

Design and Implementation of an IoT-based Monitoring and Automated Control System for Indoor Hydroponic Vertical Farm

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A project report submitted in partial fulfillment of the requirements for the degree of Bachelor of Science in Electrical and Electronic Engineering

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DECLARATION

This Final year Capstone Project report is submitted to the department of Electrical and Electronic Engineering, University of Liberal Arts Bangladesh in partial fulfillment of the requirements for the degree of Bachelor of Science. So, we hereby, declare that this report is based on the work done by us. Materials of work found by other researchers are mentioned by reference. This project report, neither in whole nor in part, has been previously submitted for any degree.

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Abstract

Nowadays need to overcome the multi-manifestations of climate change, continued environmental degradation, pressing need of growing food demand, and freshwater scarcity. Day by day the amount of farming land is reducing on the other hand worldwide food demand increasing every day. There is concern that the existing agricultural system will not be able to meet the ascending food demand in the near future. Indoor hydroponics farming is a soilless cultivation technology that provides high-quality, healthy, fresh, poison-free food. With the help of this system, can meet this increasing food demand because the vertical farming system can produce 10 to 15 times more crops compared to the traditional farming system. The purpose of this project is to design and implement of automatic control and IoT-based monitoring system for an indoor hydroponic vertical farm. This system is able to control important environmental parameters that affect plant growth such as NPK ratio, pH, CO₂, temperature, and so on, and also controls automatically the solution level, reserve water level, reserve nutrition, and light. There are used Ubidots cloud storage to store important parameter data using the Internet of Things (IoT) and also a visual representation of those data on Ubidots. This prototype was planting cherry tomatoes from seed. A user can easily access Ubidots to see the condition of hydroponic farms anywhere in the world.

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CHAPTER ONE

INTRODUCTION

1.1 Background

The population of the world is expected to reach around 9.7 billion by the end of the year 2050 and urbanization is also increasing due to the increasing rate of population growth. To feed this growing, increasingly urbanized population, The United Nations estimates food demand needs to rise by 70%. Urban built-up regions and skylines are changing quickly, presenting unhealthy living conditions that have resulted from the construction of structures and infrastructure to accommodate the greater population in the city core. The need for urban people's basic necessities for a pleasant urban environment is threatened by this circumstance. A bigger urban population also requires a supply of fresh, high-quality food. The management of a sustainable food supply, heavy use of already-existing resources like water, electricity, and land, as well as deterioration of the immediate environment, are the key problems associated with increasing urbanization. The heavy use of fresh water and energy resources for food production to feed the expanding urban population in the traditional farming method is severely impacting climate change by increasing CO₂ and other greenhouse gas emissions. On the other hand, in the traditional farming method, the farmers are using extra fertilizer and pesticides to grow more crops and kill harmful insects to fulfill the food demand. Hence, the fish and aquatic animals are dying, and the balance is also being lost. As a result, there is a growing need to modify agriculture methods and adapt technologies so that maximum crops can be grown, and human effort can be reduced. Moreover, technologies are expected not only to improve productivity but also to take care of the environment through sustainable cultivation. Urban smart vertical farming is one of the potential and sustainable solutions for societies and the environment, which can solve all these problems and secure food production, introduced at any adaptive reuse or new buildings in vertical manners. The opportunity to utilize vertical space and reduce the need for additional land and building activities adds to vertical agriculture's attractiveness in cities. Due to the popularity of organic food and the ability to produce crops throughout the year and also lowering inputs such as water, pesticides, herbicides, and fertilizers, vertical farming demand is increasing over the world. In the future, it is expected to increase on a large scale. Urban smart vertical farming is one of the potential and sustainable solutions for societies and the environment, solving all these problems [1]. This farming system will be able to grow common plants and vegetables and can operate without depending on the outside climate. Urban smart vertical farming is the practice of planting plants vertically stacked on several floors without soil and free of pesticides, which optimizes land usage. Vertical farming is practiced in about 13 different ways in the modern world and each way is so technologically advanced that it is enough to revolutionize agriculture [2]. Hydroponics, aquaponics, and Aeroponics system are the most common and popular types of vertical farming. Hydroponics is a method of growing plants that do not require soil and instead makes use of mineral fertilizer solutions in a water solvent. The nutrients utilized in hydroponic systems can originate from a variety of sources, including (but not limited to) duck dung, fish feces byproducts, and chemical fertilizers that have been purchased. The nutrient film technique or N.F.T. is one of the most popular types of hydroponics systems, which works by delivering a nutrient solution to the plants by means of using a water pump. Plants can be

