relation between CO2 concentration and rate of plant growth source

2.4 Hydroponic architecture techniques

2.4.1 Nutrient Film Technique (NFT)

The recycled NFT system uses a group of channels, which are set in different directions to grow plants in a water mixed with nutrients. This water which mixed by nutrients runs continuously, so plants can absorb these nutrients by the roots to do their photosynthesis process. The circulation starts by pumping the solution from a tank, to the growing tubes which contains plants, after that a drain tube is used to return the solution to the tank. Figure 2.9 illustrate the way to feed plants with water full of nutrients. There are designs for building an NFT system. For example, horizontal orientation system, vertical orientation system. We will focus on horizontal orientation system [48].

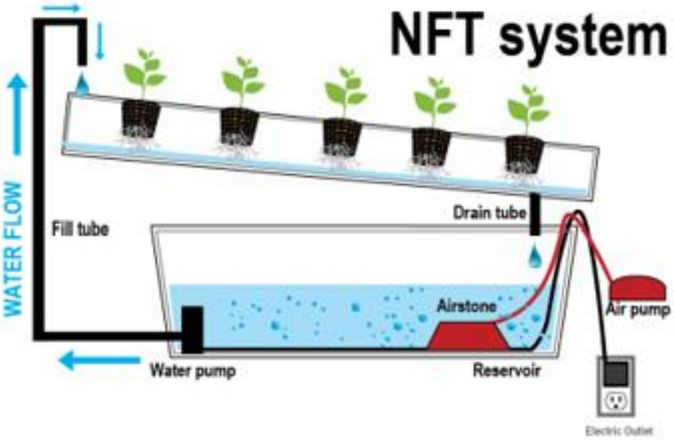


Fig.2.9 Nutrient Film Technique (NFT)

Horizontal Orientation System

The NFT system water stream flows from the water tank to the growing tubes and returns back to the water tank through drain tube, the growing tubes use a very small slope angle of 2 degrees to control water flow. As seen in Figure 2.10, the growing tubes are 9 m long each of them has 35 growing holes of 11 cm diameter, the distance between each hole is 25 cm [48].

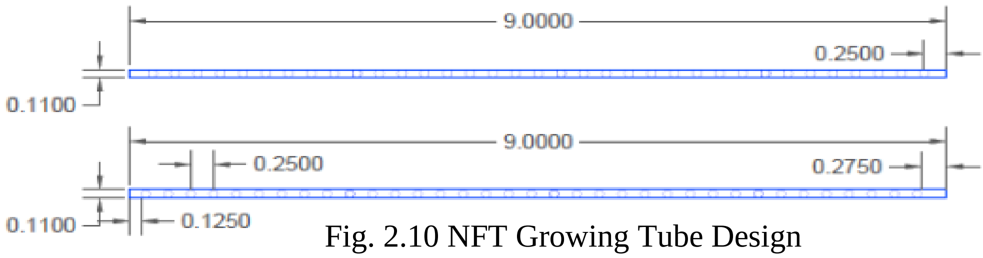


Fig. 2.10 NFT Growing Tube Design

Figure 2.11 illustrates the growing batch each contains 5 growing tubes with a distance of 0.2 m between tubes. The total area of the growing batch is $9 * 0.91\ m^2$.

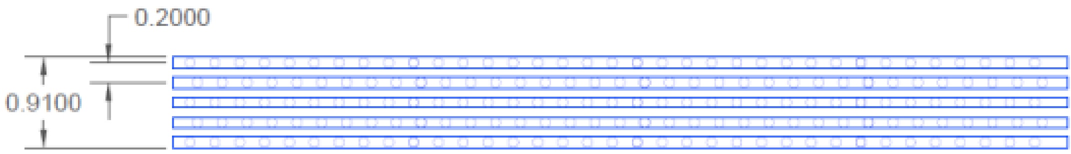


Fig. 2.11 Growing Patch

The top view of the entire design is shown in Figure 2.12. The total area of the container is 28.26 m^2. The container is divided into three parts. Part 1, the growing area consists of six batches of growing tubes, three on each side of the container, separated by a 0.53 m passage that facilitates transportation and harvesting. Part 2, the 5.94 m2 common area, which contains the water tank and nutrients this area could also be used for seedlings and other control devices, as well as the final harvest and packaging. Part3, ventilation area. The ventilation part is described by the usage of half a meter to produce ventilation fans.

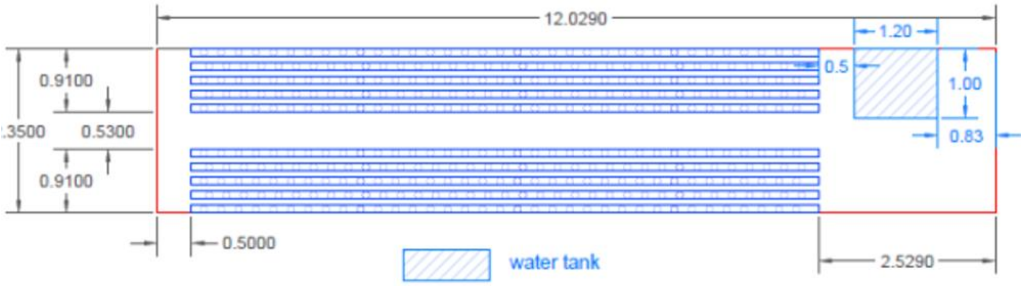


Fig. 2.12 Horizontal Hydroponic Top View

A distance of 0.5 m separates each growing level, which is required for growing, ventilation, and the construction of lights. Furthermore, in NFT systems, the slope is set at 2 degrees to maintain the water flowing constantly, as shown in Figure 2.13. This resulted in the overall number of holes being 1050.

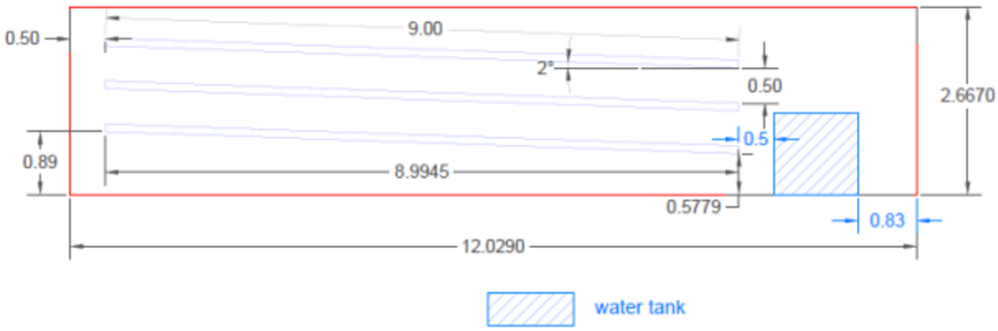


Fig. 2.13 Horizontal Hydroponic Side View

The horizontal NFT system was designed within a shipping container using SketchUp software, as shown in Figure 2.14.

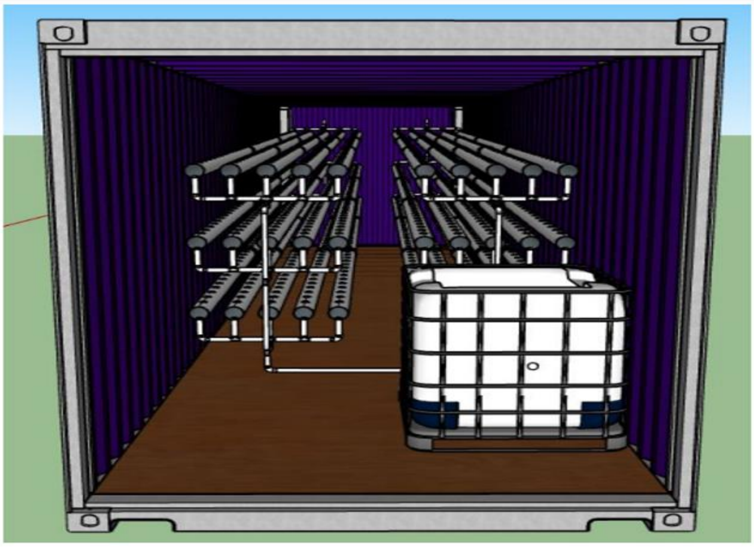


Fig. 2.14 Horizontal Container Design

Essential Component of Hydroponics Unit Intermediate bulk container

There are a variety of tank forms to choose from, including round tanks and square tanks. Because of their durability and ease of installation, inert plastic or fiberglass are used. A crucial factor to remember when utilizing plastic is that it must be UV-resistant. Figure 2.15 illustrate the shape of IBC Tank used as a water container [48].

Fig. 2.15 IBC Tank ("IBC Tanks," n.d.)

Pump

In the NFT hydroponics system, the flow is crucial, the short depth (1/4 inch) is sufficient to keep plant growth stable. So, these systems do not require a great amount of water to be pumped through them. The flow should be fast or slow. If the water reaches a state of stagnation, it begins to lose all of its dissolved oxygen and nutrients.

As plants are grown in long tubes with a fixed angle, the velocity of water flow and the depth of water in the tubes are controlled by the angle. In hydroponic systems, there are two types of pumps that are commonly utilized Submersible pumps and Inline pumps [48]. A comparison of the two types is shown in Table 2.5.

Table 2.5 Pump Types

Type	Size of System	Type of Cooling)	Place
Submersible	small-medium scale	water	inside the water tank
Inline Pump	large scale	air	outside the water tank

PVC Pipes

A Poly Vinyl Chloride (PVC) pipe is made of a mixture of plastic and combination material. The Pipes are long- lasting, robust, and difficult to damage. Over time, a PVC pipe will not corrode, degrade, or deteriorate. As a result, PVC piping is the most often used in water systems. The surface of the PVC pipe prevents bacterial contamination. As a result, many water providers use PVC pipe in their systems to avoid contamination. The following are significant aspects to consider while choosing pipes for the water supply and distribution system. Capacity to transport water, the pipe's strength, The pipe's life and durability, transportation expenditures, The process of jointing, as well as maintenance and repairs [48].

Recycled Shipping container

According to recent estimates, there are approximately 17 million shipping containers around the world, of which only 6 million are in use now and the remaining 11 million are not. The container's specifications are listed in the table 2.6 [48].

Table 2.6: Specification of the container

Inside Dimensions:		
Length(m)	Height(m)	Width(m)
12.029	2.683	2.352

Lighting

LED growing lights give all of the light that plants require to develop and flourish, and they have a number of advantages, including lower energy consumption (energy efficiency), longer life, decreased heat production, and high luminous efficiency. To ensure that all of the plants receive light, the LED grow light should be placed directly near or above them. For little seedlings, the light can be placed over the plants, then increased as the plants grow larger. Because LED grow lights produce less heat, there is no chance of burning the plant. The duration of lighting is shown in Table 2.7 based on the plant type [48].

Table 2.7: Duration of lighting

Type	Duration (hours/day)	Example
Short Day Plants	over 12	strawberries
Long day plants	around 18	lettuce
Day Neutral Plants	doesn't matter	eggplant

Ventilation System

One of the most crucial parts of any hydroponics system is air supply and exhaust. The growing space must be ventilated as part of the design. It is crucial for several reasons: temperature, humidity, illness management and control and fresh air exchange. The amount of CO2 required for all plants to survive increases when fresh air is introduced into the grow area. CO2 makes up around half of the plant's dry weight, with oxygen accounting for the remaining 42%. It is very important to supply the growing room with fresh air to avoid CO2 levels from falling too low and reducing crop yield. The continual supply and exhaust of air reduces the risk of illness development greatly. In environments where the air is still and humid, diseases are more likely to develop [48].

2.4.2 Deep Water Culture (DWC system)

In a DWC system and as shown in figure 2.16, Plant roots are submerged in a solution containing appropriate quantities of oxygen and particular nutrients. The plants will develop at least 15% faster and be healthier as a result of this. The following are the three most important ingredients found in the solution.1) water, it is the base of the solution.2) oxygen, the soil includes pockets of air, whereas water does not. An air stone and a pump are used to deliver oxygen directly into the water, ensuring that your plants get enough oxygen.3) nutrients, it depends on the type of plant. There are three types of DWC. Bubbleponics, The Kratky Method and Recirculating Deep Water. Recirculating Deep Water will discuss in details [49].

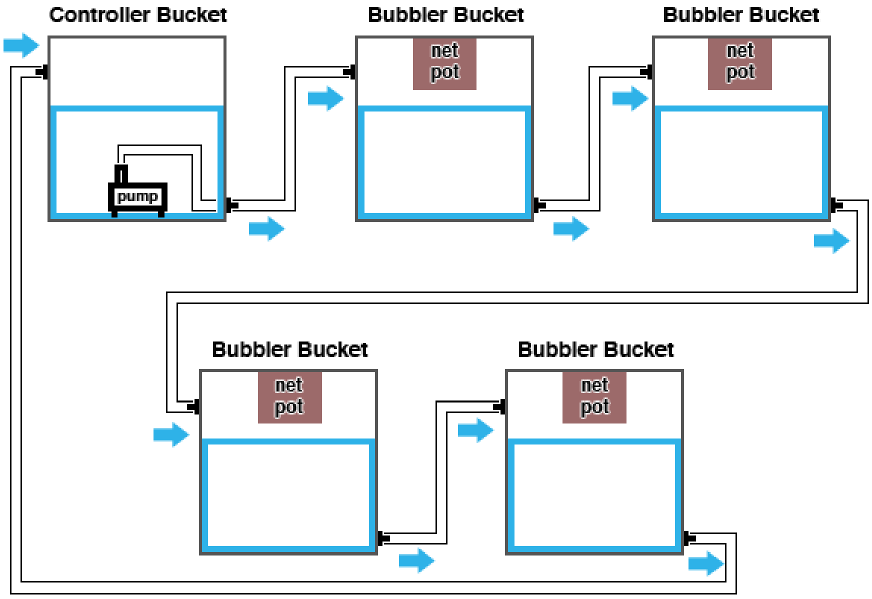


Fig. 2.16 cycle of water in DWC system

Building a Recirculating Deep Water Culture System

RDWC system is appropriate for larger scales, such as 5 buckets or more. When utilizing the traditional method, you'll have to calibrate each bucket individually, which might be time-consuming. You can create a system to circulate the nutrients if all of the buckets are for the same type of plant. All of the plants will be fed from a single reservoir. As the water with the solution circulates, the air will circulate as well [49].

Steps of building up the Recirculating Deep Water Culture System

Step1, choosing and installing the Main Container. The main container is the most crucial component of the entire system. Determine the number of plants you'll need to cultivate and the size of the reservoir you'll need. We suggest choosing one that can hold roughly 15 liters of water. Step 2, choosing Pots. Choose pots that are the right size for the plants you're growing. Net pots are the best, but they might be tough to obtain. Many individuals choose to construct their own DIY pots, which can save money while also being enjoyable and helpful. Go ahead and do it if you're confident the pots won't have sharp edges and will be the right size. However, keep in mind that any sharp object can injure the plant's roots and cause it to die. In such DWC systems, the roots grow extremely tenderly, so they need a safe environment to grow in. Choose the pots/buckets and link them to the main reservoir with tubes so that the solution can flow to each bucket and feed each root.

Step 3, measuring the Ratio of Nutrients and Additional Elements. The biggest disadvantage of such systems is the temperature range in which the plants can grow. Make sure your system is covered and protected from extremes of heat and cold. The temperature in the room is ideal. As to the nutrients, you can purchase nutrients for your greens. For the nutrients, the ratio should be specified in the manual, and you must precisely adhere to it. When it comes to incorrect calculations, such systems are particularly vulnerable. The situation with PH is the same. Normally, a level of 5,8 is acceptable, but you should study more about the plants you intend to grow. Some people may need more or less. Consult the manual for the pH control kit you've chosen for more information.

Step 4, Installing an Aeration System. An air pump should be capable of processing twice the amount of water in the main reservoir. Choose a system that can process 30 liters per hour if you have a 15-liter container. The air system will oxygenate the water that will later be pumped through the buckets containing pots, ensuring that all plants receive an equal amount of oxygen. If you don't aerate the water, no DWC system will work effectively. It must be high in oxygen in order for the roots to breathe. They do it in the soil by exploiting air pockets, but there are none in the water. Step 5, Plant the Seeds and Wait. Fill the pots with seeds. Take care of them according to the seed package's instructions. You'll notice an explosion of quick development as soon as the small young roots come into contact with highly nutritious water [49].

2.4.3 Wick System

Wick system hydroponics is the simplest and easiest in both form and function in the field of hydroponics, as shown in Figure 2.17. The name comes from the fact that these systems use the process of wicking to supply a water-based nutrient solution to plant roots. Wick system hydroponics is a passive form of hydroponics, which means it doesn't require any motors, pumps, or moving parts to operate. Only four components are required for this system (Growing container, Reservoir for the nutrient solution, Growing medium, Wicks). A short distance above the reservoir is where the growth container is placed. The wicks are set such that the nutrient solution is drawn up from the reservoir and released into the growing medium [52].

Fig. 2.17 Wick System

Working of Wick System

A wick system works just as it sounds; it simply wicks up nutrient solution from the reservoir to the plants through capillary action. In order to provide enough water (nutrient solution) to the plant, most good wick systems will have at least two or more good size wicks. The bucket/container containing the plant is positioned directly above the reservoir container. As a result, the water does not have to travel very far to reach the plant-growing media [53].

Building a Hydroponic Wick System

All you need for a hydroponic wick system are the four items mentioned above. We'll go over each of these key components one by one. First, a Growing Container for Wick System Hydroponics Made of a bucket or plastic tub. It'll hold the plants as well as the growing material. You will make small holes on the container's bottom for the wicks to pass through. Second, reservoir for The Nutrient Solution**.** Your reservoir should be a container that doesn't let light in, although it doesn't need to be covered because the wicks from the growing container above will be dangling down into it. The reservoir should be placed as close as feasible to the growing container so that the wicks can properly deliver the solution to the growing medium.

Third, growing Medium. Because this is where the plants acquire all of their water and nutrients, it's critical to use a growing medium that absorbs and holds moisture well. Coco coir chips, perlite, and vermiculite are the most common growing material for wick systems. Fourth, wicks. String, yarn, rope, or strips of fabric can all be used as wicks. The material of wicks can be anything from cotton, wool, and felt, to nylon, polyurethane, and other synthetics. Tiki torch wicks, microfiber cloths, terrycloth towels, and felt strips are all popular wicking materials. Before you start growing your plants, you might want to experiment with different alternatives to see what works best with the growing media you're using. Additionally, completely cleaning the material before use may improve its wicking ability [53].

2.4.4 Drip Hydroponic System

Drip hydroponic system is one of hydroponic systems that commonly used. All nutrients are measured and delivered as needed via hydroponic drip irrigation, which eliminates the need for soil. As the food and all nutrients are dissolved in water and delivered directly to roots. In addition to a timer-controlled pump distributes a slow feed of solution to the base of each plant. The excess solution can be collected or returned to the reservoir. When the system is running well, it requires very little maintenance, but the drip lines might become blocked, resulting in dried out plants. Because organic materials block lines considerably faster, synthetic nutrients (inorganic fertilizers) are the logical choice for these systems [50].

As shown in Figure 2.18, Water (nutrient solution) is pumped up from the reservoir through tubing to the top of the growing media (where the plants roots are), from there it drips out of the tubing onto the growing media. The nutrient solution drains down soaking both the roots and growing media all the way to the bottom of the container. From there the nutrient solution flows through an opening/s, and gravity allows the nutrient solution to flow downhill through tubing all the way back to the reservoir. There are 2 types of Drip hydroponic systems which are the most commonly used and they are Recirculating / recovery drip systems, non-recirculating / non-recovery drip systems [50].

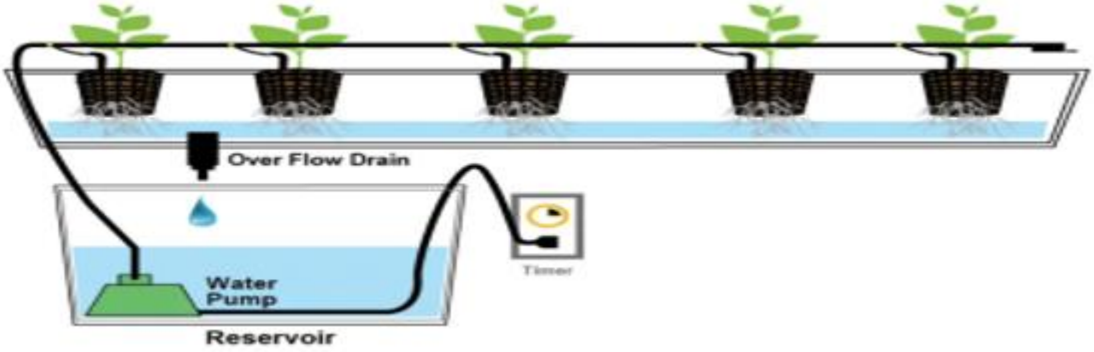


Fig. 2.18 Drip System technique

Recirculating/recovery drip systems

Recirculating drip systems simply refer to return the used nutrient solution to the reservoir after it has wet the roots, where it can be recirculated through the system and utilized again and again. Because the used nutrient solution is recovered and recirculated through the system, recirculating systems are also known as recovery systems as shown in Figure 2.19. The nutrient solution in a recirculating drip system can alter in both pH and nutrient strength levels as the plants use up the nutrients in the water as it circulates over and over, much like any other recirculating hydroponic system. As a result, recirculating systems necessitate checking and adjusting the pH as needed, as well as changing the nutrient solution on a frequent level to maintain the plants in a balanced nutritional solution [50].

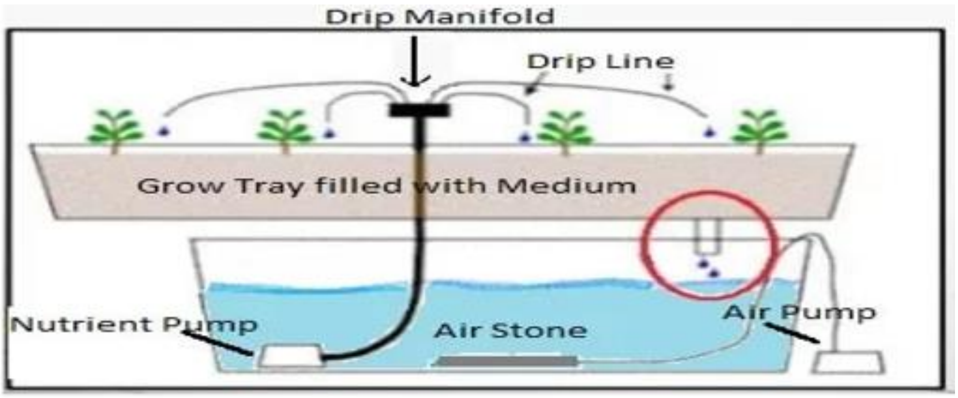


Fig. 2.19 Recirculating/recovery drip system

Non-recirculating / Non-recovery Drip Systems

The most common drip systems are non-recirculating/non-recovery drip systems. While it may appear to be a waste of water and nutrients. They accomplish this by carefully synchronizing their watering cycles as shown in Figure 2.20. They can regulate the watering times down to the minute, or even the second, if necessary, using special "cycle timers". The water (nutrient solution) that they drip onto the plants is absorbed and retained in the growing medium, where it can be accessed by the plants' roots. Because none of the wasted nutrient solution is recycled back into the reservoir, the nutrient solution in non-recirculating/non-recovery drip systems tends to be less maintenance. This means you may fill the reservoir with a balanced, pH-adjusted nutrient solution and it won't change [50].