encouraged to grow more quickly by carefully controlling the environment in which they are grown, such as the amount of water, the pH levels, and the mix of particular nutrients. Hydroponics is a less wasteful method since it produces less waste, preserves water supplies, and uses fewer pesticides, fertilizers, and other potentially hazardous substances. The overall result is increased asset utilization and increased surrender. Tomatoes, peppers, cucumbers, lettuce, and cannabis are among the plants that are commonly grown hydroponically. The Internet of Things, or IoT, is a network of connected computers, mechanical and sophisticated machinery, items, creations, or people who have been given unique IDs and can the ability to exchange information via a network without needing to contact other people or computers. These devices can link and interact with others via the internet, and they can be examined and managed from a distance thanks to the inclusion of gadgets, online networks, and other equipment types like sensors. Because of these benefits, IoT is being used by scientists in a variety of areas of daily life [[3]]. The sensors in an IoT-based smart indoor hydroponic system connect with the server via Ethernet, where all sensor parameters are monitored and controlled by the monitoring module and control module, and also all recorded data from sensors can be stored in the IoT server.

Hydroponic research has increased steadily over the past several decades, especially in improving crop productivity and addressing the limitations of hydroponic systems (Fig. 1). Various crop species have been studied in hydroponic systems, including beans, cucumbers, lettuce, tomatoes, etc. Because hydroponic systems have many benefits, demand for hydroponic produce has increased dramatically in Asian countries such as Korea, China, and Japan. A significant amount of research has been conducted in recent decades on the treatment or recovery of hydroponic wastewater, which is the waste nutrient solution drained from the system. [4]

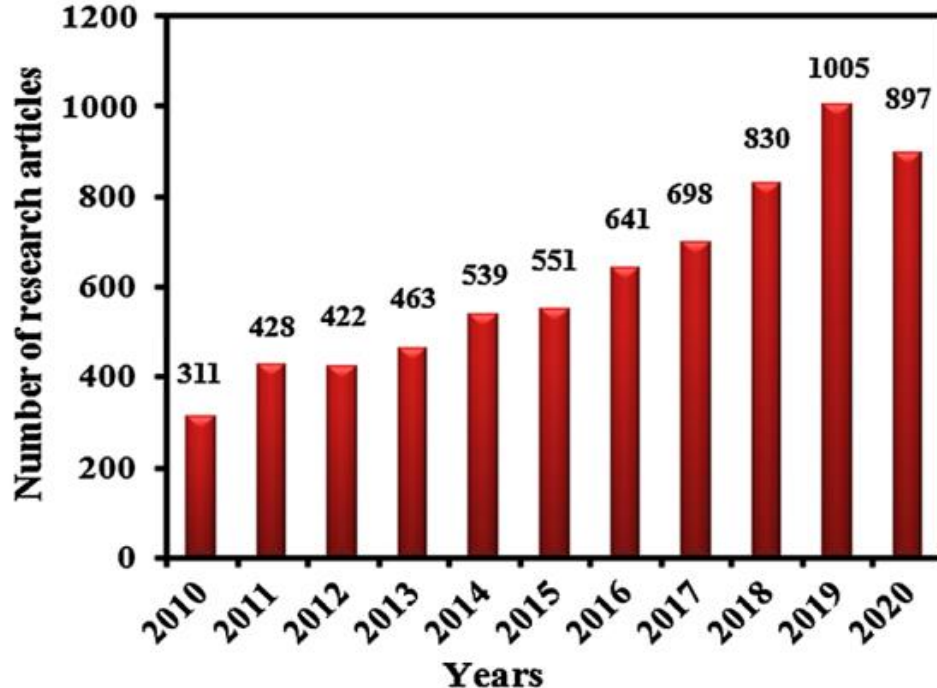


Figure 1.1: Number of research articles about hydroponics which cited by Web of Science (data analysis on 18th July 2020) [4]

1.2 Problem Statement

Nowadays hydroponics and aquaponics are getting popularity, but still, among these two systems, hydroponics is far ahead because of more food production and less maintenance cost and effort. Most of the hydroponic vertical farms that developed are not a completely closed environment. When plants are cultivated in outdoor or greenhouse-based or poly-based or open rooftop hydroponic systems, the production and quality of the products are affected by meteorological conditions. The danger of disease and insect invasion is also a concern. In some cases, pests and diseases, and the quality and quantity of food production introduce new issues and questions [5]. Growing certain plants and vegetables in remote areas such as deserts and the north and south poles can be a challenge because of the extreme outside weather. Also because of uncontrolled temperature, the winter season's vegetables in the summer season or vice versa are not possible to grow. In this type of outdoor farm, all conditions and problems can be monitored sometimes manually or automatically but not possible to control the environment automatically. So, these farms are not fully automated and remotely controlled and, the important parameters for crops such as temperature, humidity and light intensity, etc. are not possible to continuously monitor and control. As a result, these systems are not able to ensure maximum food production and can't grow crops that require low temperature, humidity, and other controlled parameters, whereas an indoor hydroponics vertical farm can be remotely monitored and controlled [6]. Moreover, in a small country like Bangladesh, agricultural land is shrinking at a great rate due to population growth and urbanization. So automatically the rate of food production decreases. This effect of low food production capacity is a major problem for this country and other Asian countries. In the course of this, people will face a dangerous food crisis in the coming years. In this scenario, nothing is more important than a fully automated indoor hydroponic farming system to feed the urban population.