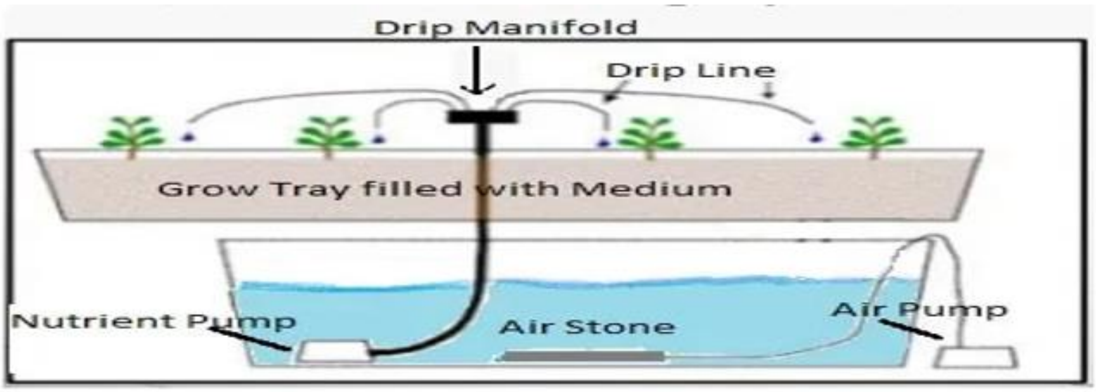


Fig. 2.20 Non-recirculating / Non-recovery Drip System

Building Hydroponic Drip System (System Parts List)

Drip Emitters, Ideally, each plant should have one drip emitter, however larger plants may require more. Irrigation Tubing, for transporting water from the reservoir to the drip emitters, PVC tubing works well. The number of tubes required will be determined by the number of drip emitters you have, and the lengths will be determined by the size of your setup. Submersible Pump, because you simply require a low-pressure stream of water to reach your drip emitters, a simple submersible pump will suffice. A Timer, a simple timer will work if you're utilizing a recovery drip watering system. It only needs to switch your pump on and off at fixed times throughout the day. If you want to proceed with a non-recovery system, you'll need a precision timer with maximum control.

A Reservoir, any opaque container with a tight-fitting lid will suffice. Growing Medium, for growing medium, Coco coir and Rockwool are the best choices specifically with a drip hydroponic system. Growing Containers, we can use Individual pots for each plant will provide you the most control over your system because you'll be able to modify nutrient flow based on the type of plant you're growing and its lifecycle stage. You could also use a larger growth tray to hold all of your plants and still place a drip emitter at the base of each one. PH test kit, to test pH of the nutrient solution. PH Adjusters (pH up, and pH down) That's to adjust the pH if needed once you have tested it [51].

Working of hydroponic drip system

Water (nutrient solution) is pumped up from the reservoir through tubing to the top of the growing media (where the plants roots are), from there it drips out of the tubing onto the growing media. The nutrient solution drains down soaking both the roots and growing media all the way to the bottom of the container. From there the nutrient solution flows through an opening/s, and gravity allows the nutrient solution to flow downhill through tubing all the way back to the reservoir. Table 2.8 showing some plants and their pH ranges [51].

Table 2.8 PH ranges for some fruits

Fruit	pH	Fruit	pH
Banana	5.5-6.5	Pineapple	5.5-6.0
Black Currant	6.0	Red Currant	6.0
Blueberry	4.0 -5.0	Rhubarb	5.0- 6.0
Melon	5.5-6.0	Strawberries	5.5-6.5
Passion fruit	6.5	Watermelon	5.8
Paw-Paw	6.5		

2.5 Technologies in hydroponics

2.5.1 Machine learning in hydroponics

Machine learning is a subset of Artificial Intelligence (AI) that enables computers to complete tasks on their own after being trained for a specific activity. Machine learning is like the human mind thinks about the past data that it has been exposed to, and then makes decisions for the future based on this data. In the field of hydroponics, the machine learning algorithm is used to manage plant development and optimize the Electrical Conductivity (EC) values of the nutrient solution. Alipio et al. (Ludwig and Fernandes, 2013) used a Bayesian network to monitor and control environmental events such light intensity control, potenz-Hydrogen levels, Electrical Conductivity, water level, and humidity in smart farming. These datasets were collected over a month in order to create a Bayesian network for doing predictive analysis and providing output decisions for autonomously regulating the system.

Ferentinos and Albright (2007) used Artificial Neural Networks to adjust potenz-hydrogen and electrical conductivity levels in hydroponic. In this case, a Feed Forward Neural Model is used, which takes 9 different inputs and produces two outputs for pH and EC. It is obvious from these predictive analyses that the Neural Network model effectively predicts the outcome [27].

2.5.2 IoT in Hydroponics

IOT stands for Internet of Things, which aims to connect people and things via the Internet and store data in the cloud for analysis. IOT has allowed the farmers to automate the hydroponic culture remotely. Water level, pH, temperature, flow, and light intensity may all be monitored and controlled with the help of IoT. As a result, a significant amount of research has been carried using IoT to monitor and operate the hydroponic system. Gosavi (2017) created an IoT-based hydroponic prototype that uses sensors like as pH, Electrical conductivity, and lumens meter to monitor pH, water conductivity, and water luminosity.

The data collected by the sensors is transferred to an ARM 7 Microcontroller, which performs continuous monitoring for optimal plant growth. For the simplicity of hydroponics, Peuchpanngarm et al. (2016) created an IoT-based autonomous control android/iOS mobile application. Different sensors are employed here, including a water level sensor, ambient temperature sensor, humidity sensor, and light intensity sensor, all of which are connected to an Arduino [27].

Chapter 3
METHODOLOGY

3.1 Introduction

One of the most common forms of hydroponic systems is the Nutrient Film Technique, also known as NFT. It's prized for its versatility and modularity. You can significantly increase your yields without putting in a lot of extra effort by adding more NFT channels to the system. The nutrient film technique is preferred by growers over other methods because of its low cost and low maintenance requirements, as well as its flexibility. There are more advantages to growing in an NFT system. Low water and nutrient consumption, no need to use a lot of growing media, simple root disinfection and setup, easy to see root quality and health, recirculating which reduces groundwater contamination, very modular and extensible, consistent flow minimizes salt buildup in the root region. An NFT hydroponic system has a simple design. Water is pushed up from a reservoir into fluid channels, which are angled at a little angle to allow gravity to flow the water from the high end to the low end, and then back to the reservoir. Plants are supported by a growing substrate and placed in holes cut in the top of the channels. The substrate serves as a place for the plant to absorb water. The roots of the plants grow into the fluid that flows across the channels' bottoms as they grow [54].

3.2 Machine learning approach in hydroponics

Machine learning is a branch of artificial intelligence (AI) that allows computers to learn and improve on their own without having to be explicitly programmed. Machine learning is concerned with the creation of computer programs that can access data and learn on their own [55]. First and foremost, before a machine to think like a human mind, it must first think and learn like a human being. The human mind considers about past events and facts that it has been exposed to, and it makes decisions for the future based on that [26]. Machine learning (ML) algorithms have the ability to solve huge non-linear problems autonomously using information from numerous sources, which is one of their key advantages [56]. In the field of hydroponics, the machine learning algorithm may be used to control plant development, optimize the Electrical

Conductivity (EC) values of the nutrient solution, predict plant maturity and crop quality, make smarter decisions and take informed action in real-world scenarios without (or with limited) human participation [27]. It provides a comprehensive and adaptable framework for data-driven decision making that may be utilized in a variety of settings, including agriculture [56].

3.2.1 prediction in Machine learning

Machine Learning (ML) prediction algorithms present a scalable and multidisciplinary method to data analysis that can have a significant impact on agricultural productivity. ML techniques are used as a tool in agricultural research for precision farming, and the results are amazing. Appropriate modelling of plant growth dynamics and crop yields is also critical in hydroponic agriculture systems, as is effective resource management [57]. Fresh weight, plant height and number of leaves, stem diameter, and plant healthiness are all attainable aim outcomes in hydroponic farming. Accurate crop forecast, effect of environmental conditions, and crop management may be implemented for high yield using ML prediction models such as Regression Algorithms, Neural Network models, and optimization models [58]. Figure 3.1 depicts the prediction and analysis of plant growth based on environmental parameters [12].

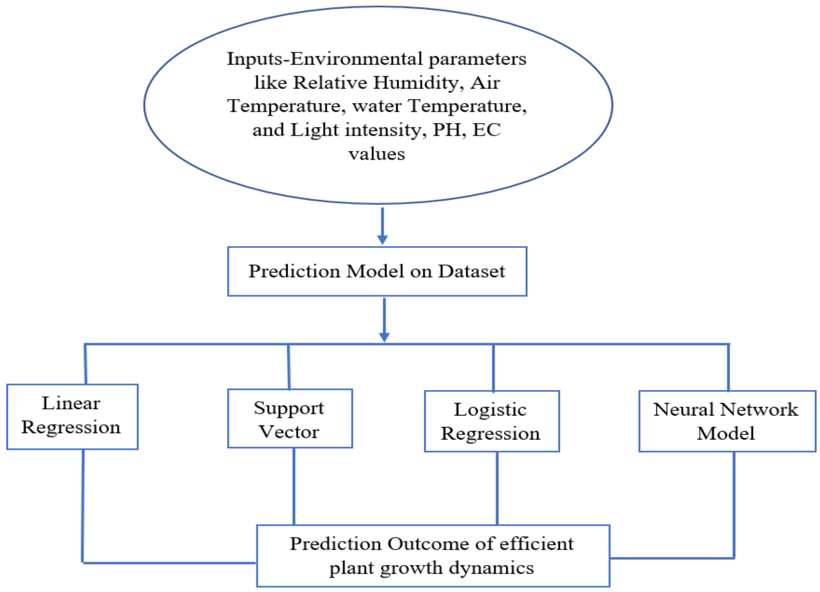


Fig. 3.1 Proposed prediction Algorithms for prediction of plant growth dynamics

For high yield production, environmental characteristics such as pH and EC values can be used to efficiently analyze plant growth rate. As a result, statistical and supervised machine learning models must be used to investigate the relationship between these factors and plant growth and health. Plant growth and health dynamics are predicted using these models, which have been trained and evaluated. By taking into account future meteorological conditions, the model should be able to anticipate future plant development [27].

Linear Regression Model

On the hydroponic time-series dataset, simple and multivariate linear regression models can be used to study the dynamics of plant progress from single and multiple independent variables, respectively. The significant parameters are picked using a correlation matrix, resulting in a lower cost function. Below is the first multivariate regression equation.

$Y = \alpha + W_1 * a + W_2 * b + W_3 * c + \cdots$ (1)

Where a, b, c, etc. are independent variables, an is a constant, w1, w2, w3... are regression coefficients, and Y is a dependent variable. The hypothesis can be established and plant height observed using the correlation coefficient between dependent and independent factors. The cost functions Root Mean Square Error (RMSE), Mean Square Error (MSE), and Mean Absolute Error (MAE) are used to calculate the accuracy of these models (MAE). To reduce the sum of square errors, a best fit line can be formed [12].

Support Vector Regression Model (SVM) in the process of prediction

This model seeks to translate predictor parameters from a lower-dimensional to a higher-dimensional space in a non-linear way. To project the input parameters into higher dimensional space, the SVM kernel function Radial Basis Function (RBF) is used. Equation 2 represents the Gaussian RBF function.

$K_{rbf}(x_1, x_2) = exponent(-\gamma * ||x_1 - x_2||^2)$ (2)

The Euclidean distance between x_1 and x_2 is determined by $||x_1\text{-}x_2||$, and the model fitting for RBF kernels is determined by γ. The tolerance margin is calculated using the threshold value € and the cost function c. In order to, minimize errors and maximize the margin between the hyper plane and data points, the trade-off complexity c with the number of support vectors should be regularized. Using Principal Component Analysis and performance evaluation, it is possible to select a high predictor variable [12].

Logistic regression Model

It is supervised learning classification algorithm logistic used to predict the likelihood of a target variable. Because the nature of the goal or dependent variable is dichotomous, there are only two classifications. In simple terms, the dependent variable is binary in nature, with data represented as 1 (representing success/yes) or 0 (representing failure/no). A logistic regression model predicts P(Y=1) as a function of X mathematically. It's one of the most basic machine learning algorithms, and it may be used to solve a variety of classification problems like spam detection, diabetes prediction, cancer diagnosis, and so on [12].

Neural Network Model in the process of prediction

The neural network model is a low-cost prediction model that may be used to forecast plant growth dynamics using the feed forward method. As shown in figure 3.2, the input parameters operate as neurons that are passed on to the hidden layers below. Finally, the target variable is forecasted by the output layer. The actual outputs are then compared to anticipated outputs, the error is estimated, and the weights are adjusted to improve performance using the back propagation technique. The neural network model is superior at dealing with complicated and nonlinear situations [12].

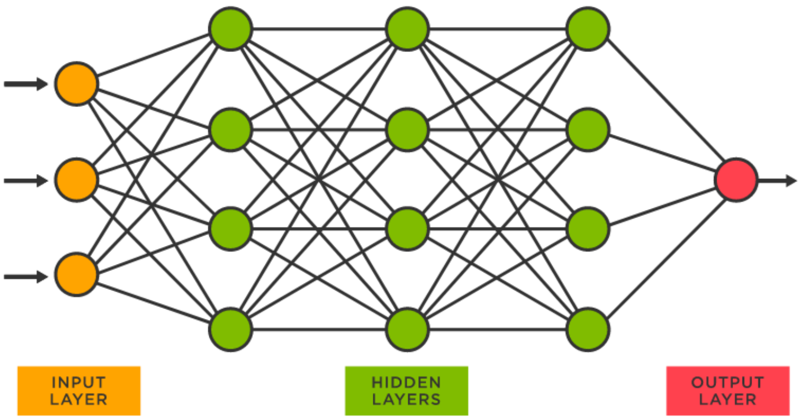


Fig. 3.2 Neural network and its mainly parts (input layer, hidden layers, and output layer)

Related works

Gonzalez-Sanchez et al. (2019) compared crop yield prediction using ANN, SVR, M5-prime, k-nearest neighbors (KNN) ML methods, and Multiple Linear Regression (MLR) in ten crop datasets. The accuracy metrics employed in their investigation were Root Mean Square Error (RMS), Root Relative Square Error (RRSE), Normalized Mean Absolute Error (MAE), and Correlation Factor (R). The results showed that M5-Prime had the lowest errors of all the crop yield models tested. According to the RMSE, RRSE, R, and MAE results, M5-Prime, KNN, SVR, ANN, and MLR were ranked from best to worst in the following order: M5-Prime, KNN, SVR, ANN, and MLR. Another study (Nair and Yang-Won, 2016) used four machine learning algorithms to estimate corn yield in Iowa State: SVM, Random Forest (RF), Extremely Randomized Trees (ERT), and Deep Learning (DL). Validation statistical comparisons revealed that DL produced more stable findings, overcoming the overfitting problem [56].

3.2.2 Decision making (control) in machine learning

Decision-making is a process involving ideas and decisions about certain events. Depending on the degree of certainty of the problem description and solution, decisions are classified as structured, unstructured, or semi-structured. An unstructured decision is deterministic and has little or no agreement on the solution, whereas a structured decision is deterministic and has a known solution. Unstructured decisions are primarily dependent on the decision maker's preferences or experiences, whereas structured decisions do not involve any judgement on the side of the decision maker. A broad range of problems called semi-structured decisions which exists in between of supervised and non-supervised decisions [27]. Semi-structured decisions can be represented with analytical models or based on data, and as a result, technology helping is focused on them the most. Technology can support decision making by identifying and selecting relevant input, selecting appropriate data, solving a decision model under a set of conditions, providing results to the decision maker, or assisting the decision maker in interpreting decision model outcomes [59].

AI and ML can help us in making the best decisions in decision-making situations especially when it comes to control several parameters such as PH, EC, humidity, water temperature, air temperature, and light intensity in hydroponic systems. Fuzzy Logic, Decision Tree, and Neural Networks are the most often used AI and ML tools for decision making (control) in hydroponic systems [60]. Models can learn or understand from experience, make sense of ambiguous or contradictory messages, respond quickly and successfully to a new situation, solve problems using reasoning, deal with perplexing situations, understand and infer in ordinary, rational ways, manipulate the environment using knowledge, think and reason, and recognize the relative importance of different elements in a situation so that's what distinguish the use of machine learning in decision making (control) over traditional ways [61]. After the process of collecting data from sensors, the readings send to ML model in order to come out with decision needed to take and it has to be known that the greater the number of datasets analyzed, the more accurate and reliable the ML model will be [62].

Fuzzy Logic as a Framework for Intelligent Decision Support

Fuzzy logic, which derives models from fuzzy sets, is a well-known technique used in ML decision-making (control). The fuzzy logic approach is a popular multi-criteria decision-making method (MCDM). It enables scientific decision-making in sectors where selecting the optimal option is extremely difficult. It combines tangible and intangible aspects in order to determine the priority associated with the problem's alternatives [63]. When the decision-aims maker's or objectives and limitations are not of equal importance, the fuzzy approach is applied. The fuzzy set is defined by a function that assigns a value of 1 to elements that belong to the set and a value of 0 to those that do not. The intermediate values are linked to items that are only partially associated with it (associated with uncertainty). The term "fuzzy set" refers to a class that allows for partial membership [34].

Let X={x} denotes a space of objects. Then a fuzzy set A in 'X' is a set of ordered pairs mathematically represented by the equation below Equation (1) and Equation (2). The grade of membership of x in set A is mathematically represented by Equation (3).

$$A = \{X, \mu_A(X)\} \tag{1}$$

$$X \in XA_m \tag{2}$$

$$\mu_A(X) \in [0,1] \tag{3}$$

Where, $A = \begin{Bmatrix} 1, c\ is\ totally\ in\ A \\ 0, X \in A \\ (1,0) if\ x\ is\ partially\ in\ A \end{Bmatrix},\ \ m\ reperesents$

number of members and $\mu_A(x)$ is the grade of membership of x in set A.

Decision Tree as a Framework for Intelligent Decision Support

Decision trees (DTs) are a popular machine learning (ML) model for making decisions (control). It's a tried-and-true method for making decisions in complex scenarios. Ensemble approaches such as decision trees and random forests are commonly utilized in machine learning. Decision trees are a supervised learning system in which input is constantly split into distinct groups based on specified factors [64]. It's a tree-based technique in which any path from the root to the leaf node is characterized by a data separating sequence until a Boolean result is obtained. It is a hierarchical exemplification of nodes and links in knowledge relationships. Nodes indicate purposes when relations are used to categorize [65].

DTs are one of the most powerful approaches utilized in a variety of domains, including machine learning, image processing, pattern recognition, and decision making (control) [66]. DT is a sequential model that effectively and cohesively connects a series of fundamental tests in which a numeric feature is compared to a threshold value in each test [67]. The numerical weights in the neural network of connections between nodes are far more difficult to construct than the conceptual rules. DT is primarily used for grouping purposes. Furthermore, in Data Mining, DT is an often-used classification model [68]. Each tree is made up of nodes and branches. Each subset defines a value that the node can take, and each node represents features in a category to be categorized. Decision trees have a wide range of applications due to their ease of analysis and precision across numerous data types. The structure of DT is depicted in Figure 3.3 [69].

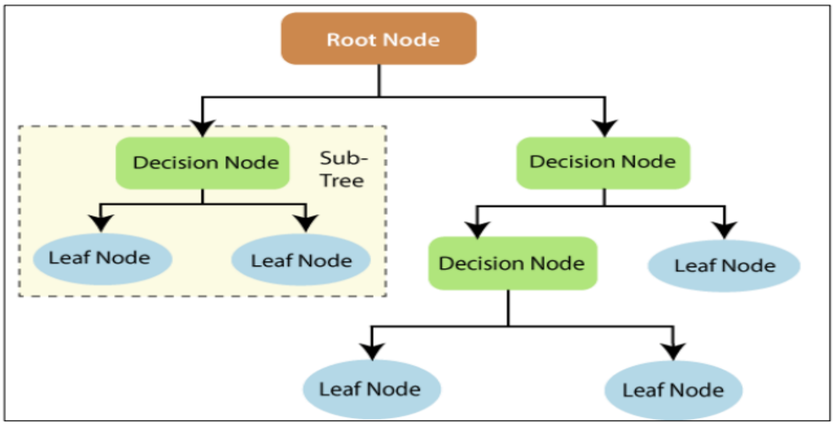


Fig. 3.3 structure of Decision tree

Neural Networks as a Framework for Intelligent Decision Support

Artificial neural networks (ANNs) (or simply neural networks, NN) are multivariate analysis computing approaches influenced by biological neuron networks [70]. Nonlinear regression models, discriminant models, and data reduction models that are highly interconnected and work together to solve a problem are referred to as ANNs. The way the human brain analyses information is the inspiration for NNs [58]. ANNs, like neural networks, are made up of layers of simple data points (nodes) that interact with each other via precisely weighted connecting lines, as seen in figure 3.4. Data is provided to ANNs before they are "trained" and balanced, and the data is used to change the ANN's interconnections. ANNs are highly recommended and dependable for assisting decision making and control, according to studies [27].

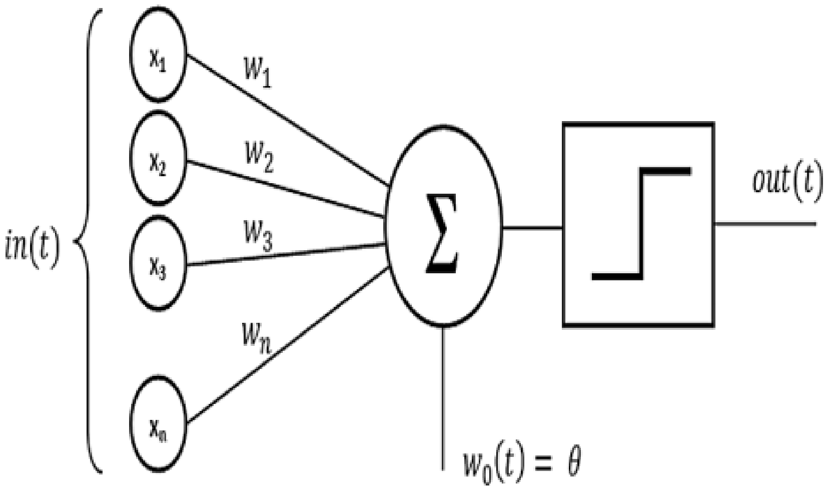


Fig. 3.4 Perceptron in ANN

In the illustration shown in Fig. 24, the perceptron has three input sources, X1, X2, and X3. To place it in more exact algebraic terms:

$$Output = \begin{cases} 0 \quad if \sum_i W_j X_j \ \leq threshold \\ 1 \quad if \sum_i W_j X_j \ > threshold \end{cases}$$

That is everything to how a perceptron function!

That is the fundamental scientific model. So, to apply it on the hydroponic system to preform decision making and control, after the readings got from sensors and collected to send it to NN model. According to threshold and reading fed to NN. If it is higher than threshold, an action would be performed and another one would be taken in the case of reading is lower than threshold. For example, An LDR Sensor Module has been used to measure the light intensity. If the LDR values fall below a threshold, then the relay switch switches on the LED Bulb for optimum lighting condition as shown in the figure 3.5 [27].

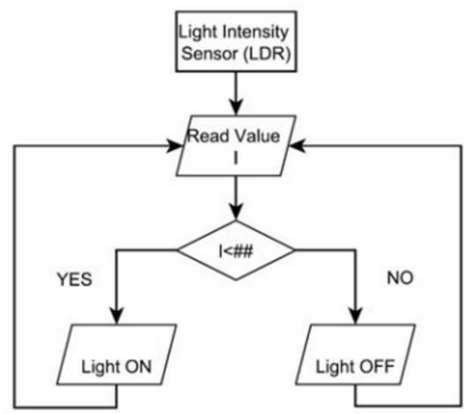


Fig. 3.5 Light intensity automation

what could be the best ML model to use it as decision making and control model in our project?

As it mentioned before, our project mainly uses ML model for decision making and control which had to be firstly, trained well by supplying to enough number of datasets as an experience to deal with inputs (readings came from sensors) because the greater the number of datasets analyzed, the more accurate the ML model will be. Secondly, the ability of deal with insufficient and unreliable data as it might be sometimes inaccurate readings come from sensors. Thirdly, the ability of dealing with more than one parameter as in hydroponics there are many parameters needed to be handled to reach fully control system such as PH, EC, air temperature, humidity, water temperature. Finally, ML model has to be stable and its performance will not decrease with the passage of time, but in the contrary, it must get better in decision making as it takes much time with feeding with data and learn from it over the time [64].

So accordingly, ANNs might be good choice to support the needs of ML model of our project as it has some advantages which fit these requirements. Firstly, the ability to work with unreliable or insufficient data because, after ANN training, the data output can be partial or insufficient. The significance of the missing data influences the lack of performance. Secondly, resistance to progressive corruption, because over time, a network's performance degrades and slows. ANNs, on the other hand, consistently improve with time. Thirdly, because these networks have numerical strength, they can perform multiple functions at the same time. Fourthly, the ability to train machines using artificial neural networks (ANNs), which learn from events and make decisions by commenting on similar events. Fifthly, the ability to tolerate error due to the output generation is not affected by the corruption of one or more than one cell of artificial neural network. Finally, data could be stored over the entire network. Similarly, to how information is stored on the network rather than in a database in traditional programming. When a few pieces of information vanish from one location, the network as a whole continues to function [71].

Related works

Alipio et al. (2017) have applied study to design a smart hydroponics system that uses exact inference in Bayesian Networks to automate the growing process of crops (BN). Physical events such as light intensity, pH, electrical conductivity, water temperature, and relative humidity are monitored and controlled using sensors and actuators. The sensor data was utilized to create a Bayesian Network in order to determine the best value for each parameter. A web interface is being created to allow users to remotely monitor and control the farm via the Internet. When comparing the automatic control using BN to the manual control, the results showed that the sensor value fluctuations were minimized in the automatic control using BN. The yielded crop on the automatic control was 66.67 percent greater than the yielded crop on the manual control, implying that using accurate inference in BN helps to produce high-quality crops [63].

3.3 Architecture

3.3.1 Frame

The water channels, as well as the water input and collecting pipelines, require support from a frame. To allow water to flow through the channels by gravity, one end should be higher than the other. A sufficient angle for water to flow through the channels is between 2° and 3°. Water may not flow quickly enough through the channels if the angle is too small, resulting in overflow and spillage at the entrance edge. To make two long and two short leg pairs, cut the square tubing into two 16.25-inch lengths and two 15-inch lengths. Cut two 23-inch lengths to attach to the top of each leg set (where the channels will rest), and secure them to the legs with flat steel bars inclined at 90°. To improve rigidity, secure all 90° flat bars with four bolts as shown in Figure 3.6. To function as a spine, cut a 24-inch length and fasten each end to each of the rear leg sets. Later on, this spine will be used as a support for the pumps to be mounted on. Figure 3.7 illustrate the detailed drawing in case of the 1-inch square steel tube frame [54].

Fig. 3.6 The frame with 90^0 Steel bars securing the real-left leg to the spine

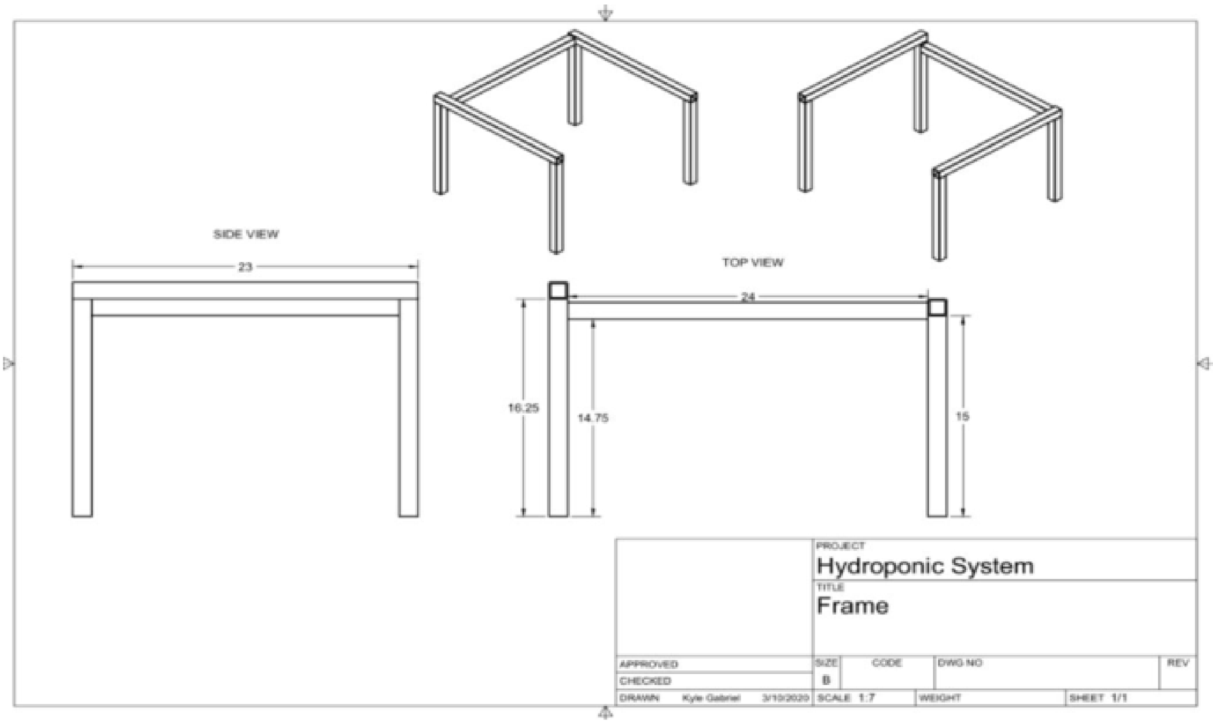


Fig. 3.7 detailed drawing of frame

3.3.2 Water channels

Cut vinyl gutter downspouts into five 2.5-foot segments to create the water channels. I utilized downspouts that sized 2 in. x 3 in. Using a hole saw, cut 1.75-inch diameter holes on the widest side of the channels, at a spacing of approximately 6 inches, on center. I alternated the cutting so when the channels were placed side-by-side, the holes alternated and formed a checkerboard pattern, which maximizes space between plants to grow. Drill a 1/4-inch hole in the top of each channel, on the inlet side, about 3 inches from the end, which will be used to supply water to each channel. Place the channels on the frame, with the inlet sides with the 1/4-inch holes resting on the higher end [54].

3.3.3 Water input

To supply water to each channel, 1-inch PVC is routed along the length of the inlet side of the frame and connected to a water pump. Cut two 11-inch PVC lengths, then cement a PVC tee in the center and PVC end caps to the ends as shown in Figure 3.8. Screw a 1/2-inch hose barb adapter into the tee after applying thread seal tape. Drill five 3/8-inch holes into the inlet pipe, one in front of each channel. Remove any burs and install a microtube grommet into each hole. Secure the inlet pipe to the frame edge with zip-ties or other fasteners, just under the channels. Connect one end of a 1/2-inch innerdiameter hose to the inlet pipe's hose barb with a hose clamp and the other end to the water pump. Last, connect a microtube from each grommet to each channel's 1/4-inch inlet hole [54].

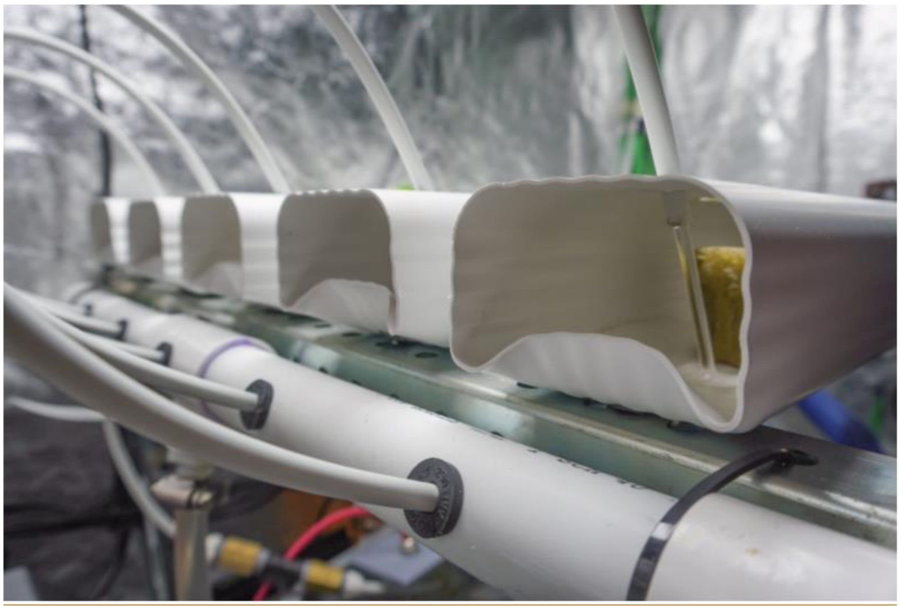


Fig. 3.8 tubes that supply water to plants

3.3.4 Water collection

We'll build an open pipe on the outlet side of the channels to collect the water exiting the channels and route it back to the reservoir [54].

3.3.5 Airflow

Airflow is critical for controlling temperature, humidity, carbon dioxide, oxygen, and vapor pressure deficit, as well as preventing fungus growth. Since this system is operating in a 2 ft. x 4 ft. grow tent, small 80 mm to 150 mm PC fans are sufficient for circulating and exhausting air. To spread the humid air created, a circulation fan was linked to an always-on outlet and put near the humidifier. The larger fan was installed in one of the wall ducts to blow outward and was connected to the power control box so that the exhausting could be modulated by the control software [54].

3.3.6 Lighting

If you're growing outdoors in the sun, you probably won't require any additional lighting. You'll need at least one grow lamp if you're growing indoors. We may use both a Sun Blaze (T5HO 24) 96Watt fluorescent fixture for germinating seeds and a Galaxyhydro (HYG05) 300Watt LED fixture for the mature plants in the grow tent in our project. The grow lamp emits a lot of light, which can degrade photo quality. I required a less harsh and more neutral light source for illuminating the plants during photo acquisition because I wanted to capture photos with both a DSLR and a Raspberry Pi camera. While this secondary light was operational and the images were being taken, I also needed a mechanism to switch off the grow light(s). Although the automated configuration will go through this in depth [54].

3.3.7 Building the Automation Hardware

Control panel

To connect all of the hardware components to the Raspberry Pi, which will coordinate the automation operations, a central location is required. We will use 0.375inch thick high-density polyethylene (HDPE) plastic panel to mount everything. This is a tough material that can be cut with either hand or power tools. We will use breadboards to create many of connections. Breadboards have capability to easily make and break connections. A diagram of the Raspberry Pi with all pin designations on the 40-pin header is shown below in figure 3.9 and Figure 3.10 [54].

Fig. 3.9 Raspberry Pi 40-pin header

Connecting the Sensors, LCD, and Pump

The sensors, LCD, and pumps will all be connected to the Raspberry Pi's four pins. Which is the ground pin, 5-volt pin, serial data (SDA) pin, and serial clock (SCL) pin. Both SDA and SCL pins represent I2C.which was designed to communicate with sensors and external devices. By default, Atlas Scientific sensors and pumps use the UART communication mode rather than the I2C communication mode. Before you can connect with them on the I2C bus, you'll need to manually switch each device to I2C mode according to the datasheet published by Atlas Scientific. Figures 3.10, 3.11, and 3.12 below show the complete connection of components with Raspberry Pi graphically and physically respectively [54].

Fig. 3.10 Raspberry pi 3 B+

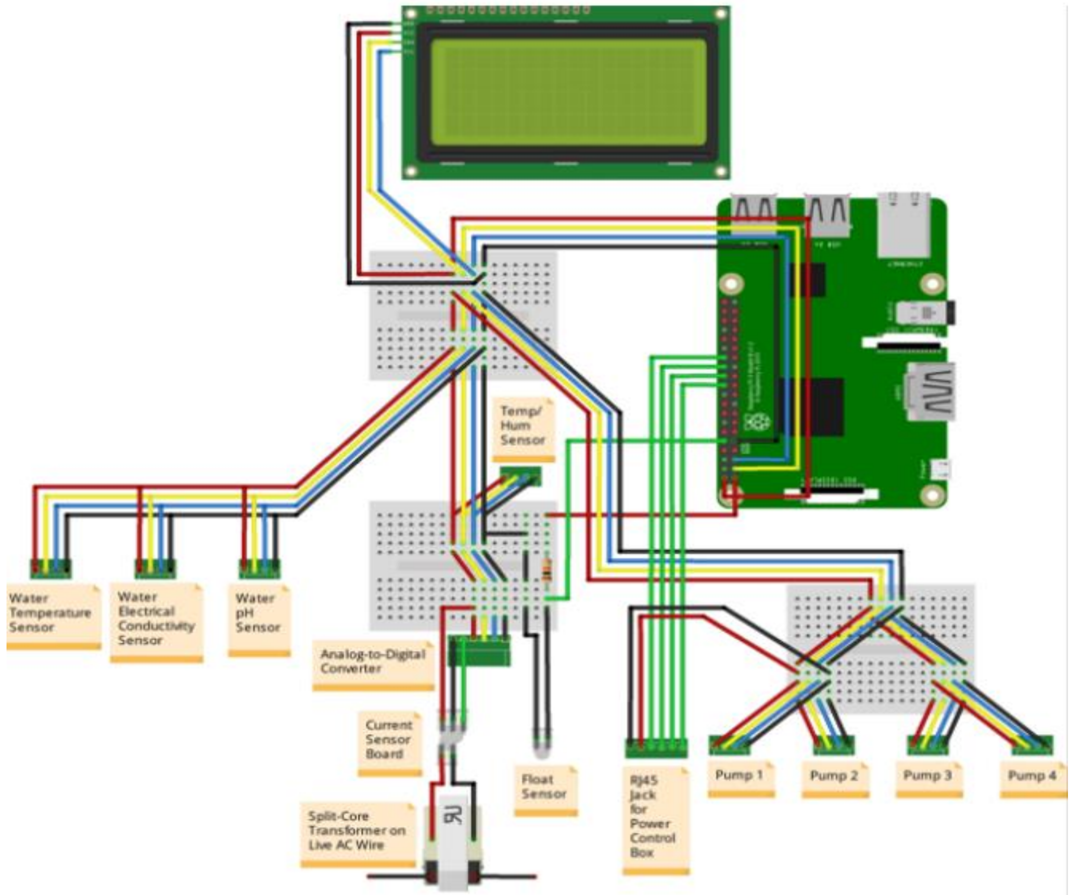


Fig. 3.11 Schematic connection of different components

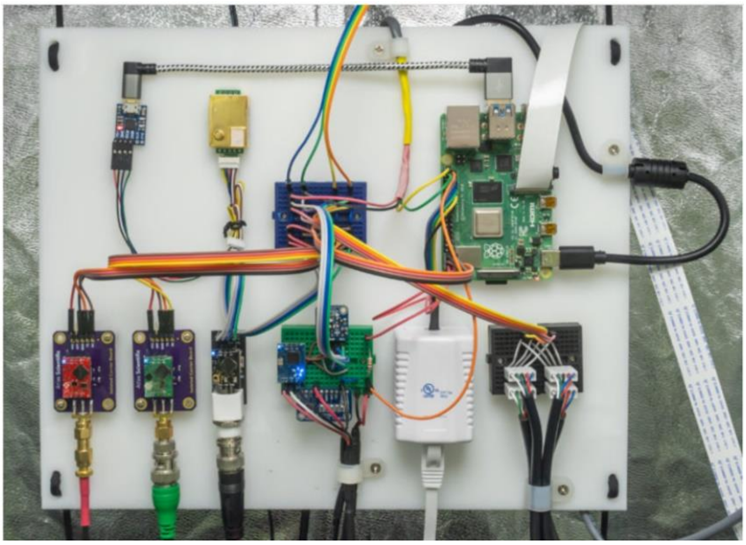


Fig. 3.12 complete connections of components with Raspberry Pi

Connecting the float switch

The float sensor is used to detect when the water level is high or low. To build this circuit Connect a GPIO pin, a ground pin, and a 3.3-volt pin from the Raspberry Pi to their own terminal strips on a breadboard. Connect the GPIO terminal strip to the ground terminal strip on the breadboard using a 10k resistor to pull the GPIO connection low. Connect the float switch's one end to the GPIO terminal strip and the other end to the 3.3-volt strip. Figure 3.13 below shows the connection of float sensor [54].

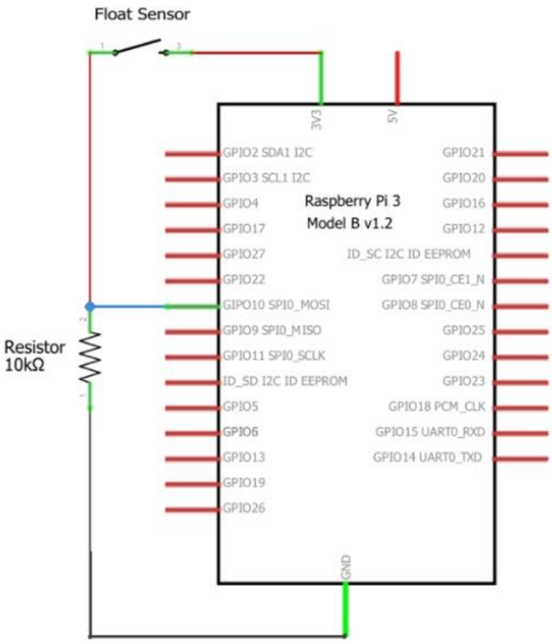


Fig. 3.13 Float sensor wiring schematic

Connecting the RJ45 surface mount jack

An RJ45 (Ethernet) surface mount jack will connect the control box to the control panel, which will then connect to ground, 5-volt, and four GPIO pins on the Raspberry Pi. The power control box will be powered and triggered by these connections, with each GPIO pin switching a relay. The Raspberry Pi's ground and 5-volt pins should be connected to the relay modules' GND and VCC, respectively, and each GPIO pin to each relay module's channel. The RJ45 jack on the control panel can be connected to the RJ45 connector on the power control box using a short Ethernet cable once the power control box is built [54].

Liquid solution dispensing

As shown in Figure 3.14 and Figure 3.15, small volumes of acid (lowers pH), base (raises pH), and nutrient A and B solutions (raises electrical conductivity) will be dispensed by four peristaltic pumps to modify the water chemistry. To reduce hose length and allow four solution tanks below the pumps, the pumps must be situated near to the water reservoir [54].

Fig. 3.14 Liquid Solution Dispenser

Fig. 3.15 Dispenser feed water tank

sensor sample reservoir

A sample reservoir was built to divert a small amount of water from the main reservoir to be measured by the water sensors. This is done in order to sub-sample the main water reservoir, which will protect our sensors from the immediate effects of high pH and electrical conductivity swings that can occur when the pumps are dosing solutions as shown in Figure 3.16 [54].

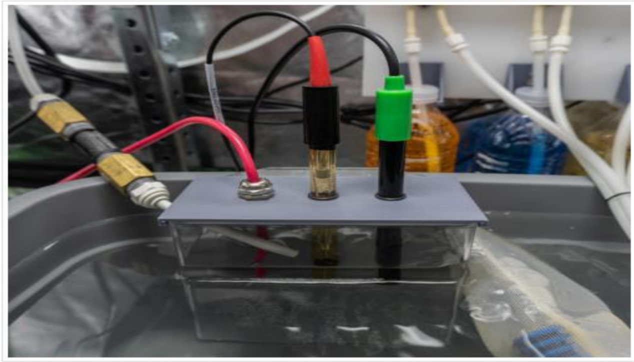


Fig. 3.16 sensor sample reservoir

water flow sensing

A water flow meter can be simply installed on the water line that feeds the sample reservoir and is important for determining whether the pump is working properly (and notifying you when it is not) [54].

electrical current sensing

We'll use a transformer to measure one wire of the main alternating current (AC) power cord that powers the system in order to determine how much electrical current it consumes. The transformer will proportionally convert the AC current to a DC voltage. With an ADS1115 analog-to-digital converter attached to the Raspberry Pi, this DC voltage will be converted to a digital signal. The software will then be able to determine the amount of current utilized over time in Amps using this voltage [54].

Power control box

The power control box will allow the Raspberry Pi's GPIO pins to safely switch AC devices like grow lights, exhaust fans, humidifiers, and other devices using the 3.3-volt DC signals that exist from GPIO pins. Two types of relays will use mechanical relay and Solid-state relay. mechanical relay Mechanical relays can turn on or off the power to another device, such as a switch. When given a small quantity of power, mechanical relays will switch. This allows high-power circuits to be controlled by low-power devices. To open or close a circuit, mechanical relays use an electromagnetic coil. When current flows through the input and energizes the coil, a small magnetic field is created, which either pulls the switch arm away from the other contact, or pushes it down to close the switch, depending on how the switch is constructed. Because the control (input) and load (output) end of the relay are not electrically connected, it also acts as an isolator. This gives you the ability to protect the device you're using. Mechanical relays will be used in this project for processes requiring high current loads and slow switching, such as grow lights that turn on and off just a few times each day. Solid state relays (SSRs) turn on or off the power to another device. Internally, the control inputs are linked to an LED that shines across an air gap to light sensors as shown in Figure 3.17. The light sensor is connected to the transistors, which open and close to deliver power to the relay's load. When a transistor is closed, current can freely flow through the relay, connecting the load and power supply. When a transistor is open, almost all current is blocked, which disconnects the load from the power supply. Mechanical Relays and SSRs both do the same work, however SSRs have a few advantages. During operation, SSRs create less electromagnetic interference than mechanical relays. SSRs are faster than mechanical relays in turning on and off which mechanical relays take 10ms to turn on and off, whereas SSRs take 1ms. As a result, SSRs are used in applications where significantly faster switching is required, such as heating and humidity control (multiple switches per minute) or pulse-width modulation (PWM) (multiple switches per second). Figure 3.18 shows the mechanical circuit of relay [54].