1.3 Motivation

The amount of arable land is dwindling every day as a result of climate change. Therefore, alternative ways of farming are needed to overcome the situation. People may adapt to environmental change by using hydroponics. Farmers are currently experimenting with hydroponic farming in several developed nations. Many of Bangladesh's arable areas will be submerged in water in the future due to the sea level continuous rising. Thus, there will be significantly less area accessible for agricultural production. Then farmers may find hydroponics to be the finest solution for growing. Additionally, floods ravage Bangladesh every year. Farmers in flood-affected areas are unable to raise any crops and must wait for government assistance to feed their families. Instead, people may survive catastrophes by employing hydroponics skills to produce food on the water. A farmer may often double his earnings by cultivating both his land and any other watery places he owns. Some lands, such as steep places, cannot be farmed. Using their expertise in hydroponics, people may produce various crops by establishing tiny marshy regions. Bangladesh is a populous and middle-income country. Unlike developed countries where modern farming is progressing, our farming in Bangladesh is still not touched by modernity in this way. Developed countries are farming in hydroponics vertical farming systems. Standard field farming methods have received a lot of bad press, including articles concerning soil erosion, excessive water use, and outbreaks of food-borne illnesses. Many of these issues are addressed by the hydroponic farming sector. Hydroponic systems are water-based, soilless cultivation techniques. Crops are supplied with nutrient-rich water instead of utilizing soil for plant nourishment, mitigating a number of the

drawbacks of soil-based techniques. Population expansion in our nation is causing a decline in arable land, increased urbanization, rising food demand, a shortage of agricultural land, a scarcity of fresh water, the consequences of greenhouse gases, and other issues. Climate change so now the hydroponics farming system best option in our country because small space lot of Cultivation, the cheap cost, and the environment are friendly. 1st plan is to grow tomatoes for the first test in the IoT-based Monitoring and Automated Control System for Indoor Hydroponic systems.

1.4 Objectives

The objectives of this work are as follows:

- Monitoring all parameters from every sensor data using an IoT platform named Ubidots.
- Controlling the system automatically as per the conditions.
- Storing the monitoring data on Ubidots.
- Designing a viable system for any type of plant with minimum remorse utilization.
- Developing an energy-efficient, cost-effective, and environmentally friendly system.

1.5 Project Outline

This report has been divided into five chapters and every chapter has discussions on different topics related to the project. An overview of each chapter is given below:

Chapter one of the report contains the background study on the growing need for the vertical farming system to fulfill food demand for increasing population growth. It outlines the problems that exist in this field and highlights the reasons behind choosing this project topic. It also includes the objectives that have been tried to be reached through this project.

Chapter two contains the details of the previous research done in this field and includes the general theory behind monitoring and control systems and also the concept and methodology of the project.

Chapter three contains the main work and the descriptions of the different apparatus required for the development of the monitoring system and structure and details of the connections and circuitry.

Chapter four contains the analysis of the data that is recorded using the monitoring system and the results and observations of the project.

Chapter five of the report contains the summary of the entire project and highlights future work.

CHAPTER TWO

LITERATURE REVIEW & METHODOLOGY

Introduction

This chapter contains the details of the previous research done in this field and includes the field-specific theory on hydroponic Vertical farming and its types, system parameters and conditions of it and behind IoT-based monitoring and control systems as also the concept and methodology of the project.

2.1 Research Preliminaries

“Vertical Farming Using Hydroponic System: Toward a Sustainable Onion Production in Nueva Ecija, Philippines.” [7] the purpose of this study is that, if nutrients are present in the soil, plants can survive there. These nutrients are delivered in water with particular treatment in hydroponics. And it turns out that hydroponic plants can thrive and produce the same outcomes as those obtained using traditional methods. The Wick System, Nutrient Film Technique, Deep Water Culture, Drip System, and Flow System are a few types of hydroponics that are frequently employed. The Nutrient Film Technique (NFT) method uses a PVC pipe and recirculation to continually stream the nutrient solution to the plant's roots.