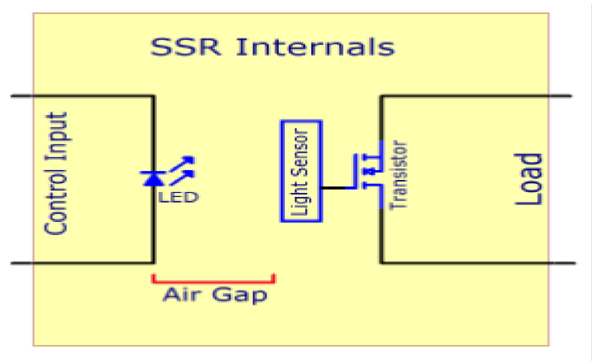


Fig. 3.17 Solid state relays (SSRs)

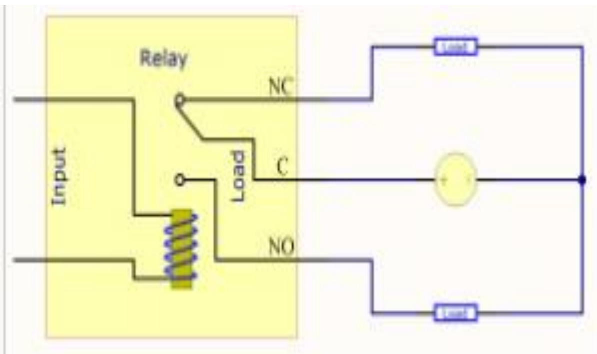


Fig. 3.18 mechanical relay

3.4 Hardware components

The implementation of intelligent based Hydroponics system involves hardware components which are outlined below.

3.4.1 Microcontrollers

In order to make the hydroponic system automated there must be microcontrollers which responsible for control the different aspects of the system, so the following two components support this requirement.

Raspberry pi

Raspberry pi is the microcontroller which responsible for implementing the Neural Network (NN) Algorithm which receive data (readings) from Arduino and feed it to NN which use and process it in order to come out with decisions and control orders which sent back to Arduino in order to perform it. Still not sure which raspberry pi microcontroller to use, but the choices are narrowing between the Raspberry Pi 3 B+ and the Raspberry Pi 4. Both Raspberry 4 and the previous Raspberry Pi 3B+ models are great choices. Although the faster processor and higher levels of RAM provided on Raspberry Pi 4 with 1GB, 2GB, or 4GB LPDDR4-3200 SDRAM (depending on model), in the other hand, Raspberry Pi 3B+ provides 1GB LPDDR2 SDRAM which make pi4 much more versatile desktop computer. It also supports more demanding software, such as Scratch 3 (which only runs on the newer Raspberry Pi 4). The shape of raspberry pi 3B+ is illustrated in figure 3.19 and Raspberry pi 4 is shown in figure 3.20 [72].

Fig. 3.19 raspberry pi 3B+

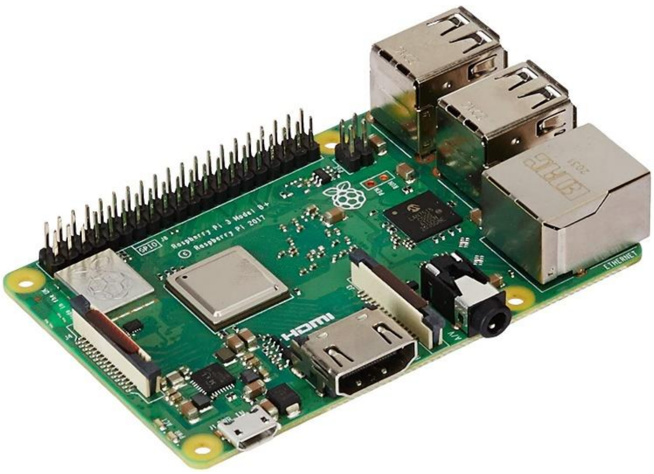


Fig. 3.20 Raspberry pi 4

Arduino

Arduino is the microcontroller which responsible for collecting data (readings) from different sensors such as water temperature sensor or light intensity sensor which communicate with them in order to send it to raspberry pi which process it and transmit back actions and control orders which Arduino is going to perform it such as turn on or off light to control light intensity or turn on or off water cooler to control water temperature. Still not sure which Arduino to use as there is too many types of Arduino boards, but the choices are narrowing down between Arduino UNO and Arduino Mega. The key to solve this dilemma is presented in how many sensors and actuators will be used and accordingly, it reflects on the number of ports on the board, the speed of response, and memory needed. Both Mega and Uno have a clock speed of 16MHz but the memory and storage space is different. Mega has a flash memory of 256kB while that of Uno is 32kB. Mega has a large number of pins among both. There are 54 digital pins used and 16 analog pins used in the system. Uno has only 14 digital pins and 6 analog pins. Among the digital pins, 15 have PWM in Mega and 6 in Uno. Both come with a through-hole to fit into the system. So, Arduino mega could be a better choice, but this decision still in progress. Figure 3.21 depicts the shape of the Arduino ONU, whereas Figure 3.22 illustrates the shape of the Arduino Mega [73].

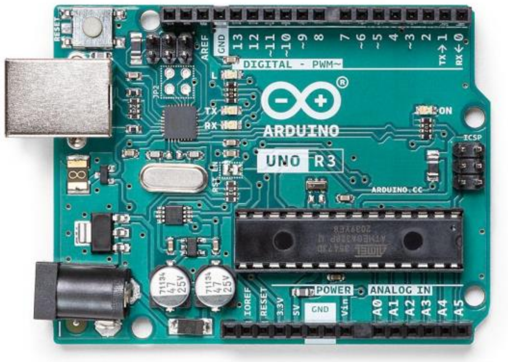


Fig. 3.21 Arduino ONU

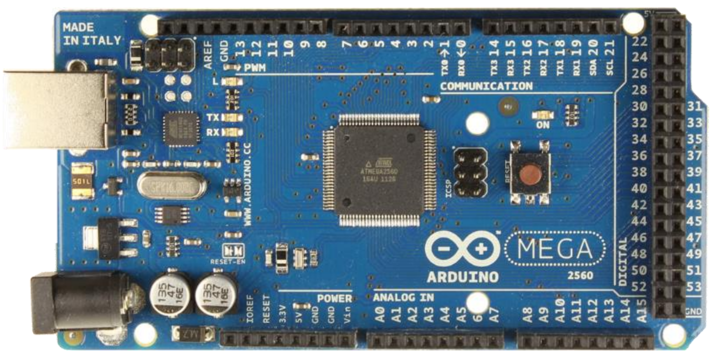


Fig. 3.22 Arduino Mega

3.4.2 Sensors

In contemplation of be able to measure aspects (parameters) from the surrounding environment and tanks used, several types of sensors need to be used to perform these tasks and this will be illustrated in this part as follows.

Air temperature and humidity sensor

The sensor which responsible for measuring Air humidity and temperature as it attached and communicate with Arduino using I²C bus interface (communication protocol) in order to sends Air humidity and temperature readings and depends on these readings action will be taken such as turn on or off fan. There are too many types and shapes of Air temperature and humidity sensors such as DHT22 and DHT11. The DHT22 is the more expensive version which obviously has better specifications. Its temperature measuring range is from -40°C to +125°C with $\pm$0.5 °C accuracy, while the DHT11 temperature range is from 0°C to 50°C with $\pm$2 °C accuracy [74] [75]. There is also HTU21D-F with cost between DHT22 and DHT11 and temperature measuring range is from 30°C to 90°C with $\pm$1 °C accuracy [76]. The following 3 figures which are figures 3.23, 3.24, and 3.25 shows DHT11, DHT22, and HTU21D-F respectively.

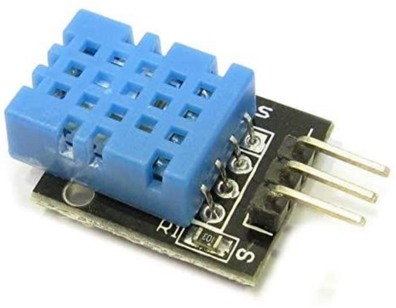


Fig. 3.23 DHT11

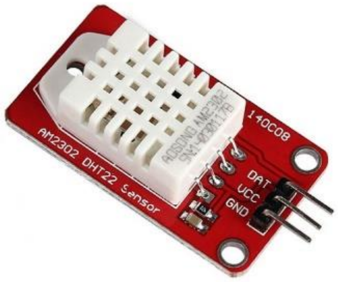


Fig. 3.24 DHT22

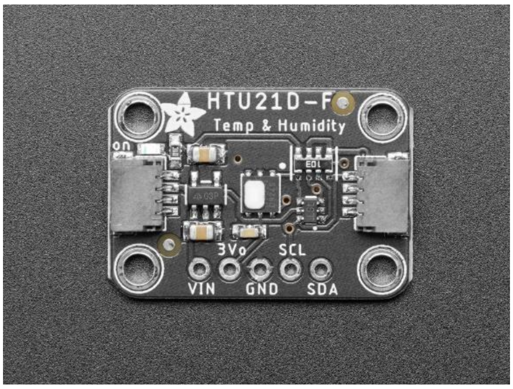


Fig. 3.25 HTU21D-F

Water Temperature Sensor

The sensor which responsible for measuring water temperature as it attached and communicate with Arduino using 1-wire bus interface (communication protocol) in order to send water temperature readings of water tank which feed hydroponic system with water with nutrients dissolved in it needed to grow plants. There are 2 kind of water temperature sensors are known in handling hydroponic system projects which are DS18B20 and PT1000. The DS18B20 temperature sensor is quite accurate and does not require any external components to operate. It can measure temperatures from -55°C to + 125°C with an accuracy of ± 0.5°C [77]. On the other hand, The PT1000 will need some conditioning of its value (resistance), it looks easy to mount onto various surfaces. It has no accuracy to state, as you will have to calibrate it against a known reading, the final temperature will depend on circuit parameters used to read it. The most common type (PT1000) has a resistance of 1000 ohms at 0 °C and 138.4 ohms at 1000 °C [78]. On the price side, PT1000 is way expensive than DS18B20 as it includes more elements than DS18B20. Figure 3.26 and Figure 3.27 illustrate the shape of DS18B20 and PT1000 respectively.

Fig. 3.26 DS18B20

Fig. 3.27 Atlas Scientific PT-1000 Temperature Kit with 50mm Thermowell

Water level sensor

It is the sensor which uses to measure level of water in tanks because when the water decreases below a certain level, it sends a signal to the Arduino which is communicate with it using 1-wire bus interface (communication protocol) to transmit signal to turn on the water pump in order to let water into the tank and turn off the pump when the water reach to a certain level in the tank. Level sensors can be broken into two classifications which are point level sensors and continuous level sensors. Point level sensors only indicate whether the sensing point or level, while continuous level sensors measure level within a specified range and determine the exact amount of substance in a certain place. In our project Point level sensors may be helpful and enough, so there are five types of point level sensors, but there are two of them that can handle our project in the field of measuring water level which are conductivity level sensor and capacitance level sensor. Figure 3.28 depicts the shape of conductivity level sensor, whereas Fig. 3.29 illustrates the shape of capacitance level sensor [79].

Fig. 3.28 conductivity level sensor

Fig. 3.29 capacitance level sensor

Electrical Conductivity (EC) Sensor

The conductivity of a solution is measured by the EC sensor. This sensor is used in hydroponics farming to help us grow nutrient-rich, healthier plants by measuring nutrients, salt, and other contents of the solution. Accordingly, we can adjust the elements in solution. This sensor is attached to Arduino by using I²C bus interface (communication protocol) to send the EC readings of nutrient solution in order to make an action such as adding some nutrient A or B to the nutrient solution with defined amounts. There are two recommended high quality EC sensors used in the field of hydroponics which are Atlas-Scientific-EC-KIT-1.0 and DFR0300 as shown in Figure 3.30 and Figure 3.31 respectively. EC-KIT-1.0 has accuracy of ± 2%, temperature range 1 - 110°C, and Supply voltage range 3.3V − 5V, in the other hand DFR0300 has accuracy of ± 5%, temperature range 0 - 40°C, and Supply voltage range 3V − 5V [82][83]. In the matter of price, EC-KIT-1.0 is way expensive in comparison to DFR0300.

Fig. 3.30 DFR0300

Fig. 3.31 EC-KIT-1.0

PH (potential of hydrogen) Sensor

When it comes to measuring the pH of water, a pH sensor is one of the most important tools. This sort of sensor can detect alkalinity and acidity levels in water and other solutions. pH sensors can ensure a product's safety and quality, as well as the processes that take place in a wastewater or manufacturing plant. This sensor is attached to Arduino by using I²C bus interface (communication protocol) to send the PH readings of nutrient solution in order to make an action such as adding some acid or alkali to the nutrient solution with defined amounts to increase or decrease alkalinity or acidity levels of the nutrient solution. There are two recommended high quality PH sensors used in the field of hydroponics which are EZO-pH and SEN0161-V2 as shown in Figures 3.32 and 3.33 respectively. EZO-pH has accuracy of ± 0.002%, temperature range (-5) − 99°C, and Supply voltage range 3.3V − 5V, in the other hand DFR0300 has accuracy of ± 0.1%, temperature range 5 - 60°C, and Supply voltage range 3.3V – 5.5V [84][85]. In the matter of price, EZO-pH is way expensive in comparison to SEN0161-V2.

Fig. 3.32 EZO-pH

Fig. 3.33 SEN0161-V2

3.4.3 Actuators

When thinking about the possibility of implement orders come from Arduino which was issued on the basis of different measurements came from various sensors, there should be some actuators which are responsible for adjust different parameters that control environment of hydroponic system and this will be clarify in this part as follows.

Pumps

Pumps are very important and essential in applying the concept of automation in hydroponics as it can be programmed by interfacing it with relay in order to keep tank parameters (EC and PH) stable and removes the need for mixing supplements daily. There are four pumps to connect them to nutrient A, nutrient B, acid, and alkali, each and every one of them in different storage bucket. There is also water pump to supply tank by water when the water in the tank drops below a certain level. There are two recommended high-quality pumps used in the field of hydroponics which are EZO-PMP and DFR0523 as shown in Figures 3.34 and 3.35 respectively. EZO-PMP has accuracy of ± 1%, flow rate range 0.5ml to 105ml/min, and 2 Supply voltage range, first one is 12V − 24V and used to drive motor and second one is 3.3V − 5V and used to drive control system, in the other hand DFR0300 has accuracy of ± 0.1%, flow rate is less or equal to 45ml/min, and 2 Supply voltage range, first one is rated voltage 6V and used to drive motor and second one is 5V − 6V and used to drive control system [86][87]. In the matter of price, EZO-PMP is way expensive in comparison to DFR0300.

Fig. 3.34 EZO-PMP

Fig. 3.35 DFR0300

Hydroponic Exhaust fan

In bigger or poorly ventilated hydroponic gardens, a hydroponic exhaust fan is a ventilation device used to maintain ideal temperatures and humidity levels. The size and capacity of the fan you choose is determined by a variety of factors, including the size of the area, the types of plants you're growing, and the lighting you're using. It could be the normal exhaust fan such as the one used in kitchens or Exhaust fan specially used for hydroponics as shown in Figures 3.36 and 3.37 respectively [90][91]. The difference is the size of normal exhaust fan which is bigger and less expensive than hydroponic exhaust fan.

Fig. 3.36 normal exhaust fan

Fig. 3.37 hydroponic exhaust fan

Relays

The most crucial aspect of our project is getting a relay switch to kick on and power on a certain area of our design if we want to have an autonomous system where parts of our design do not have to be controlled manually by a user. A normal plug outlet was used to power an exhaust fan. We needed a way to turn the fan on and off on demand. In order to do this, we found the Relay switch as shown in Figure 3.38. A relay is a low power electromagnetic switch which is used to turn ON and turn OFF a circuit. It is used to control power goes to different pumps, LED bulbs, and exhaust fan [18].

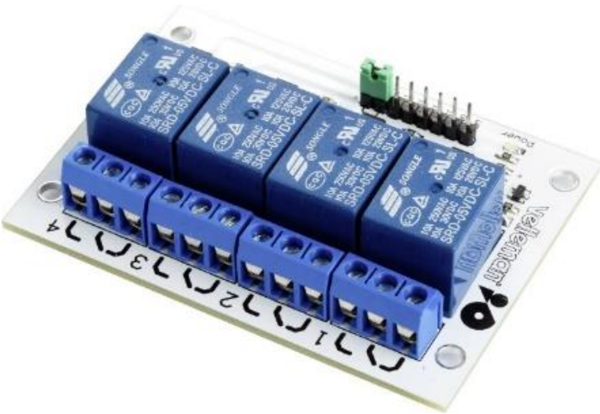


Fig. 3.38 4 Relay switches

Chapter 4
Proposed system

4.1 Introduction

This chapter introduces the required analysis for the proposed system. the coming sections have the block diagram and flowchart of the system, hardware and software analysis. It explains the testing of different algorithms used to monitor and control the parameters. By the end of this chapter, the implementation phase of the proposed system will be ready to start an operational mode for the resultant prototype.

4.2 Block Diagram

4.2.1 Controlling part

It divided into two parts, embedded system and AI. Embedded system includes water sensing sensors such as (water temperature sensor, water electrical conductivity sensor, water PH sensor and float switch sensor) and air sensing sensors such as (temperature sensor and humidity sensor).AI is responsible for applying machine learning model and sending suitable actions to Arduino to execute.

4.2.2 Tray

An NFT hydroponic system has a simple design. Water is pushed up from a reservoir into fluid channels, which are tilted at a little angle to allow gravity to flow the water from the high end to the low end, and then back to the reservoir. Plants are planted in holes cut in the channels' tops and supported by a growing substrate. The substrate serves as a container for water absorption and/or plant support. The roots of the plants grow into the fluid that flows across the channels' bottoms as they grow.

4.2.3 Water and nutrient tanks

Water tank is connected to nutrient tank through four peristaltic pumps these four peristaltic pumps will dispense small volumes of acid (lowers pH), base (raises pH), and nutrient A and B solutions (raises electrical conductivity) to modify the water chemistry.

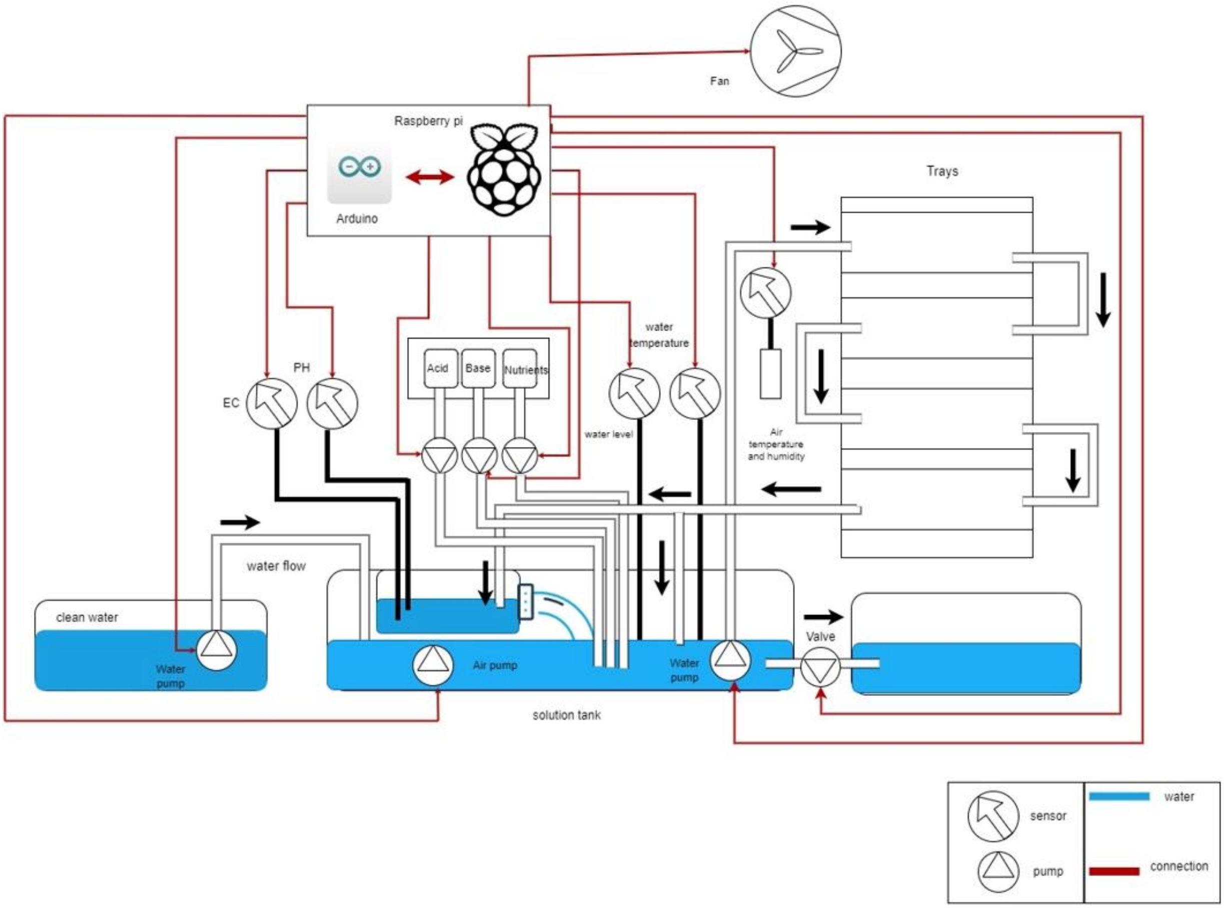


Fig. 4.1 Block Diagram

4.3 Flow Chart

As you can see from the following figure, this is our flow chart which is a continuous system means when it starts there is no end of it maybe there is an end in the harvest time. This is a very important point as if our system stops working then there is no water mixed with nutrients (solution) go throw tubes in order to feed planets and no controlling on the temperature and humidity of the greenhouse which means crop loss. So, in order to save our system from this disaster there must be a backup plan such as using an electrical generator at the situation in case of power outage or make big solution pump which carry solution to trays works individually connected to adaptor which means not connected or controlled by Arduino. Let's talk about our flow chart block by block.

Firstly, when our system starts, there must be an initialization to different sensors such as temperature and humidity sensor and water level and temperature sensors, Arduino, Raspberry pi, and the connection between them. Secondly, make sure that every part of the system and different connections are successfully working. If there is an issue or problem, we must first fix it before going throw next steps. So, if everything works fine, let's go to the next block which is data gathering procedure using Arduino. It's very important to know that from this point every next process is working simultaneously.

So, as one of the Arduino responsibilities which is receiving readings from different sensors. It is then going to send it to raspberry pi throw the connection between them which is a serial communication over USB cable using UART serial protocol. As the Raspberry pi receive readings from Arduino, it is going to do two tasks which are store these readings in excel sheet and use these readings as inputs to let it go throw machine learning (ML) model as it is going to process it and finally come up with label which indicates decisions (output of ML model).

Next raspberry pi is going to send label (output data) to Arduino throw USB cable between them. Arduino is going to take these orders and apply them on the different actuators such as water chiller or heater. Let's take an example to clarify the idea, EC sensor gives us readings of decreasing EC for lettuce under 1.2 mS/cm, so Raspberry pi is going to process this information and come up with a decision of turning on pump of nutrient solution to be add to the water in order to increase EC value and adjust it to the desired range. After applying actions on different actuators, Arduino is going to show these readings with decisions took on different actuators on LCD in order if there is someone in the greenhouse, he/she can see directly the one-time readings from different sensors and then send these decisions in string format back to raspberry pi then raspberry pi is going to store these decisions with readings in the same excel sheet and after that store excel sheet in database .As we mentioned before our system is continuous so all of these steps are going to be done again start from Arduino is going to gather readings from different sensors again, but it is important to know that all these processes take place at the same time (simultaneously).

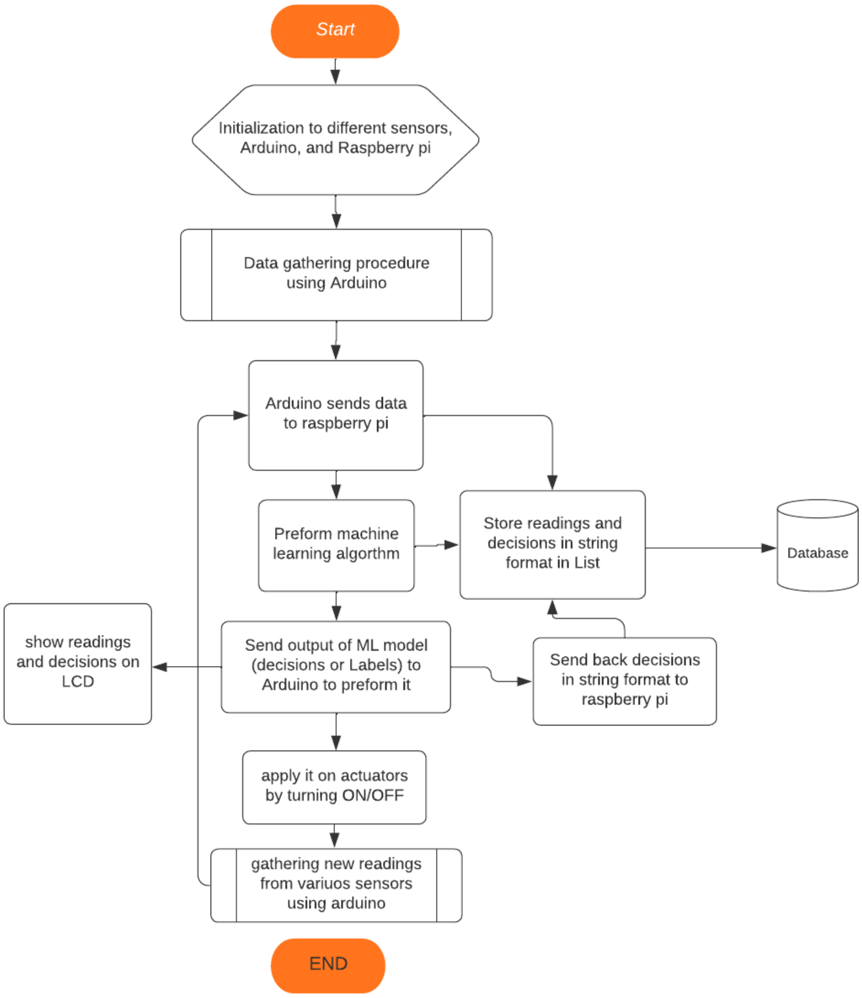


Fig. 4.2 Flow Chart

4.4 Software Analysis

4.4.1 Data Collection

There are 6 data variables taken from our initial setups of hydroponic system namely pH, TDS, farm air temperature, farm humidity, temperature reservoir, and level reservoir. Data is collected using sensors. the sensors used in this study were Ultrasonic Distance Sensor - HC-SR04, PH 4502C Liquid PH Value Detection Sensor, DFROBOT Gravity: Analog TDS Sensor, Air temperature and humidity DHT22 sensor, and DS18B20 sensor. Arduino is used to collect all 6 sensor measurements and send them all to the raspberry pi 3B+ through USB cable using serial communication.

4.4.2 Labeling system

The dataset for classification algorithm was created using data obtained from Thingspeak, tagged using lettuce parameters, and it was 6421 samples which we used to train and test our ML model. Data labelling refers to 3 readings which are PH, PPM, Air-temperature that have been taken from PH sensor, TDS sensor, DHT22 respectively which is the first phase that we are going to apply machine learning algorithm on them. Each of these sensors has 3 probability conditions: normal if the sensor values are between parameters ranges, low if the sensor values are lower than parameters ranges, and high if the sensor values are higher than parameters ranges. Then, if the sensors are 3 and the probability conditions are 3 as well, the nutrient system condition should have 3^ (3) = 27 labels probability classification, which we specify using the table 4.1 below. Figure 4.3 shows simple of data used to train our ML model.

Label	Condition	Action
0	all normal	PH +&– pumps, PPM A&B PUMPS, Water Pump, and fan are down
1	all high	- PH + pump and PPM A&B PUMPS are down - Water Pump, PH – pump, and fan are up
2	all low	- PH – pump, fan, and Water Pump are down - PH + pump and PPM A&B PUMPS are up
3	PH & PPM normal & Temp low	PH +&– pumps, PPM A&B PUMPS, Water Pump, and fan are down
4	PH & PPM normal & Temp high	- PH +&– pumps, PPM A&B PUMPS, and Water Pump are down - fan is up
5	PH & Temp normal & PPM low	- PH +&– pumps, fan, and Water Pump are down - PPM A&B PUMPS are up
6	PH & Temp normal & PPM high	- PH +&– pumps, fan, and PPM A&B PUMPS are down - Water Pump is up
7	Temp & PPM normal & PH low	- PH – pump, fan, Water pump, and PPM A&B PUMPS are down - PH + pump is up
8	Temp & PPM normal & PH high	- PH + pump, fan, Water pump, and PPM A&B PUMPS are down - PH – pump is up
9	PH normal & PPM & Temp low	- PH +&– pumps, Water Pump, and fan are down - PPM A&B PUMPS are up
10	PH normal & PPM & Temp high	- PH +&– pumps and PPM A&B PUMPS are down - Water Pump and fan are up
11	PH normal & PPM high & Temp low	- PH +&– pumps, PPM A&B PUMPS, fan are down - Water Pump is up
12	PH normal & PPM low & Temp high	- PH +&– pumps and Water Pump are down - PPM A&B PUMPS and fan are up

13	PPM normal & PH & Temp low	- Water Pump, PPM A&B PUMPS, PH – pump, fan are down - PH + pump is up
14	PPM normal & PH & Temp high	- Water Pump, PPM A&B PUMPS, and PH + pump are down - fan and PH – pump are up
15	PPM normal & PH high & Temp low	- Water Pump, PPM A&B PUMPS, fan, PH + pump are down - PH – pump is up
16	PPM normal & PH low & Temp high	- Water Pump, PPM A&B PUMPS, and PH – pump are down - PH + pump and fan are up
17	Temp normal & PH & PPM low	- fan, Water Pump, and PH – pump are down - PH + pump and PPM A&B PUMPS are up
18	Temp normal & PH & PPM high	- fan, PH + pump, and PPM A&B PUMPS are down - PH – pump and Water Pump are up
19	Temp normal & PH high & PPM low	- fan, Water Pump, PH + pump are down - PH – pump and PPM A&B PUMPS are up
20	Temp normal & PH low & PPM high	- fan, PH – pump, and PPM A&B PUMPS are down - PH + pump and Water Pump are up
21	PH high & PPM & Temp low	- fan, PH + pump, and Water Pump are down - PH – pump, and PPM A&B PUMPS are up
22	PH low & PPM & Temp high	- PH – pump, and PPM A&B PUMPS are down - fan, PH + pump, and Water Pump are up
23	PPM high & PH & Temp low	- fan, PH – pump, and PPM A&B PUMPS are down - PH + pump and Water Pump are up
24	PPM low & PH & Temp high	- PH + pump, and Water Pump are down - fan, PH – pump, and PPM A&B PUMPS are up

	A	B	C	D
1	PH	PPM	Air_temp	Label
2	5.92	670.22	24.22	0
3	5.89	665.17	24.76	0
4	5.82	649.59	24.45	0
5	5.77	638.23	23.67	0
6	5.71	630.73	24.12	0
7	5.74	625.55	23.55	0
8	5.67	618.46	24.43	0
9	5.58	610.57	23.61	0
10	5.51	604.66	23.45	0

Fig. 4.3 sample of data gathered from sensors used to train out ML model

4.4.3 Machine Learning model

It wasn't easy to decide which machine learning (ML) algorithm to use as there are various types of ML algorithms such as K-Nearest Neighbors, Logistic Regression, Decision Tree, Random Forest, Support Vector Machines, etc. Selection scale for which ML algorithm to use is by applying hit and trial method with all of these algorithms one by one, but we only applied it only on K-Nearest Neighbors, Decision Tree, and Random Forest and compare results, the model which gives the best result such as accuracy test and classification report test is the model which we are going to use.

K-Nearest Neighbors

K-Nearest neighbor is a simple ML algorithm that takes into consideration all the available cases or labels and classifies the new data based on a similarity measure and based on the only factor K it decides if the new input belong to which class as shown in figure 4.4. It's commonly used to classify a data point based on the classification of its neighbors.

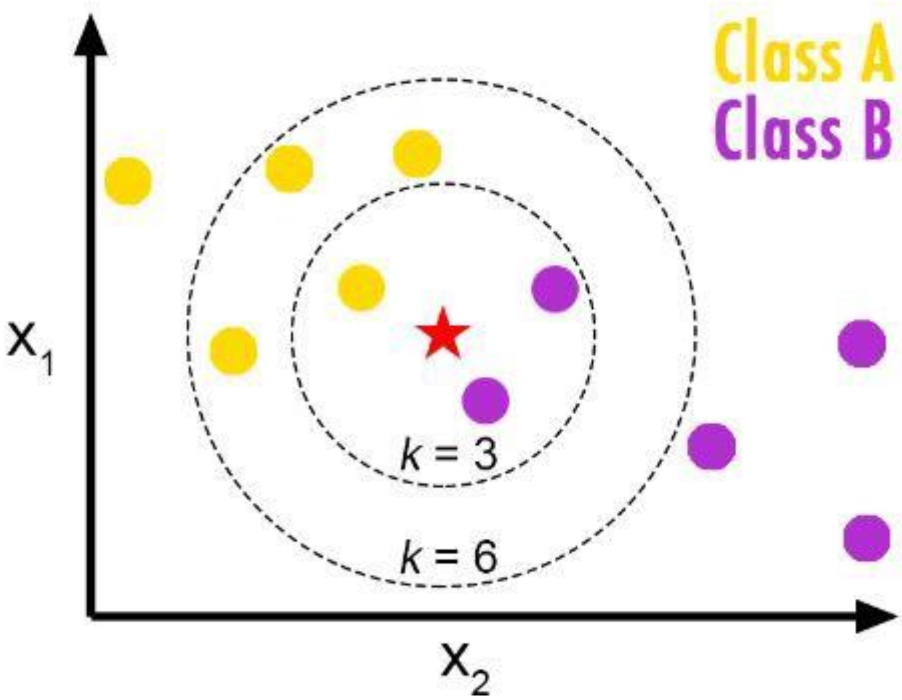


Fig. 4.4 Illustrative example for K-Nearest Neighbor

Decision Trees

The Decision Tree algorithm is part of the supervised learning algorithms family. The decision tree approach, unlike other supervised learning algorithms, may also be utilized to solve regression and classification algorithms. Our ML algorithm is in field of classification, so as shown in figure 4.5, a decision tree classifier looks like a flowchart with the terminal nodes indicating classification outputs/decisions. The purpose of employing a Decision Tree is to develop a training model that can use basic decision rules inferred from prior data to forecast the class of the target variable (training data). We start from the root of the tree when using Decision Trees to forecast a class label for a record. The values of the root attribute and the record's attribute are compared.

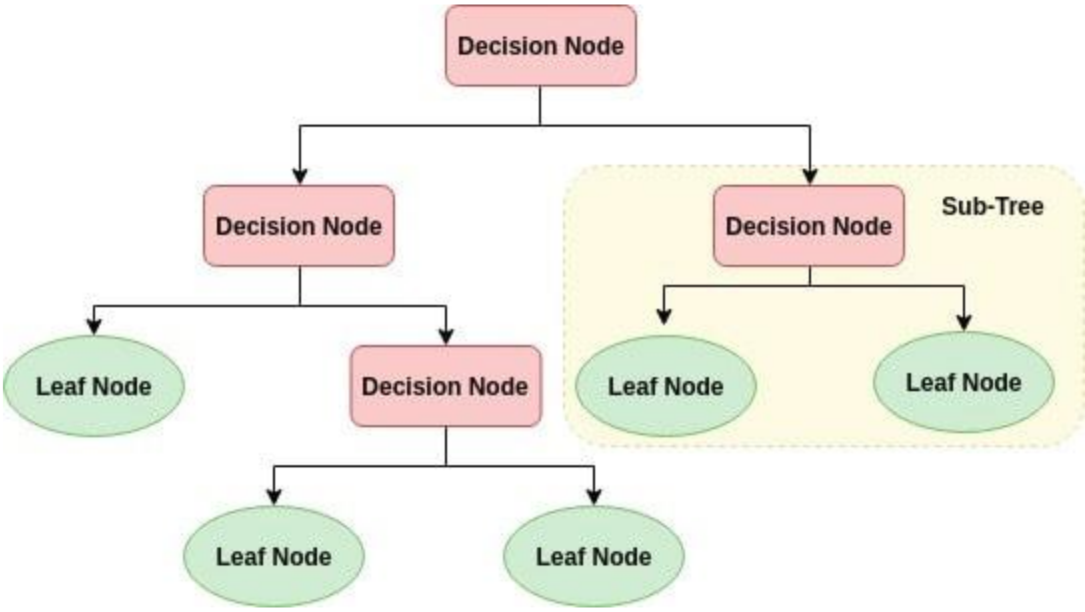


Fig. 4.5 Illustrative example for Decision Tree

Random Forest

Random forest is a supervised learning algorithm. The “forest” it builds, is an ensemble of decision trees which means it follows the same rules and methods to come up with decisions, usually trained with the “bagging” method. The general idea of the bagging method is that a combination of learning models increases the overall result. Decision in a random forest classification is obtained by majority voting of individual trees like shown in figure 4.6. It has some advantages which make better than decision trees which also serve our system. First, as we mentioned it consist of many decision trees and use voting system which means it is most of the times has higher accuracy than decision tree. Second, it can automatically balance data sets when a label is more infrequent than other labels in the data. Finally, random forest is a (mostly) fast, simple, and flexible tool which is very suitable for our system.

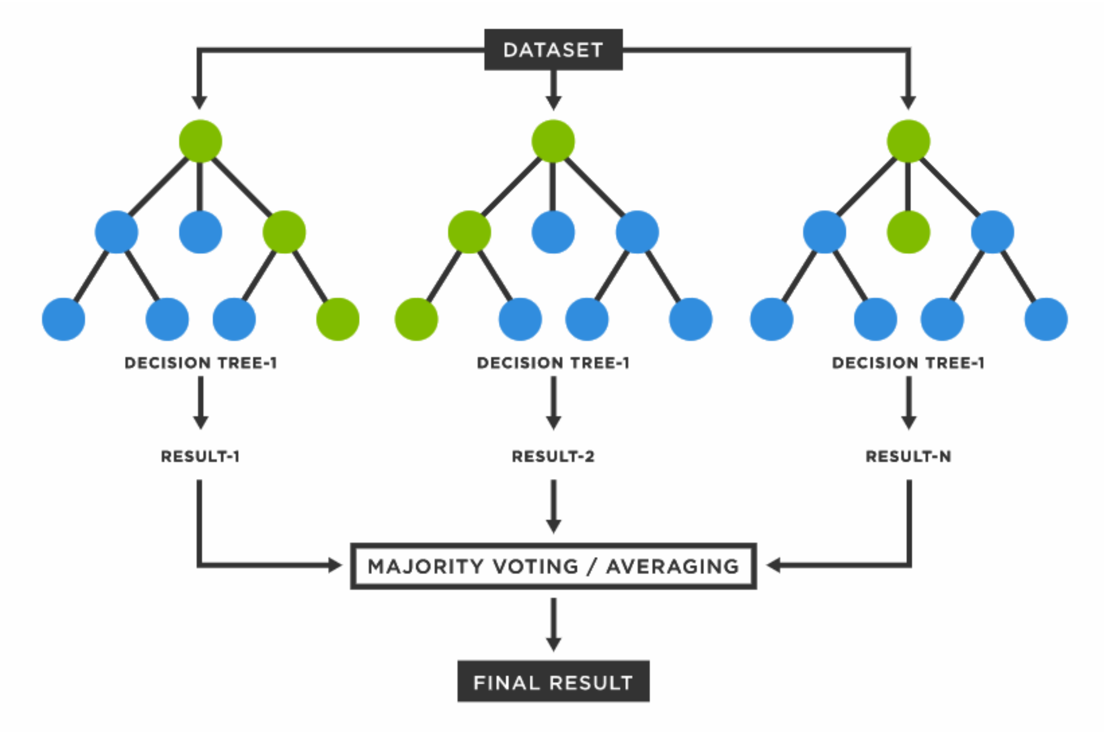


Fig. 4.6 Illustrative example for Random Forest

4.4.4 Software modules

• Arduino IDE: The Arduino IDE (Integrated Development Environment) is an open-source software, which is used to write programs and upload it to the Arduino boards such as Arduino UNO and MEGA. The IDE application compatible with a variety of operating systems, including Mac OS X, Windows, and Linux. It works with the C and C++ programming languages.

• C/C++: The Arduino IDE employs C/C++, however because the physical environment is constrained, not all C/C++ features are available. The Arduino environment includes auxiliary functions to make using the hardware easier, as well as a serial monitor for input and output. We use it to assign readings or measurements from various sensors to variables and by employing serial communication to send them to raspberry pi and also receive labels to apply it on various actuators through if and else statements.

• Python 3.9.7: Python is an open source interpreted language. We have used python3.9.7 which is the latest version of python throughout our project for developing the Random Forest code and also coding the serial communication to the Arduino communicating to the Raspberry Pi.

• NumPy: Open-source library available for python which we are using manipulate readings or measurements from various sensors that stored in data frame.

• Pandas: Open-source library available for python which we are using to convert list that we are using to store readings or measurements came from Arduino through USB cable into data frame that is easier to interact with ML model and manipulate.

• pickle: Open-source library available for python which we are using to read the ML model stored on Raspberry pi to use it to predict action (label) need to be taken by actuators through Arduino.

• serial: Open-source library available for python which we are using to stablish serial communication between Arduino and Raspberry pi to receive various readings or measurements through USB cable (serial communication).

4.5 Hardware Analysis

4.5.1 Schematic Diagram

The following figure 4.7 is the Schematic Diagram of our projects which consists of Arduino Mega, Raspberry Pi 3 Model b+, 5 sensors which are DFROBOT Gravity TDS sensor, DIY MORE PH sensor, DS18b20 Water temperature sensor, DHT22 Air temperature and humidity sensor, and Ultrasonic Water level sensor. There are also 16*2 LCD and 5 pumps for nutrient A and B, Acid, and Base are connected to power supply 12V – 2A and water lifting and water level pump are connected to power supply 12V – 10A all of them connected to Arduino through Relays. All of these components are will explained individually through the following paragraphs.

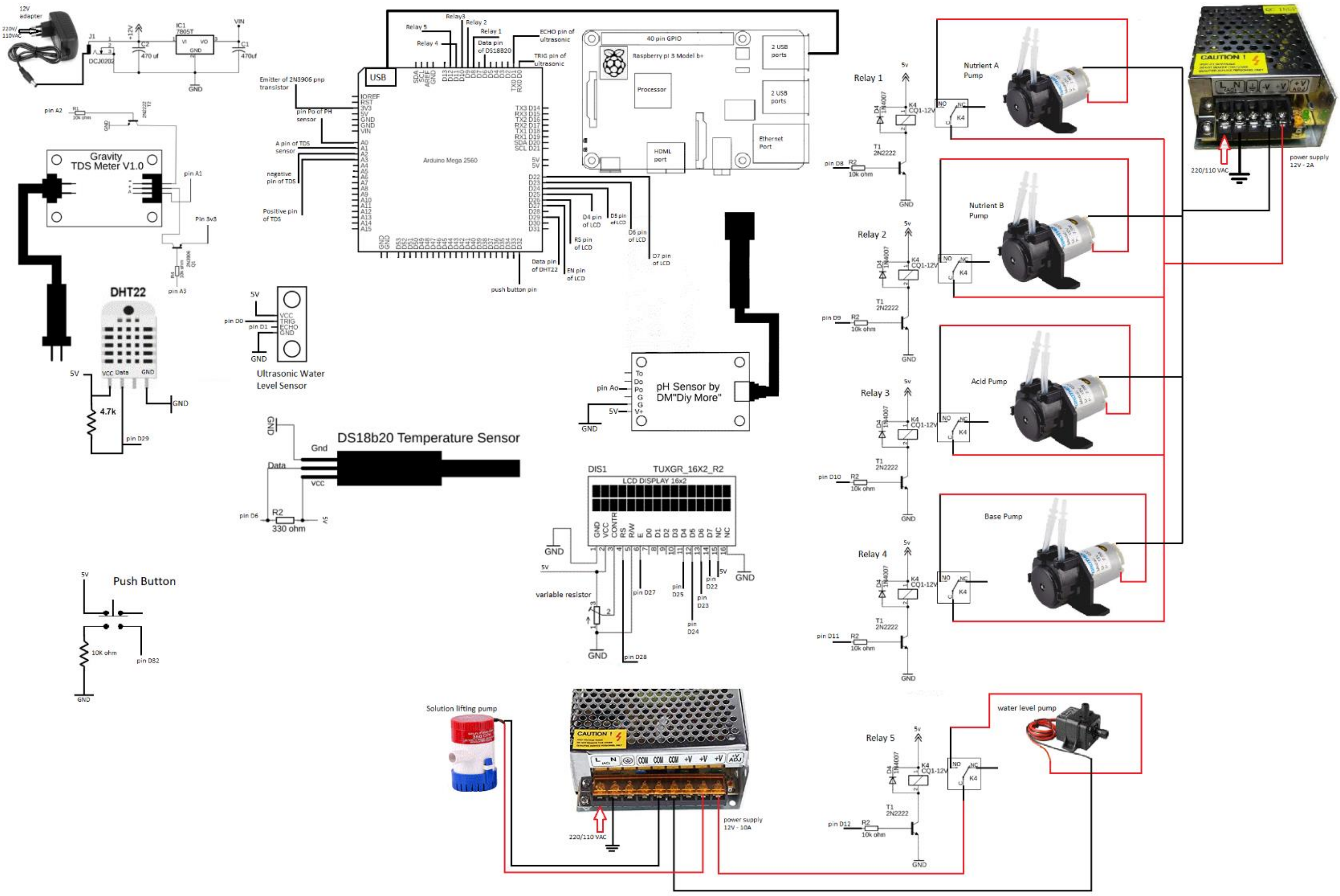


Fig. 4.7 Schematic Diagram

4.5.2 Raspberry Pi 3 Model b+

The Raspberry Pi 3 Model B+ is the most recent product in the Raspberry Pi 3 line with Broadcom BCM2837B0, Cortex-A53 64-bit SoC @ 1.4GHz processor, 1GB LPDDR2

SDRAM memory, 4 USB 2.0 ports, Micro SD port for loading our operating system and storing data, 5V/2.5A DC power via micro-USB connector to power up Raspberry Pi, and there are also other features mentioned in figure 4.9. Raspberry Pi is responsible of sending labels (the output of Random Forest and indicate a specific controlling-decisions to be made by Arduino Mega) which depends on readings collected by the Arduino Mega via UART serial communication protocol through USB cable between them using USB connectors which is shown in figure 4.7. Figure 4.8 shows raspberry pi in schematic diagram.