“Nutrient Solutions for Hydroponic System.” [8] the purpose of this study is that solution acidity, electrical conductivity, nutrient composition, and temperature are variables that affect nutrient uptake and availability in the solution. Nitrogen, phosphorus, potassium, calcium, magnesium, and sulfur are the main nutrients that are thought to be crucial for plant growth. The electrical conductivity and osmotic potential of the solution will depend on the makeup of these nutrients

“Automated pH Controller System for Hydroponic Cultivation” [9] has created a method that automatically controls pH. In hydroponics, plants are grown in nutrient solutions as opposed to soil. Different hydroponics techniques exist. In the Deep-Water Culture (DWC) method, nutrients are transferred to the plant's roots directly while they are submerged in the nutrient solution. The manual pH adjustment necessary for this method, however, can have an impact on the plant's growth.

“Design of Fully Automated Low-Cost Hydroponic System using Lab view and AVR Microcontroller” [10] proposes a strategy for using the data to successfully affect the counteractive actions in real time. Utilizing current technologies tends to create a self-contained, intelligent system. AVR microcontroller real-time data will be transferred to NI Lab View for monitoring, and then over the network to IoT applications.

“An Overview on pH Measurement Technique and Application in Biomedical and Industrial Process” [11] proposes the relevance of pH value in biomedicine and industry, as well as how it can be used to evaluate how acidic a water solution is. To meet the criteria, the invasive pH measurement technology must be updated to a non-invasive technique.

“A Development of an Automatic Microcontroller System for Deep Water Culture (DWC)” [12] proposes that terrestrial plants may be cultivated in an inert medium or with their roots only in mineral nutrition solutions. Deep Water Culture was one of the hydroponic varieties (DWC). The benefit of a DWC system is that it is highly oxygenated, consumes less fertilizer, and has few maintenance requirements.

“Ontology-Based Nutrient Solution Control System for Hydroponics” [13] is proposed in the studied pH, solution strength, plant species, and the position of the device in the system all play a role in helping to choose the most appropriate strategy for controlling a hydroponics fertilizer solution system.

“Automated pH Controller System for Hydroponic Cultivation” [14] in this paper the level of acidity in the solution is another factor that will impact the availability of nutrients (pH). The pH of the solution must not be higher than 7, as this will make soluble salts like Fe^{2+} , Mn^{2+} , PO_3^{4-} , Ca^{2+} , and Mg^{2+} insoluble and lower salt levels. The ideal pH range for plant growth is 5.5 to 6.5. It was discovered that if no action is taken, the pH value will decline from day one to day five, necessitating the use of a solution to elevate the pH. In order to keep the ideal pH level in a 10-liter water container, 2.6ml of the pH-lowering solution is administered every day.

At present, Spread Co Ltd, located in Kyoto, Japan, is the largest automated vertical farm in the world, capable of producing up to 30,000 heads of lettuce per day in an automated farming method using environmental monitoring technology [15]. A variety of approaches have already been explored to produce high-quality crops with the help of smart farming systems and to manage and monitor the systems. In the literature, it has been noticed that there is some work related to IoT-based hydroponic systems. Most studies have focused on hydroponics-based cultivation of conventional vegetables such as tomatoes, spinach, peppers, etc. It also employs Nutritional Film Techniques (NFT) [16] to measure pH, total soluble solids (TDS), and nutritional value in an agricultural system with various sensors. They have achieved greater accuracy by implementing the K-Nearest Neighbor (k-NN) algorithm to predict different nutritional statuses and provide nutrients accordingly. The Hydroponics smart farming system has been researched by various researchers at different times to develop the management and monitoring system. Because the more accurate the operation and monitoring of the system, the higher the production. So, the various sensors used in this hydroponics farming system are BeagleBone Black (BBB) microcontroller for accurate quality management and monitoring along with IoT, Bayesian Network (BN) [17], ZigBee [18], LoRaWAN [19] [20] used networking technology like. As a result, the management and monitoring of the farming system from a distance has become much more perfect. But in the review, each of them had some problems and limitations in their research. The research proposed by [21] presents that their smart hydroponics system developed at normal room temperature, the nutrient supply is manually controlled, and their system does not have any backup energy. In the other literature, when the conductivity sensor is activated the pH value is disturbed, the carbon dioxide level and the air quality is not observed, and crop color analysis is not done to determine crop quality in their system [22]. But in some other studies, temperature, nutrient supply, pH value, etc. are easily monitored and controlled automatically [23]. Also, solar photovoltaic and solar thermal is used as a source of energy for the system which has also been converted into backup power [24].

2.2 Field Specific Theories

2.2.1 *Hydroponics vs traditional farming*

The most easily available growing medium for plants is typically soil. It offers support, nutrients, air, water, and other things necessary for proper plant growth. However, soil can occasionally impose significant restrictions on plant growth. Some of these include the presence of nematodes and disease-causing organisms, inappropriate soil reactivity, unfavorable soil compaction, poor drainage, deterioration brought on by erosion, etc. Additionally, typical soil crop growth (Open Field Agriculture) is rather challenging because it requires a lot of lands, work, and water. In addition, some areas, such as metropolitan areas, lack any soil suitable for crop growth, or we find a shortage of fertile cultivable land area because of poor topographical or geographical characteristics. The inability to get the labor for traditional open-field agriculture has recently become a severe issue. Soilless culture can be introduced successfully in these conditions. Comparing hydroponic farming to traditional farming, there are several benefits. Growing crops on contaminated or arid soil is one of the key benefits. Additionally, plants produced hydroponically are more salt-water tolerant. Another benefit is the absence of pests, creatures, and diseases like fungi in the growing media. For hydroponic farming, labor-intensive tasks like tilling, growing, fumigating, and watering are not necessary. Labor expenses drop significantly if the method is automated utilizing pumps or even computers. The primary drawback of hydroponic systems is their hefty early startup costs. Additionally, in hydroponic systems, diseases can quickly spread to all beds that share a nutrient tank. Therefore, daily inspection is needed. Plants in hydroponic systems receive a properly balanced nutrition. One of the most cutting-edge growing methods is hydroponics, which is highly effective in producing vegetables while protecting the environment. Since plants grow more quickly in hydroponic systems than in traditional soil cultures, crop output is more intensive and repeated throughout the year.

A continuous water flow containing mineral fertilizers is used in hydroponics to grow plants without utilizing soil. This technique saves money, space, energy, and water. Due to the recycling mechanism, it uses 5 to 10 times less water and yields up to 10 to 15 times more food than conventional soil-based systems. Compared to dirt, soilless growing media are more manageable and might offer a superior growing environment. One of the key elements of sustainable protected horticulture is soilless cultivation. In reality, the use of closed growing systems, where drainage water is collected and reused after nutrient replenishment, can lower the consumption of water and fertilizers as well as the environmental degradation that is typically linked to over-irrigation. In terms of water and fertilizer use efficiency, hydroponic greenhouse systems are thought to be better to field production systems. This growing method resulted in a 90% reduction in water usage. Growing the right fig cultivars can also lower farming expenses (manual labor) and the need for fertilizer and pesticide applications. Furthermore, by planning harvest so that high-quality fruit is available all year long, the highest fig market demand might be satisfied. Systems using hydroponics are quite effective. Because most water in conventional farming quickly passes through the root layer, hydroponic plants often consume only one-tenth of the water that soil-grown plants use. Only 25% of the key elements present in fertilizers based on soil are needed in the nutrient solution needed for hydroponic cultivation. In a hydroponic system, more plants can be produced with less space since plants don't have to compete for available nutrient reserves in the soil around them. The sole factor limiting the amount of space is the amount of light. In

hydroponic systems, plants also grow considerably larger and more quickly. As a result, hydroponic systems produce more food per unit of land than conventional farming does [24].

2.2.2 Vertical Farming

Growing food in vertically stacked layers is known as "vertical farming." The technique may employ hydroponic, aeroponic, or soil-growing techniques. In tough circumstances, such as those where arable land is few or unavailable, vertical farms try to generate food. The technique uses skyscraper-like designs and precision agriculture techniques to assist mountainside settlements, deserts, and cities grow various varieties of fruits and vegetables. For improved natural light exposure, most vertical farms use enclosed structures like greenhouses that stack vertically, either directly on top of one another or far apart. When space is at a premium, using hydroponic methods to grow plants rather than soil enables weight reduction and up to a 70% [25] reduction in water usage. Aeroponics further minimizes the amount of water and weight needed. Most vertical farms use hydroponic or aeroponic growing methods instead of runoff, which would add weight to the potted plants. Natural light and artificial light are frequently combined in vertical farming. Artificial lighting is frequently based on LED technology and may be powered by a renewable energy source, such as solar or wind energy [25]. Supporters of vertical farming applaud its potential to improve human health and promote food security both today and in the future. It would enable metropolitan areas to become self-sufficient by using less farming, which might minimize deforestation and pollution. Most designs, according to vertical farming detractors, ineffectively produce the artificial light required to maintain the design green. Many vertical farms spend a lot of money on electricity to get decent yields. Furthermore, some people question whether vertical farming is necessary, claiming that poor use of land rather than a lack of arable land is the real issue.



Figure 2.1: Vertical Farming

2.2.3 Hydroponic System

Growing plants, typically crops, without soil using water-based mineral fertilizer solutions in aqueous solvents is known as hydroponics, a subclass of hydroculture. Plants that are grown on land or in water can have their roots exposed to the nutrient-rich liquid or they can also have their roots physically supported by an inert material like perlite, gravel, or other substrates. Hydroponics, or soilless gardening, is another name for the field of study. It mainly entails cultivating healthy plants without the need for conventional soil by employing a nutrient such as a mineral-rich water solution as a substitute. To thrive, a plant only requires a few specific nutrients,

some water, and sunlight. In addition to growing without soil, plants frequently fare much better when their roots are submerged in water.