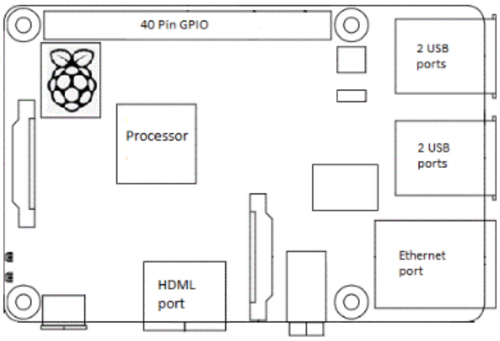


Fig. 4.8 raspberry pi in Schematic Diagram

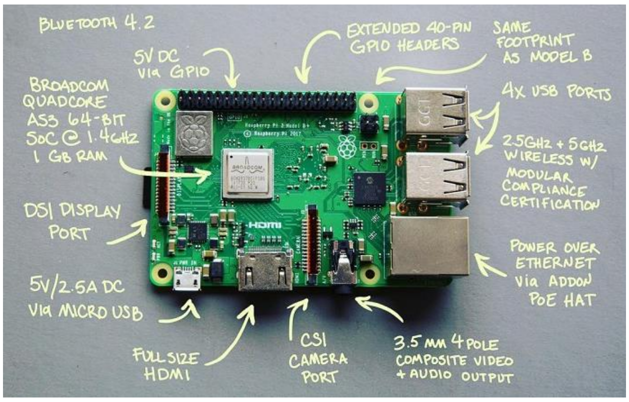


Fig. 4.9 Raspberry Pi 3 Model b+

4.5.3 Arduino Mega 2560

Arduino Mega 2560 is an ATmega2560-based microcontroller board. A 16 MHz crystal oscillator, 54 digital input and output pins (of which 15 can be used as PWM outputs), 16 analogue inputs, 4 UARTs (hardware serial ports), 8KB SRAM, 4KB EPROM, 256KB flash memory of which 8KB used by bootloader, a USB connection, a power jack, an ICSP header, and a reset button are all included as shown in the figure 4.11. All sensors, actuators, and LCD in the system are connected to Arduino which is shown in figure (). The main function of Arduino is collecting of data from sensors then displays them on 16*2 LCD and also sends them to Raspberry Pi through serial USB cable. After that it receives control actions in form of label from Raspberry Pi to turn on and turn off actuators for certain period of time. Figure 4.10 is how Arduino Mega is look like in Schematic Diagram.

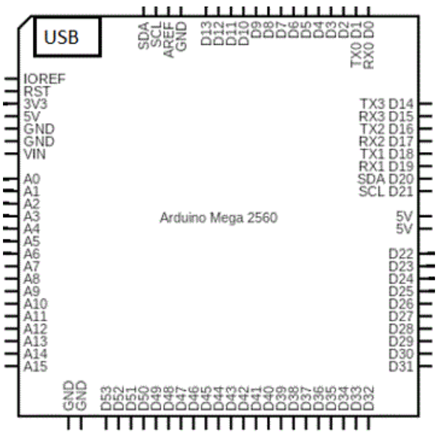


Fig. 4.10 Arduino in Schematic Diagram

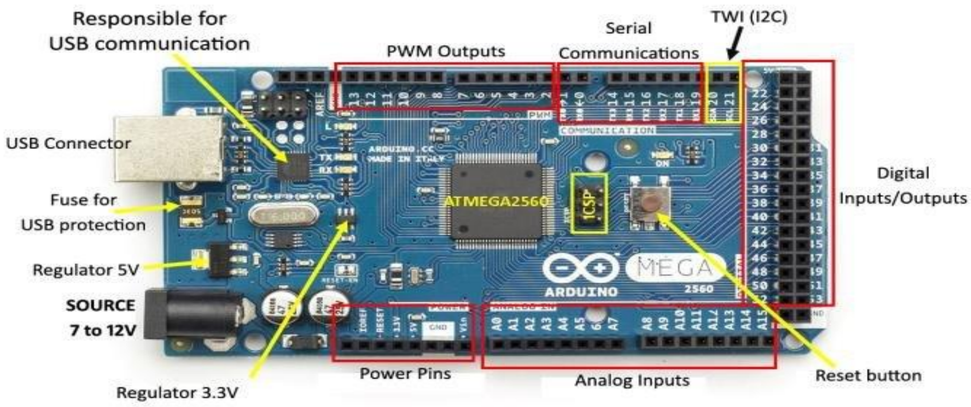


Fig. 4.11 Arduino Mega 2560

4.5.4 DHT22 (Humidity and Air Temperature) sensor

It operates at 3.3 to 6 V which is compatible with Arduino, with operating range 0 - 100% RH for humidity, and from -40 to 80 Celsius for temperature. It's accuracy +-2%RH for humidity and +-0.5 Celsius for temperature. This sensor consists of 4 pins as mentioned in the figure 4.12 below which also indicates how it looks like in schematic diagram. VCC pin to operate the sensor, data pin for sending the data to microcontroller, NC pin which is mostly not used, and GND pin as shown in table 4.2. This sensor is responsible of measuring air temperature and humidity which Data pin is connected to Arduino on digital pin 32. The data collected by this sensor will defines the operation time of cooling fans to decrease the temperature of air.

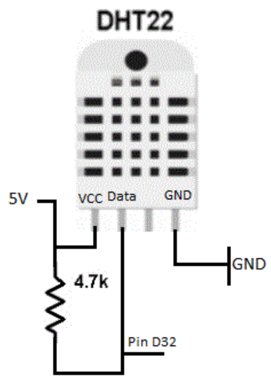


Fig. 4.12 DHT22 in schematic diagram

Table 4.2 DHT22 pins

DHT22 pins	
1	VCC
2	DATA
3	NC
4	GND

4.5.5 16*2 liquid-crystal display (LCD)

There are two modes to display on LCD which are 8-bit mode and 4-bit mode. 4-bit mode is used in the system to decrease number of digital pins used on Arduino. LCD consists of 16 pins as mentioned in the figure 4.14. It is connected to Arduino on digital pins 22,23,24,25,26,27 since it is responsible of displaying data of sensors. Pins 2,3,4,5 are used for displaying data while pins 11,12 are used for register select and enable. Figure 4.13 indicates the connection of LCD with Arduino.

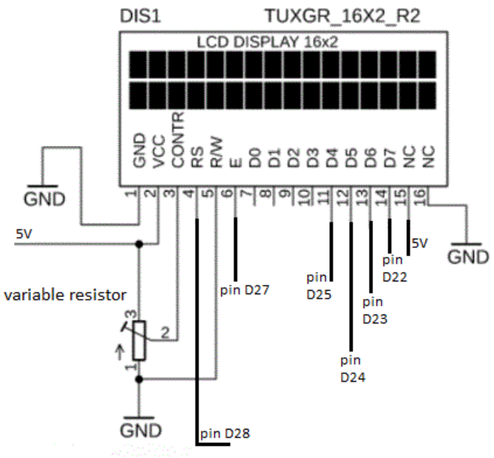


Fig. 4.13 2*16 LCD in schematic diagram

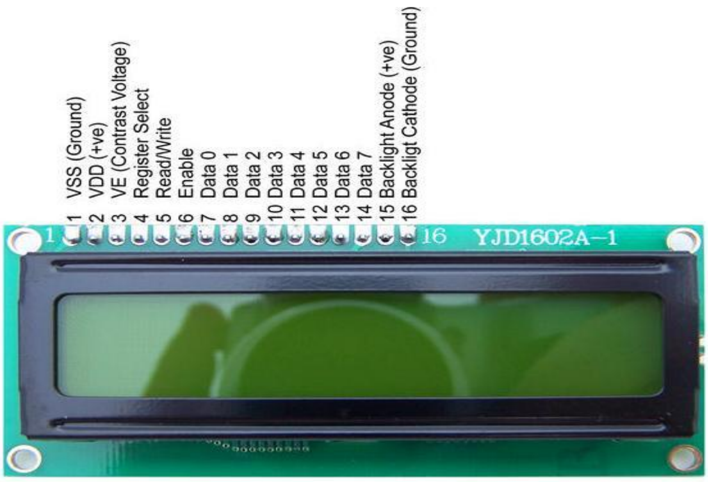


Fig. 4.14 Description of 2*16 LCD

4.5.6 Analog DIY MORE PH sensor

It operates at 3.3 to 5.5 V and exists voltage from 0 to 3 V which is compatible with Arduino. It consists of signal conversion board, PH probe and analog cable as shown in the figure 4.16 below. It has ability to measure PH with accuracy +-0.1 at 25 Celsius. The output signal of PH sensor filtered by hardware circuit has low jitter. Pin Po of PH sensor is interfaced with the Arduino at pin number A0 which is responsible of measuring PH of the water. If PH is low, quantified of acid will be dispensed and if PH is high, quantified of base will be dispensed to adjust PH level of solution. Figure 4.15 indicates the connection of PH sensor with Arduino.

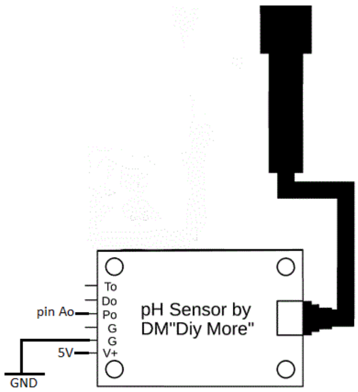


Fig. 4.15 PH sensor in Schematic Diagram

Fig. 4.16 DIY MORE PH sensor

4.5.7 DFROBOT analog TDS sensor

TDS sensor operates at 3.3 to 5 V and exists voltage from 0 to 2.3 V which is compatible with Arduino. It consists of signal transmitter board, TDS probe and analog cable as shown in the figure 4.18. It has ability to measure TDS from 0 to 1000 PPM with accuracy +-10% FS at 25 Celsius. Pin A of TDS sensor is Interfaced with the Arduino at pin number A4 and used to measure the total dissolved solids in water. Which dissolved solids such as salts and minerals in water, increase the conductivity of water. Nutrient A and B solutions will be used to adjust the conductivity of water. According to figure 4.17 which shows the connection between Arduino and DFROBOT Gravity TDS sensor and Arduino and there are 2 transistors. First one is 2N3906 PNP transistor and second one is 2N2222 NPN transistor.

When we tested TDS sensor with PH sensor together in the same solution and both of them are working at the same time, it is very clear that TDS sensor effects PH sensor and make its readings fluctuate considerably, so to solve this problem we needed to isolate TDS sensor while PH sensor turned on and this was acomplished by using 2 transisitors. In case of PH sensor is measuring PH value of solution, 5v is feeding through base of 2N3906 PNP transistor to block 3.3v on emitter from feeding collector which is connected to + pin of TDS sensor. For 2N2222 NPN transistor, analog pin 3 is low which connected to base of NPN transistor and means no connection between collector that connected to – pin of TDS and emitter which connected to ground, in other words TDS circuit is opened which also means it is turned off. After Arduino gets reading from PH sensor, TDS sensor will be turned on.

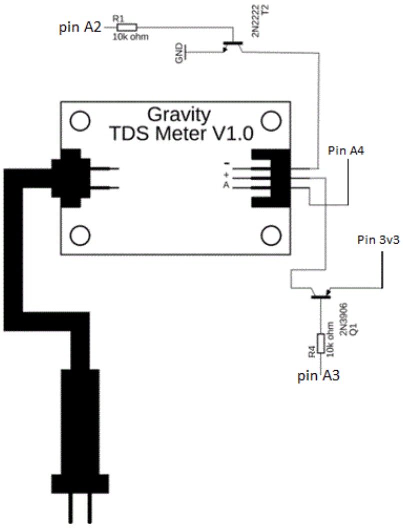


Fig. 4.17 TDS sensor in Schematic Diagram

Fig. 4.18 DFROBOT analog TDS sensor

4.5.8 Ultrasonic water level sensor (HC-SR04)

This sensor supports 5V voltage input which is compatible with Arduino and can measure distance till 400cm. This sensor has 4 pins as shown in the figure. VCC pin to operate the sensor, trigger pin to send pulses, echo pin to receive the reflected pulses, GND pin. This sensor detects the depth of water in a tank or container. ECHO and TRIG pins are interfaced with the Arduino using the digital pin 34,33 respectively as shown in figure 4.19. The sensor will send out a short ultrasonic pulse and measure the time it takes for that pulse to travel to and from the liquid (the echo). The water depth is then calculated by subtracting that distance from the tank's overall depth.

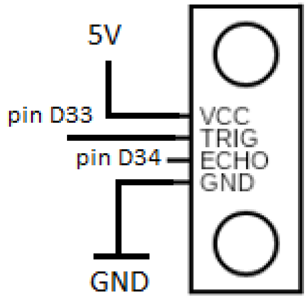


Fig. 4.19 Ultrasonic sensor in Schematic Diagram

4.5.9 DS18B20 Waterproof Temperature Sensor

Water temperature sensor supports 3 to 5V wide voltage input which is compatible with Arduino and can measure temperature from -55 to 125 Celsius with accuracy +- 0.5 Celsius. It consists of 3 wires as shown in the figure 4.21. VCC wire to operate the sensor, GND wire, and data wire to send the data. Data wire is interfaced with the Arduino at analog pin number 1. This sensor does not require an analogue to digital converter or other additional hardware and it uses a digital protocol to send accurate water temperature measurements directly to Arduino. Figure 4.20 shows the connection between Arduino and water temperature sensor in schematic diagram.

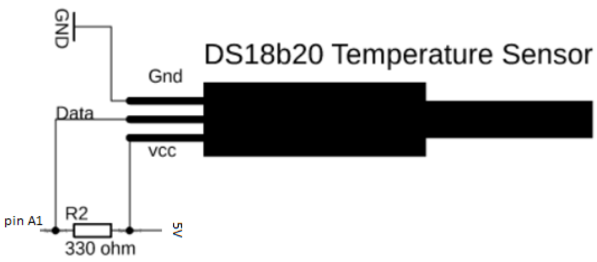


Fig. 4.20 Water temperature sensor in Schematic Diagram

Fig. 4.21 Water temperature sensor

4.5.10 Water (Dosing) Pump

It operates at 12V, draw 0.5 A current maximum, so it needs relay to operate and lift water up to 300 cm maximum as mentioned in the figure 4.23 below. This pump is used as water pump, nutrient, and acid/base pump in our system. Water level pump controlled by an Arduino and a single channel relay switch. It is triggered when the water level in the main tank falls below a specified level, water is pumped into the main tank from an external water tank. Nutrient pump controlled by an Arduino and 5V four channel relay module. This motor pump is triggered when the nutrients need to add to main tank. Figure 4.22 and 4.24 shows the connection between water pump or dosing pump, relay, and 12v adapter.

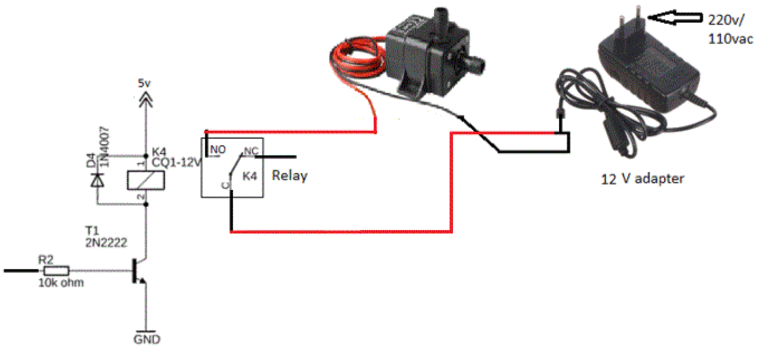


Fig. 4.22 water pump in Schematic Diagram

Fig. 4.23 water dosing pump

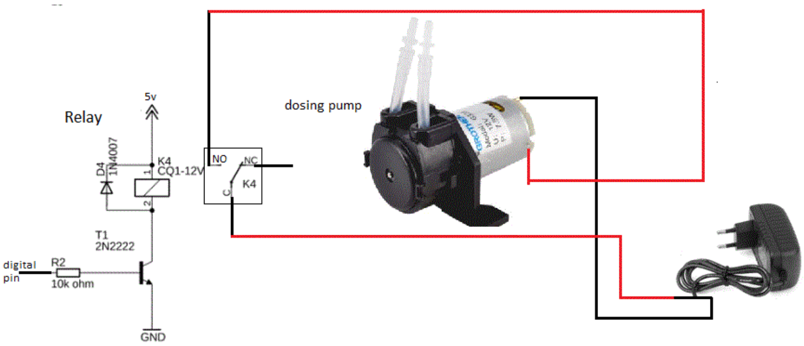


Fig. 4.24 water dosing pump in Schematic Diagram

4.5.11 Solution Lifting Pump

It works at 12V, draw 2.0 A current maximum, transfer 350 gallons per hour (GPH) and lift water up to 3.8 m maximum as shown in the figure 4.25. It controlled by an Arduino and a 5V single channel relay switch. This motor pump is triggered when the water needs to lift up to tubes from main tank. Figure 4.24 shows the connection between lifting pump, relay, and 12v adapter.

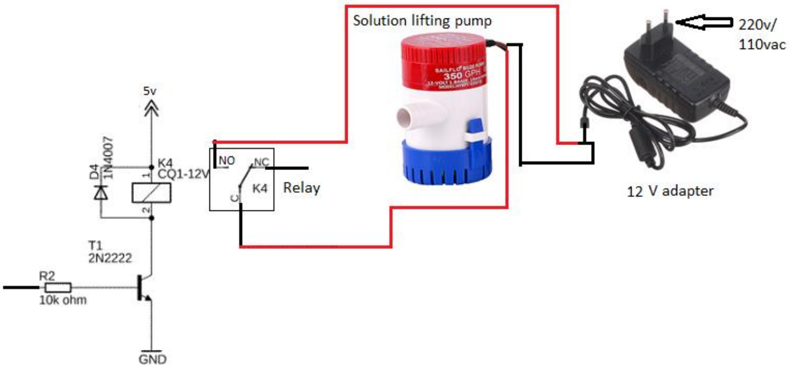


Fig. 4.25 solution lifting pump in Schematic Diagram

Fig. 4.26 solution lifting pump

4.5.12 05VDA Relay Module

It is an electrical switch which open and close an electrical circuit based on signal from microcontroller. It works at 3.75 to 6V and draw 2m A current maximum. It consists of 6 pins as shown in the figure 4.27. Relay trigger (input) pin to activate the relay, ground pin, VCC pin for powering the relay coil, normally open pin which normally open terminal of the relay, common pin which common terminal of the relay, and normally closed pin which normally closed contact of the relay. Figure 4.26 indicates how relay looks like in schematic diagram.

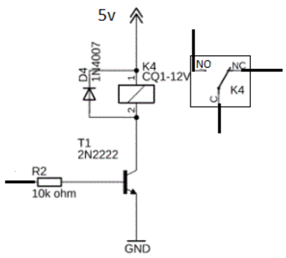


Fig. 4.27 05VDA Relay Module in Schematic Diagram

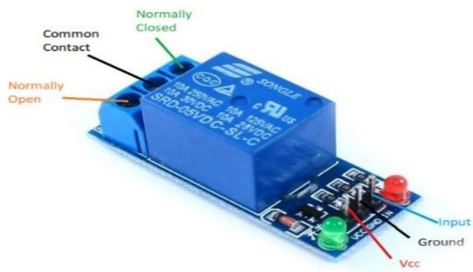


Fig. 4.28 05VDA Relay Module

Chapter 5
Implementation and results

5.1 Introduction

This chapter introduces the final structure and circuit diagram for the proposed system in addition modes of operations that occurred during the implementation of the proposed system such as connection mode, hardware and software testing mode, training mode, operational mode and finally evaluation mode. It as well explains the final results analysis and the accuracy achieved by the proposed system.

5.2 Final structure

The figures 5.1, 5.2, 5.3, and 5.4 below show the transferring of water between tanks and structure and the recirculation operation of the system and all the detailed Architecture Measurements.