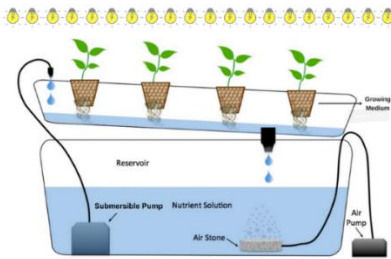


Figure 2.2: Hydroponic System

There are six main types of hydroponic systems to consider for a garden [26]:

- Wicking:** The most fundamental hydroponic technique is the wick system, popularly known as "the training wheels of the hydroponic world." Even before the term "hydroponic" was thought up, this method of growing has been practiced for thousands of years. You'll find systems like these in children's science classes. In a wick system, a wick, such as a rope or a piece of felt, is used to carry nutrients and water to the roots of the plants. The plants are suspended in a growth media, such as perlite or coconut coir. A water and nutrient solution reservoir is located beneath the growing tank. The wick has one end in the solution and the other end in the growing medium. This enables the wick to move the nutrients and water at the same rate that the roots of the plants need them. The nutrients from the wick will be absorbed by the roots whenever they are prepared to do so.

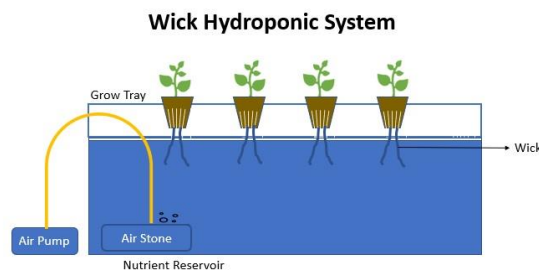


Figure 2.3: Wicking Hydroponic System

- Deep Water Culture (DWC):** For most producers, the deep-water culture (DWC) system is the simplest to manage. A DWC comprises a reservoir that is filled with nutrient solution and water. With the use of a net pot and growing medium, the plants are hung over the reservoir. The reservoir itself covers the roots, giving them a steady supply of water and nutrients. Without oxygen, plant roots risk "drowning." In order to continuously oxygenate the water and provide the roots with the energy they require; you must utilize an air pump with an air stone to pump bubbles into the reservoir.

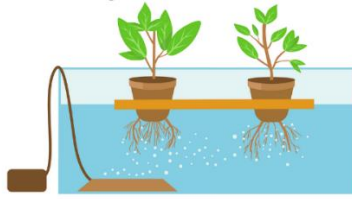


Figure 2.4: Deep-Water Culture (DWC) Hydroponic System

- Nutrient Film Technique (NFT):** The roots of the plants are given a thin nutrient layer by the nutrient film technique (NFT). A sizable reservoir holding the water and nutrition solution is equipped with an air pump and an air stone to maintain oxygen levels (like a DWC system). The roots of NFT-system plants are grown in a nearby channel, as opposed to the submerged roots of a DWC (in net pots). Water is pushed through the canal by a water pump that is timed. In areas where the roots are not totally immersed, this provides the plants with a thin film of nutrients and water. The solution is returned to the system's main reservoir at the channel's terminus for reuse.



Figure 2.5: Nutrient Film Technique (NFT) Hydroponic System

- Ebb And Flow:** The plants are flooded with nutrients on a cycle by an ebb and flow system, commonly known as a "flood and drain" system. As a result of its lack of adaptability to the demands of your plants, this approach is less popular. However, because this approach doesn't expose the plant roots to the fertilizer solution continuously, some gardeners prefer it. To house the plants, you fill a tray with a growth medium. A timed pump will periodically "flood" the tray with a nutritious solution. The plant type, water tests, air temperature, the growth cycle, and other factors all affect the flooding cycle. Gravity allows the solution to drain from the tray and return to the reservoir for later use. As the reservoir sits idle, an air pump should oxygenate the water while it waits for the subsequent flood cycle. If you have robust monitoring procedures in place to understand the nutrients your plants are using during growth, this system may function well.

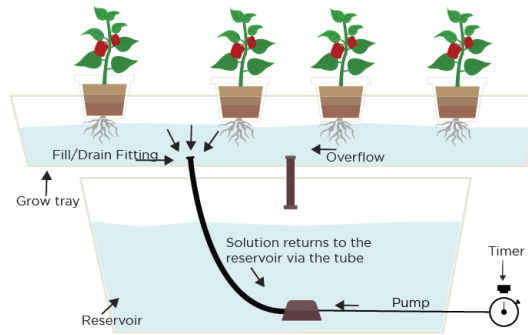


Figure 2.6: Ebb and Flow Hydroponic System

- Aeroponics:** The most sophisticated and frequently most expensive systems are aeroponic ones, but they are also among the most successful ones. The roots and plants in an aeroponic system are suspended in the air. Mistlers located in the reservoir's oxygenating air pump shower a fine mist over the plant roots. Some growers mist continuously with a fine mist, while others mist in cycles. With only a few minutes between each cycle, the misting model's cycle is shorter than the flood and drain type. As a result, the roots may continuously get nutrients without becoming overly saturated or submerged. Additionally, it gives the roots a more natural chance to be exposed to oxygen, which is essential for growth and development.