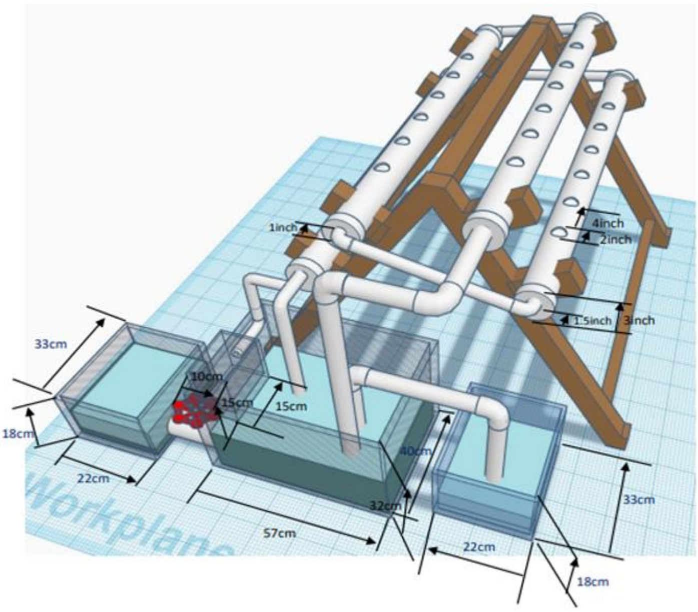


Fig.5.1 front side of structure's tinker cad design with measurements

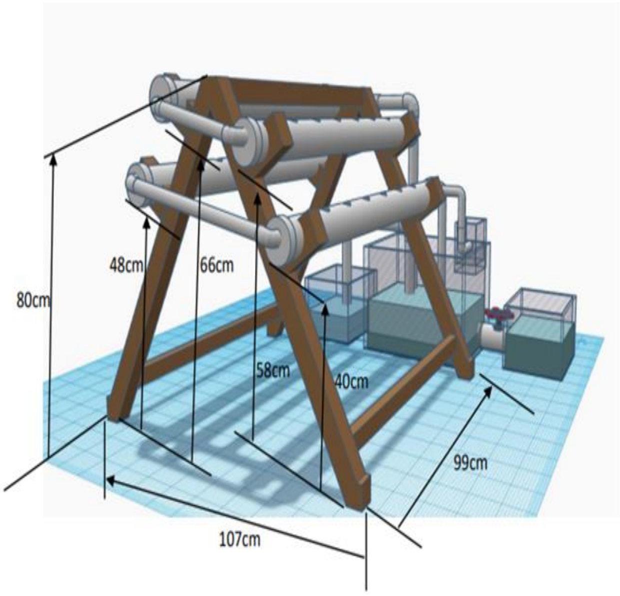


Fig.5.2 back side of structure's tinker cad design with measurements

Fig.5.3 upper side of physical structure

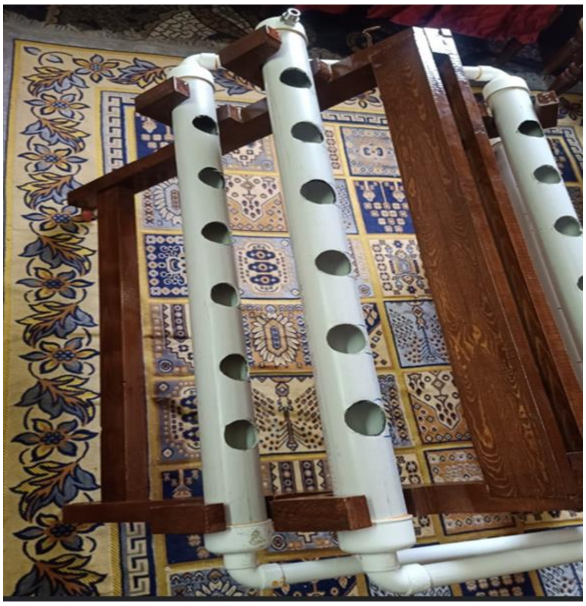


Fig.5.4 left side of physical structure

5.3 experimental setup

Figure 5.5 below shows the hardware connection of the whole system for experimenting all of 5 sensors.

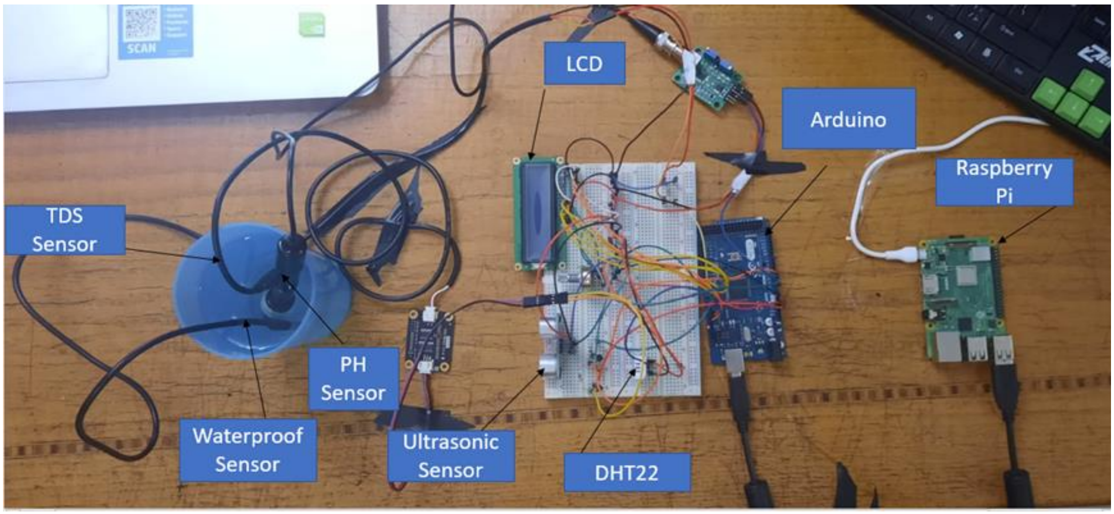


Fig.5.5 experimental setup for the whole system

5.4 Modes and Operations

5.4.1 Connection Mode

First, the connection between Arduino and various sensors which comes in two forms. First TDS and PH sensors connected to Arduino analogue pins. Second DHT22, ultrasonic, and DS18B20 sensors connected to Arduino with digital pins as shown in block diagram of chapter 4 section 4.5.1. Second, the connection between Arduino and LCD which we are depending on 4bit mode and from D4 to D7 connected to digital pins on Arduino as shown in chapter 4 section 4.5.5. Finally, the connection between Arduino and Raspberry pi which is UART serial protocol over USB cable between both USB ports on both of them.

5.4.2 Hardware Testing and Monitoring

Calibration

For the part of hardware testing, only one senor needed calibration which is PH sensor as we first use wire to short the external part and the center of the probe connector as shown in the following figure 5.6 This must cause 2.5V and by using Screwdriver to modify potentiometer to reach to 2.5V. Second, by using buffers such as 4 PH and 9 PH and put PH probe in it and see if it has the same value or not on LCD or serial monitor. Finally, modifying the calibration value in the PH sensor code on Arduino to match value on lcd or serial monitor with buffer's value.

Fig. 5.6 short on PH module

Precautions

For TDS sensors by testing it, we notice that it works fine and its values is close to testers values when water flow is near to stable and small like shown in the following figure 5.7, so first to protect TDS and PH sensors from changing their values in big tank as with adding acid or base and there is high chance that PH value in some place in big tank is high which can harm PH sensor, so we protect them by putting them in small tank which attached to big tank which take small drops of solution back from trays and drop it back to big tank as shown in block diagram in chapter 4 section 4.2. By these precautions, we managed to protect PH and TDS sensors and try to reach to ideal environment to TDS sensor to get correct readings. Figure 5.7 and 5.8 explains the hardware connection for TDS sensor testing and the readings chart that shows the correlation between the readings of the tester and TDS sensor is 96.2%

Fig. 5.7 Illustration of how our TDS sensor is close to TDS tester

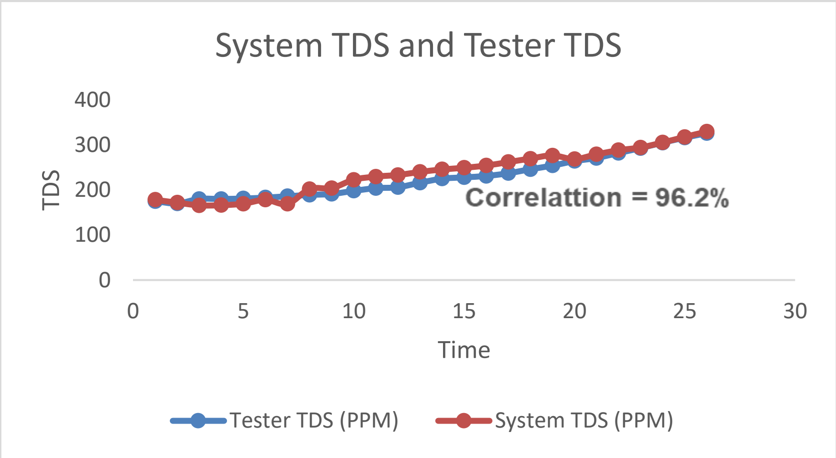


Fig. 5.8 System TDS and Tester TDS

Concerning to the testing process of the PH sensor, Figure 5.9 presents the relation between the readings of the system PH readings and the tester. The correlation is 95.76%.

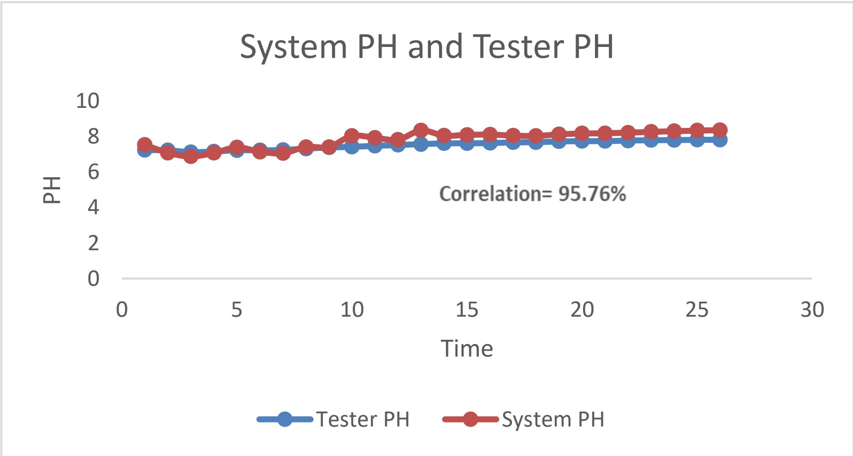


Fig. 5.9 System PH and Tester PH

Monitoring

For the part of monitoring, we have 2 modes. First one is when all sensors are connecting to Arduino and works fine with normal reading gathered by Arduino and this mode is the main mode of our system and called normal mode and it is shown in flow chart of chapter 4 section 4.3, but let's say something happened to one of sensors such as disconnecting of PH or TDS sensors, this mode called failure mode and shown in the following figure 5.10, we tested it and manage to know value got in each disconnection of sensor such as for DHT22, it always shows on LCD 0 value for air temperature and Nan for humidity value in case of it disconnect form Arduino. For DS18B20 water temperature sensor in case of disconnection, it shows on LCD -127 and it also effect TDS sensor as we use water temperature value as input to get PPM value. We fix this problem as there is going to be an indication on LCD shows that there is a problem with sensor disconnected, all actuators are going to be disconnected except lifting pump as it is the backbone of our project, and there is going to be push button which is going to use to return system to normal mode as by fixing the problem we are going to press the push button to make flag back to 0 which is going to let system run again in normal mode.

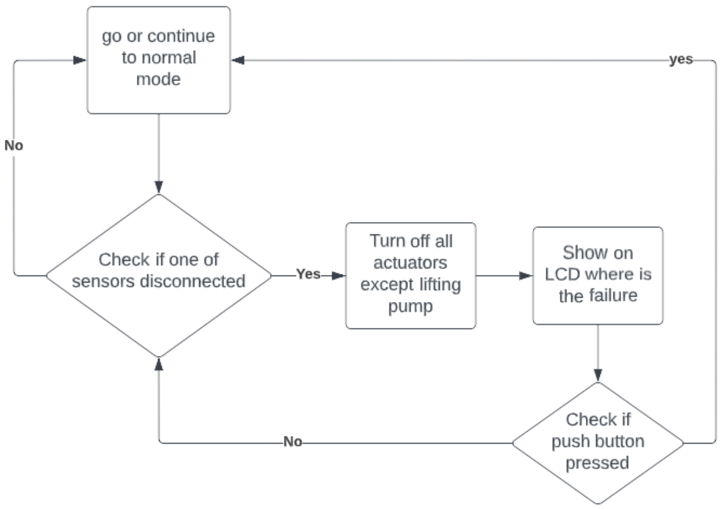


Fig. 5.10 flowchart of failure mode

5.4.3 Training Mode for ML model

As we mentioned before, we have collected 6421 real time data from hydroponic system over one month to pH, air temperature, and TDS (PPM) and used them to build our random forest ML model, and we took 80% of these data which are 5137 samples to train our model and for random forest classifier parameters (max_features = 1, max_depth = 4, n_estimators = 193, min_samples_split = 2, min_samples_leaf = 1, bootstrap = False, criterion= ‘entropy’, ccp_alpha=0.0001, random_state=0) and we got for Training Accuracy 98.972%.

5.4.4 Testing Mode for ML model

For testing our random forest ML model, we took 20% of dataset which are 1294 samples to test our model and we got 97.536% and the following table 5.1 shows classification report for ML model.

Table 5.1 classification report for random forest

	precision	recall	f1-score	support
0	1.00	1.00	1.00	15
1	1.00	1.00	1.00	21
2	1.00	1.00	1.00	27
3	0.62	1.00	0.76	21
4	1.00	1.00	1.00	32
5	1.00	1.00	1.00	13
6	1.00	1.00	1.00	9
7	1.00	1.00	1.00	29
8	1.00	1.00	1.00	21
9	1.00	1.00	1.00	16
10	1.00	1.00	1.00	20
11	1.00	0.38	0.55	24
12	1.00	1.00	1.00	16
13	1.00	1.00	1.00	46
14	1.00	1.00	1.00	34
15	1.00	1.00	1.00	35
16	1.00	1.00	1.00	35
17	1.00	1.00	1.00	10
18	1.00	1.00	1.00	14
19	1.00	1.00	1.00	15
20	1.00	1.00	1.00	18
21	1.00	1.00	1.00	24
22	1.00	1.00	1.00	24
23	0.91	1.00	0.95	20
24	1.00	1.00	1.00	24
25	1.00	1.00	1.00	24
26	1.00	1.00	1.00	22
accuracy			0.98	1294
macro avg	0.98	0.98	0.97	1294
weighted avg	0.98	0.98	0.97	1294

5.4.5 Operational Mode

we combined hardware which represents in sensors and pumps (dosing, small, and lifting pumps) connected to Arduino and itself connected to raspberry pi with software which represents in Arduino code to gather sensors readings and applying certain decisions on various actuators and also ML model on raspberry pi and it looks like everything is running normal without any problems like it showed in chapter 4 section 4.3.

5.4.6 Evaluation Mode

We mentioned before in chapter 4 section 4.4.3 our selection method is based on applying the 3 ML models which are K-nearest Neighbors, Decision Tree, and Random Forest on our dataset and see which one gives us the best testing accuracy and the one with the highest accuracy is the one that we are using in our project.

K-Nearest Neighbors

As we applying k-nearest neighbor on our dataset and according to the following figure 5.11, the testing accuracy is 84% which is acceptable, but compared to the other 2 ML algorithms it is the lowest between them.

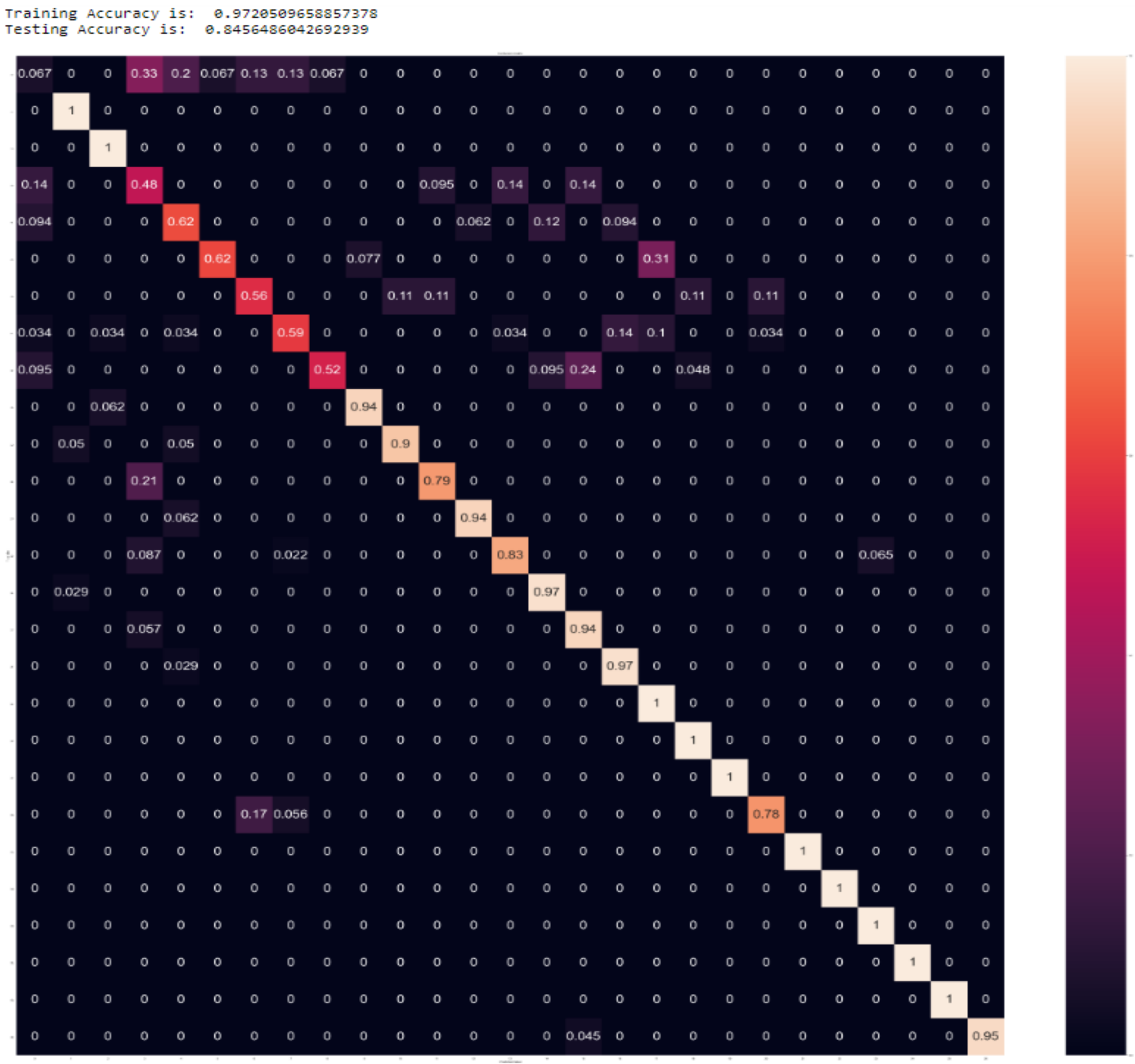


Fig. 5.11 confusion matrix of K-Nearest Neighbor

Decision Trees

As we applying Decision trees on our dataset and according to the following figure 5.12, the testing accuracy is 93% which is good and better than K-Nearest neighbor, but lower than the testing accuracy of Random Forest.

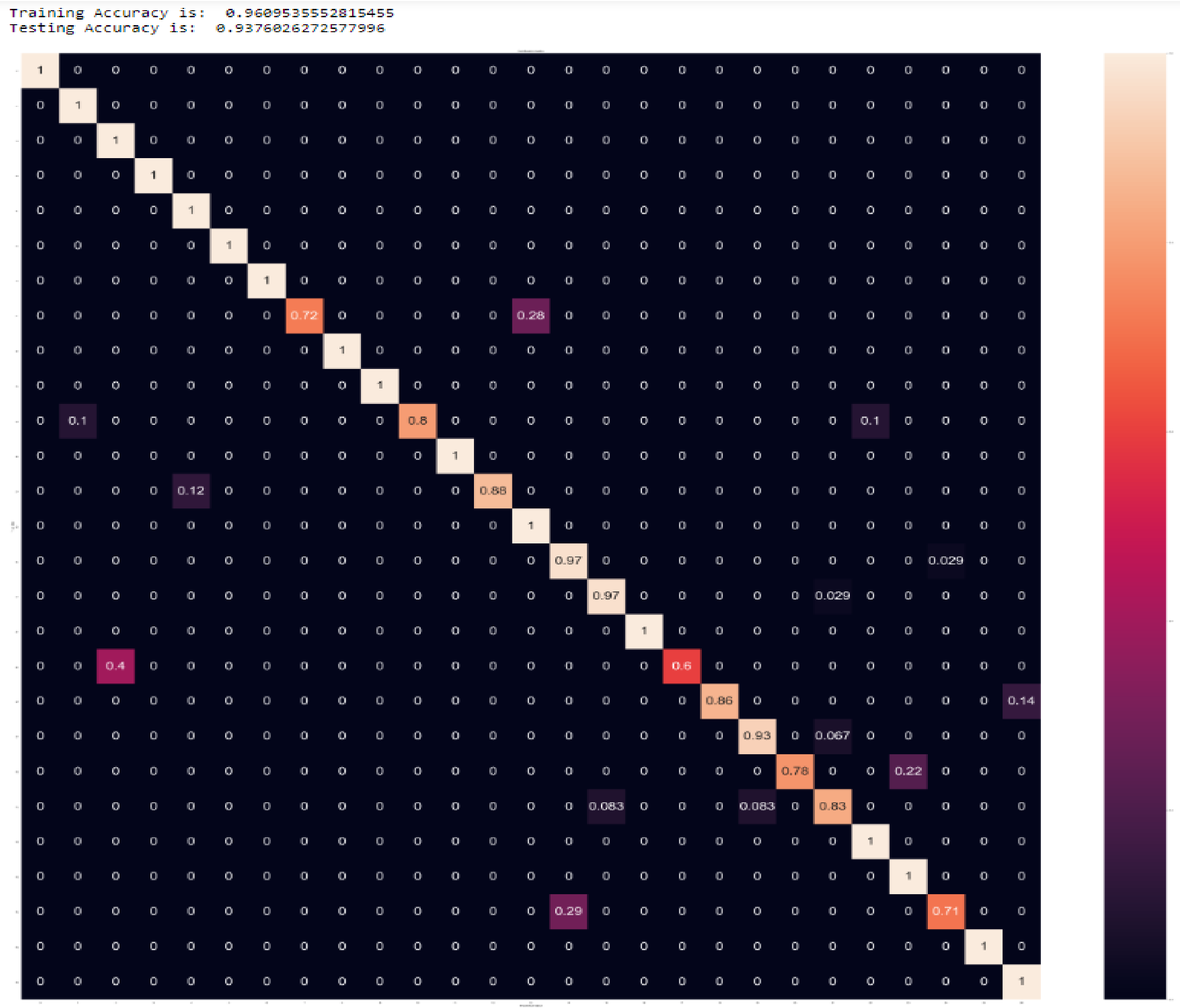


Fig. 5.12 confusion matrix of Decision Trees

Random Forest

As we applying Random Forest on our dataset and according to the following figure 5.13, the testing accuracy is 97% which is very good and better than K-Nearest neighbor and Decision Trees and based on this fact it is clear that we are using random forest as ML model in our project and its accuracy is 97%.

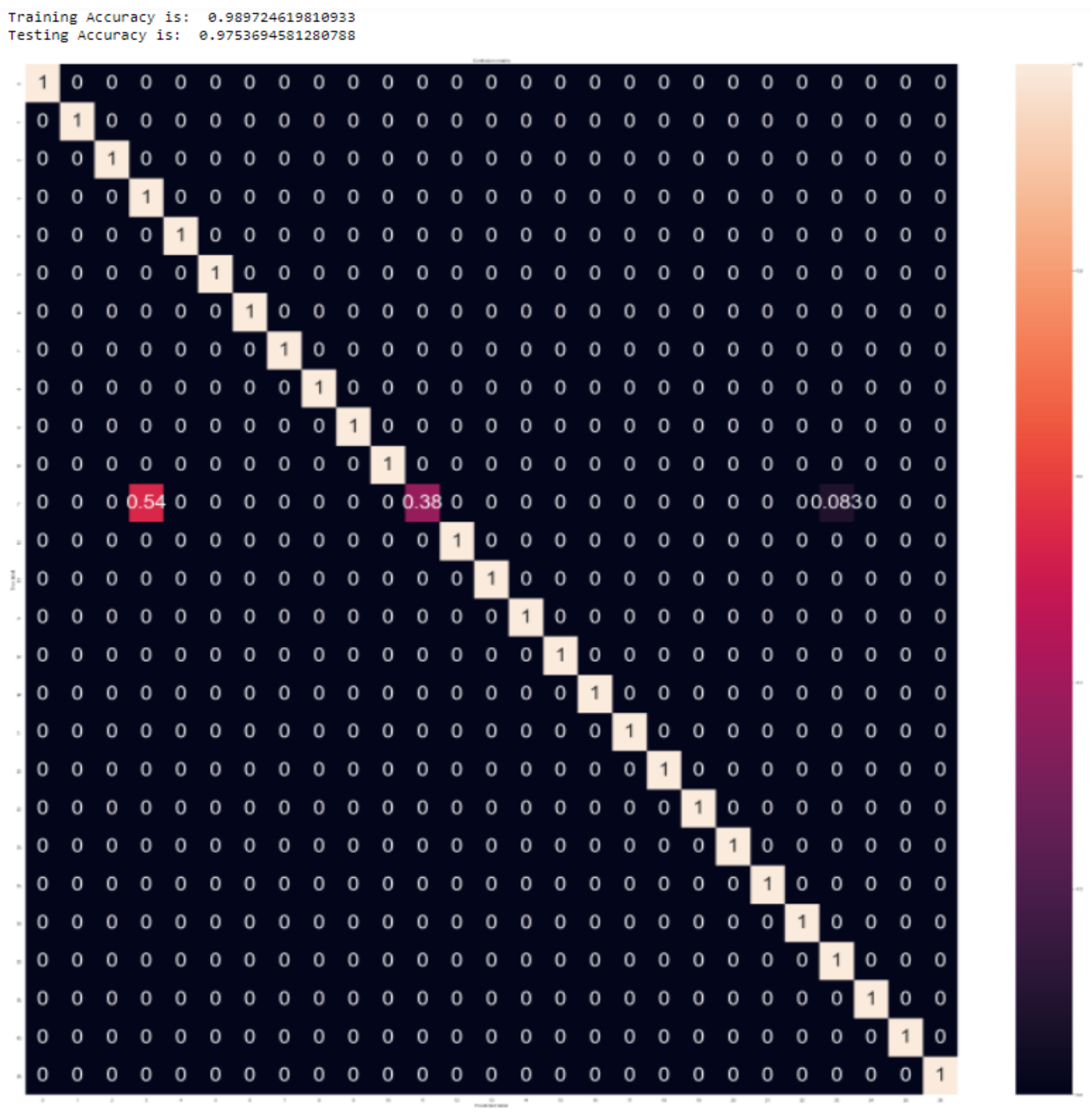


Fig. 5.13 confusion matrix of Random Forest

5.4.7 Results and Analysis

Throughout data obtained in previous studies which are Hydroponic Nutrient Control System based on Internet of Things and K-Nearest Neighbors and A Smart Hydroponics Farming System Using Exact Inference in Bayesian Network that using the same sensors, Temperature, PH, and TDS sensors indicated that for the first paper, the classification by using these three sensors in Realtime is efficient and can be used to control PPM, PH, and temperature levels for surrounding environment which is done using proper actuators such as dosing pumps. For the second paper, it concludes that it is possible to count on these 3 sensors to make an autonomous NFT system without human intervention. This section presents the implemented system sensors' readings and charts explaining how the PH and TDS sensor's readings are changed when adding the nutrients. It also shows the effect of the acid and base on the water PH and TDS and how the software detects the acidity and alkalinity to adjust and correct itself automatically.

That is presented practically and visualized throughout the following charts:

Figure 5.14 shows the PH and TDS relation when the acid is added to the water; it is observed from the PH readings that the system changes its state from alkalinity to water acidity.

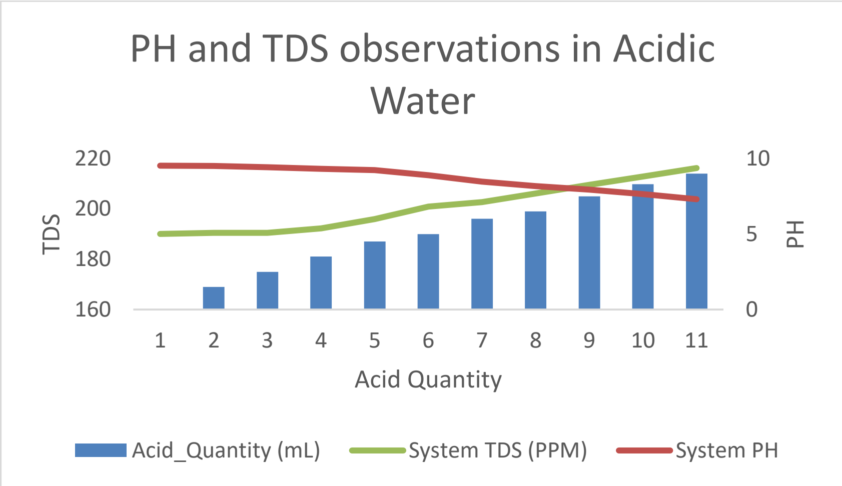


Fig. 5.14. PH and TDS observations when adding Acid to water

By similarity, Figure 5.15 shows the PH and TDS relation. When the base is added to the water, the system changes its state from acidic water to alkaline, with PH closer to 10.

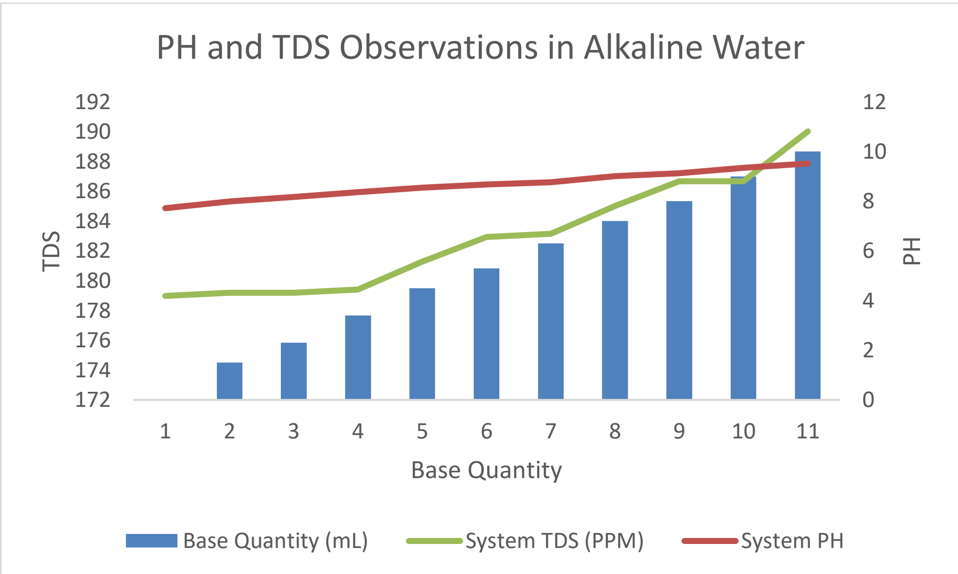


Fig. 5.15 PH and TDS observations when adding base to water

On the other hand, the PH and TDS readings have been recorded with nutrients A and B added to water. Figure 5.16 shows the relation between these readings as the nutrients A and B quantities increase.

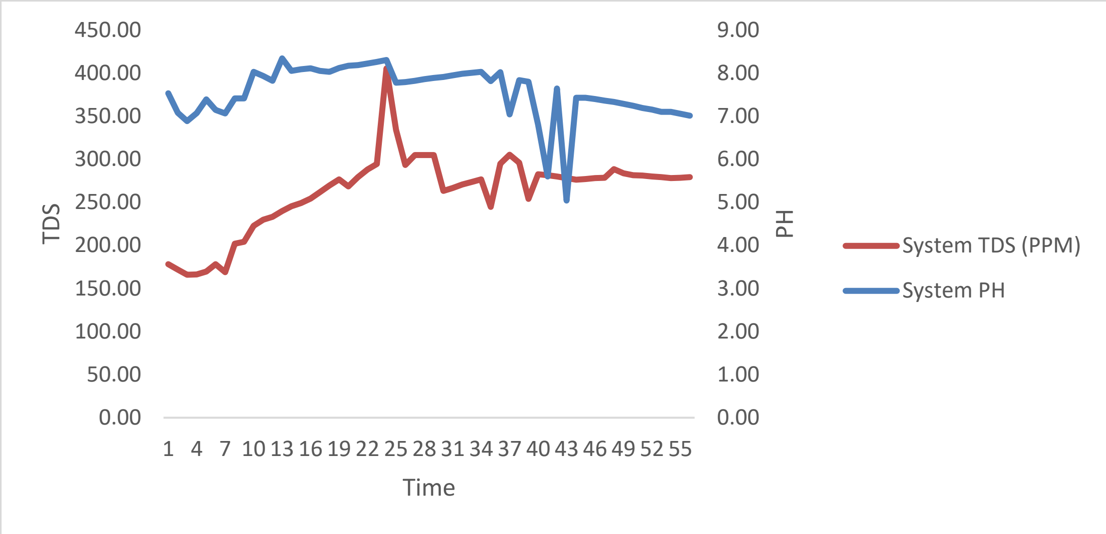


Fig. 5.16 PH and TDS observations when adding nutrients to the water

5.5 Conclusion

In this chapter we manage to present our final structure with detailed measurements, all modes of connection which includes connection between Arduino with various sensors, LCD and various actuators, and Arduino with raspberry pi, and different stages of running our system which includes calibrations, precautions, and test all sensors and how it adapts in the environment, the journey at which Arduino collects various reading form different sensors and at the end showed it on LCD, testing and training our ML model, and at the end evaluate system as hardware plus software which comes in form of accuracy of ML model. Finally, let's conclude if our project achieves its objectives which have been mentioned in the abstract, first we managed to control the environment around the plants throughout making action using different actuators such as dosing pumps to modify PH and PPM levels in the solution tank depends on readings collected by Arduino. Secondly, we managed to monitor all the parameters in the environment around plants remotely such air temperature and humidity and saving the human factor. Finally, we managed to recirculate the solution as we use nutrient film technique system which mainly depends on recirculate solution by pulling solution from tank using lifting pump to trays and returning it to the same tank after the solution has passed through all the trays and according to the visit which we have made to Bustan Aquaponic in 6

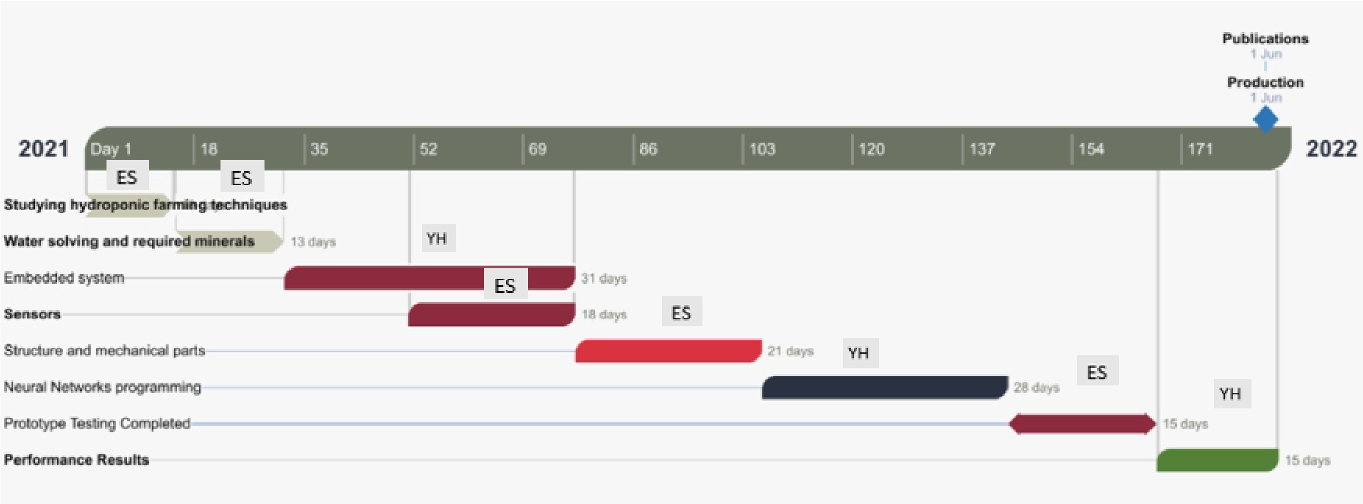
October city and photos of it is in Appendix A after references, they are using the same quantity of water since 2017 and they done this by filtering it continuously. They also give us an advice to change the solution every 3 to 4 weeks, exchange it with new solution, filter the old one, and again after 3 to 4 weeks exchange it with the filtered old solution and take the new solution and filter it and so on.

Chapter 6
Gantt chart

6.1 Tasks accomplished and executed

Task No.	Task Holder	Task Description	Expected Time to be executed
1	Eslam osama Saad	Over all circuit design	**3 weeks**
2	Eslam osama Saad	Prototype testing	**3 weeks**
3	Youssef Hussein Abdelnaby	prototype implementation	**3 weeks**
4	Youssef Hussein Abdelnaby	Performance results	**2 weeks**

6.2 Time Plan of the project



Chapter 7
Cost analysis

7.1 Cost Analysis per tray

The following table presents the cost analysis of one tray of the proposed hydroponic system.

Component/tool	no.	Price (EGP)	
Atlas Scientific Flow Meter	1	2119.50	Water Condition Sensing
Atlas Scientific Flow Meter Totalizer	1	660.08	
Atlas Scientific EZO Carrier Board	1	188.24	
1/4 in. O.D. x 3/8 in. MIP NPTF Push-to-Connect Adapter Fitting	2	137.218	
3/8 in. FIP Brass Pipe Coupling Fitting	2	62.88	
Water Level Float Switch with Pipe Mount	1	297.894	
Atlas Scientific Peristaltic Pump	4	1367.4828	
Atlas Scientific PT-1000 Temperature Sensor Kit	1	1084.5228	
Atlas Scientific EZO Carrier Board (for Temperature Sensor)	1	188.4828	
Atlas Scientific pH Sensor Kit	1	2562.2028	
Atlas Scientific Electrical Conductivity Sensor Kit	1	3521.1228	
Solder	2	50	Essential Tools
Saw or Dremel with Cutting Kit	1	1241.88	
Heat Gun	1	471.6	
Cordless Drill	1	3112.4028	
Drill Bit Set (16-Piece)	1	207.3468	
1 3/4 in. Hole Saw Bit	1	233.5992	
thread seal tape waterproof	1	50	
Raspberry Pi v3 or Raspberry Pi v4 (only one, not both; v4 recommended)	1	1886.4	Environmental Monitoring and Regulation System
Micro SD Card (32 GB)	1	182.352	
Raspberry Pi v2 Camera Module	1	943.2	
Raspberry Pi Camera Ribbon Cable	1	82.3728	
HDPE Plastic Mounting Panel	1	516.2448	
6-Outlet Power Strip	1	199	
20 character, 4 line I2C LCD	1	135.0348	
#1 x 7/16 in. Stainless Steel Screws	1pack	78.6	
Round Nylon Spacers (H 6 mm, OD 7 mm, ID 4 mm)	1 Pack	135.0348	
Mini Breadboards	1 Pack	94.32	
Jumper Wire Kit	1 Pack	97.3068	
Arduino Uno R3	1	160	

HTU21DF Temperature/Humidity Sensor (or AM2315, SHT31, etc. See Supported Sensors)	1	371.4636	Air Condition Sensing (These materials enable various air conditions to be measured)
Dupont Crimping Tool and Connectors	1	1965	
MH-Z19B CO2 Sensor	1	503.04	
UART to USB Converter (USB Interface)	1	86.3028	
Analog-to-Digital Converter	1	125.76	Electrical Power Sensing
AC Current Sensor with Split Transformer or Greystone CS-650-R1 Solid Core Current Sensor (only one, not both)	1	393	
Sum per tray		**25510.89**	

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[2] V. H. Andaluz, A. Y. Tovar, K. D. Bedón, J. S. Ortiz, and E. Pruna, "Automatic control of drip irrigation on hydroponic agriculture: Daniela tomato production", In 2016 IEEE International Conference on Automatica (ICA-ACCA), Curicó, Chile, (2016, October), (pp. 1-6), IEEE.

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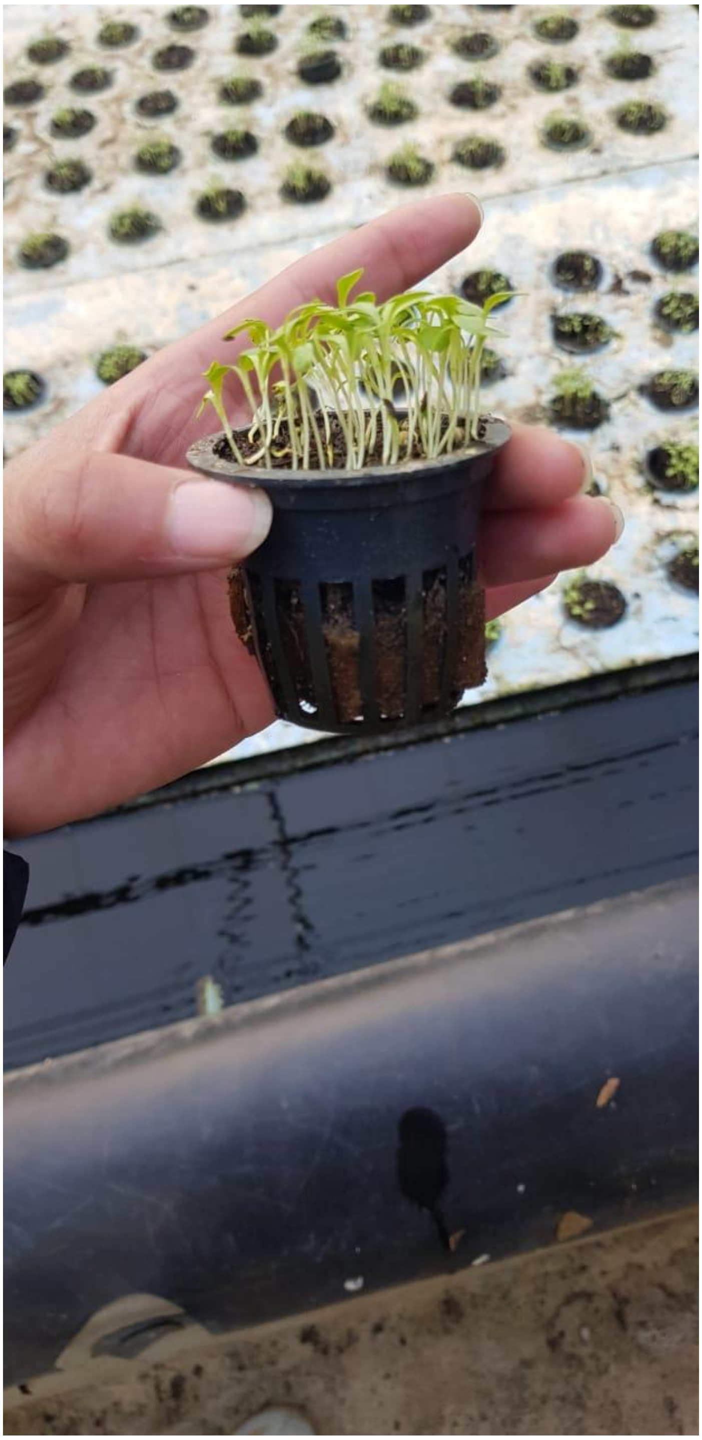
Appendix A

Bustan Aquaponic Visit

ملخص المشروع باللغة العربية

" نظام ذكي متكامل للزراعة المائية في مصر "

أصبحت ندرة المياه المشكلة الرئيسية في جميع أنحاء العالم. بسبب تغير المناخ ونقص المياه العذبة وموارد المياه النظيفة ، لا توجد موارد كافية لتلبية الطلب الذي يؤدي إلى نظام بيئي غير مستقر. ستساعد إعادة تدوير المياه في تقليل خطورة المشكلة. تتمتع الزراعة المائية بفوائد عديدة على الزراعة التقليدية القائمة على التربة. زيادة الحفاظ على المياه وتقليل استخدام الأسمدة. لا يعمل العديد من المزارعين في المزارع المائية بسبب الافتقار إلى السيطرة على الأمراض وسيؤدي ذلك إلى انخفاض إنتاج المحاصيل ونقص جودة المحاصيل. يتم تغطية كل ذلك وحلها طوال هذا المشروع.

تتم عملية الزراعة المائية من خلال نظام ذكي متكامل يغطي مراقبة ري النباتات وإعادة تدوير المياه ، مع الحفاظ على النسبة المئوية المطلوبة من العناصر الغذائية للزراعة السليمة وإنتاج المحاصيل العضوية. سيؤدي ذلك إلى جعل أنظمة الزراعة المائية جذابة ، وتتطلب إعادة تدوير الأنظمة المتكاملة خوارزميات محددة للغاية باستخدام التعلم الآلي.(ML)

يتم تطبيق خوارزمية ML للتحكم في نمو النبات ، وتحسين قيم التوصيل الكهربائي (EC) لمحلول المغذيات ، والتنبؤ بنضج النبات وجودة المحاصيل ، واتخاذ قرارات أكثر ذكاءً ، واتخاذ الإجراءات المناسبة في سيناريوهات العالم الواقعي بدون (أو مع عدد محدود) من البشر مشاركة. يوفر إطارًا شاملاً وقابلاً للتكيف لاتخاذ القرارات التي تعتمد على البيانات والتي يمكن استخدامها في مجموعة متنوعة من البيئات الزراعية.

من ناحية أخرى ، يلعب مشروعنا دورًا مهمًا في تقليل التلوث الناجم عن تصريف مياه الصرف حيث يعيد استخدام المياه المصرفة بعد عملية حقن المغذيات في الزراعة. بالإضافة إلى ذلك ، ليست هناك حاجة لاستخدام مبيدات الأعشاب أو أي أسمدة كيميائية حيث سيتم القضاء على نمو الحشائش باستخدام أنظمة الزراعة المائية. تسبب مبيدات الأعشاب أو الأسمدة الكيماوية في الزراعة التقليدية تلوث الهواء وتلوث التربة.

جامعة أكتوبر للعلوم الحديثة والآداب
كلية الهندسة

قسم هندسة نظم الاتصالات و الالكترونيات

"نظام ذكي متكامل للزراعة المائية في مصر"

مشروع التخرج
قدم ضمن متطلبات درجة البكالوريوس فى الهندسة الكهربية والحاسبات

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"2022-2021"