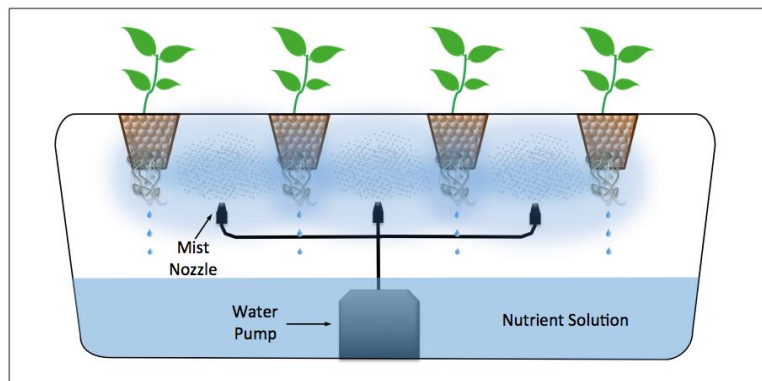


Figure 2.7: Aeroponics Hydroponic System

- Drip Systems:** The most sophisticated and frequently most expensive systems are aeroponic ones, but they are also among the most successful ones. The roots and plants in an aeroponic system are suspended in the air. Mistlers located in the reservoir's oxygenating air pump shower a fine mist over the plant roots. Some growers mist continuously with a fine mist, while others mist in cycles. With only a few minutes between each cycle, the misting model's cycle is shorter than the flood and drain type. As a result, the roots may continuously get nutrients without becoming overly saturated or submerged. Additionally, it gives the roots a more natural chance to be exposed to oxygen, which is essential for growth and development.

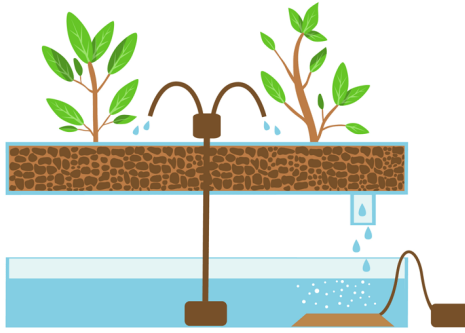


Figure 2.8: Drip Hydroponic System

Because it uses resources more sustainably than traditional growing techniques, hydroponic farming is quickly gaining popularity among gardeners all over the world. Here are a few of its numerous advantages:

- Hydroponics enables plants to develop up to 50% quicker than they would in soil because it continuously and easily provides nutrition. Furthermore, a hydroponic garden may provide fresh food all year round.
- Compared to typical soil gardening, hydroponic farming eliminates the need for herbicides and pesticides, which is great for the environment and the produced product.
- Any water used in hydroponic farming is retained in the system and can be recycled, which lessens the requirement for a steady supply of new water.
- A shortage of arable land frequently results in a reduction in available gardening space. Hydroponics is a fantastic choice for those with little outdoor area or a small balcony. It also works well for interior gardening.

2.2.4 Parameter Specifications

There are important environmental factors that need for the proper growth of a plant such as nutrients, light intensity, air temperature, air humidity, CO₂, and pH.

Nutrients

In the soil and in hydroponic systems, the primary principle of vegetable production is to provide the plants with all the nutrients they require. It is essential for plants to have several chemical elements in order to grow and produce. Without soil, plants are grown in highly oxygenated, nutrient-rich water. The success of a hydroponic system is dependent upon the management of the nutrient solution. To maintain plant growth, soluble mineral elements, water, and oxygen are needed in hydroponic nutrient solutions. Organic matter is broken down by biological decomposition into basic nutrients in the soil. These nutrients are subsequently dissolved in water and taken up by the roots. Everything in the soil needs to be in ideal condition in order to give plants a balanced diet. There are 17 different kinds of components that are essential for a plant's proper growth. These 17 elements were added to the plants in the hydroponic system as nutrient solutions [27].

Nine of these are needed in large quantities for plant growth and are referred to as macronutrients: carbon (C), oxygen (O₂), hydrogen (H), nitrogen (N), phosphorus (P), potassium (K), sulfur (S),

calcium (Ca), and magnesium (Mg). The other eight elements, are classified as macronutrients and include the elements zinc (Zn), iron (Fe), copper (Cu), boron (B), manganese (Mn), cobalt (Co), chlorine (Cl), and molybdenum (Mo), are only required in low amounts. Depending on the grade (pure, technical, food, or fertilizer) utilized, the cost, purity, and solubility of the chemicals making up a nutrition solution might vary significantly. Smaller businesses frequently purchase pre-mixed nutrient formulations, to which water must simply be added to create nutrient solutions. The solutions to standard or slightly modified formulas are prepared by large organizations. In an article written by, the mixing, formula, and other details of nutritional solutions are fully described. Nutrient components are combined in all hydroponic systems in the precise solutions, dosages, and ratios that different plants need. The roots of the plant are in direct touch with the solution. The quality and production of vegetables and fruits are significantly influenced by nutrients. As a result, the quality of the product is greatly influenced by the balanced application of nutrients. In contrast to soil media, soilless media typically require higher nutrient concentrations [27]. Nutrient concentrations in soilless crops are shown in Table 1.

Elements	Ionic form	Concentration range mg/l or ppm
Nitrogen(N)	NO_3^- , NH_4^+	100–200
Phosphorus (P)	H_2PO_4^-	30–15
Potassium (K)	K^+	100–200
Calcium (Ca)	Ca_2^+	200–300
Magnesium(Mg)	Mg_2^+	30–80
Sulfur (S)	SO_4	70–150
Micronutrients		
Boron(B)	BO_3^-	0.03
Copper(Cu)	Cu^{2+}	0.01–0.10
Iron(Fe)	Fe^{2+} , Fe^{3+}	2–12
Manganese (Mn)	Mn^{2+}	0.5–2.0
Molybdenum (Mo)	Mo^{2-}	0.5
Zinc (Zn)	Zn^{2+}	0.5–0.50

Table1.1: Nutrient Concentrations in Soilless Crops [26]

The NPK ratio (150:112:82.5ppm) is optimal for obtaining higher values in terms of growth, yield, and quality [27].

Light intensity

Several research has been done to determine how low light levels or intensities affect crop productivity. Low light is a concern in northern latitudes, according to this research. Due to the production of relatively small fruit, greenhouse yield will be minimal when lighting levels are low or suboptimal. Low light intensity decreased the assimilation of carbon by leaf. Low light intensity caused the buildup of sugar in flowers to decrease. Additionally, tomatoes and strawberries grown in full sunshine will have higher sugar content and dry matter than those produced in shadow. When there is a shading effect in strawberry fruit, there is a reduction in dry matter, sugar, acids, and taste-determining compounds. Due to the weather's shading impact, the flavor of vegetables cultivated in the autumn is occasionally poor. A warning follows, with some crops' flavor being negatively impacted by low light levels. Vegetable crops' internal and external quality are both impacted by excessive illumination. Excessive light in medicinal plants raises the concentration of essential oils and other chemicals. A wide variety of crops are negatively impacted by too much light. Excessive sun energy results in tissue breakdown, cellular death, and pigmentation deterioration [28].

In addition, a plant's growth is influenced by light in three ways: photosynthesis, photorespiration, and photoperiodism. For most greenhouse vegetable crops, light intensities between 50000 and 70000 lux are ideal. For plants to flourish, light is necessary. The light energy is captured and used by the carbohydrate. Reduced light intensity causes photosynthesis to slow down, which has an impact on growth. Even at greater ideal intensities, the damage to the chloroplasts causes the growth to slow down once more. In photoperiodism, a plant's response to the day-night cycle, light plays a second role. Numerous reactions, including leaf form, stem elongation, flowering, and other responses, are governed by the temperature differences between the daylight and nighttime periods. In the winter, light is frequently a constraint. However, light penetration into a crop stand is crucial for determining the microclimate there as well as being an integral part of plant growth. The amount of photosynthesis depends on the brightness of the light and dramatically rises with it. The light intensity used on the greenhouse crops ranged from 100,000 lux on sunny summer days to 3200 lux on cloudy winter days. Neither of the extreme conditions was optimal for the majority of the crops, and many of them were light-saturated. In other words, with light intensities below 32300 lux, the rate of photosynthesis did not rise. Light's wavelength is also significant. Since PSI and PSII absorb energy most effectively around 700 and 680 nm, respectively, light with a higher concentration of energy at these wavelengths will result in a higher rate of photosynthesis [29].

However, the required light spectrum, also known as photosynthetically active radiation, is between 400 and 700 nm, which is visible light (PAR). Additionally, flowering plants require high levels of both red and blue light, whereas non-flowering plants only require high levels of red light [30].

Temperature

The main environmental factor affecting vegetative growth, fruit setting, cluster development, ripening, development, and quality of the fruit is air temperature. The growth rate of the crop is said to be influenced by the average 24-hour temperature; the higher the average air temperature, the quicker the growth. Additionally, it is thought that plants grow taller and their leaves get narrower the more the difference between day and night air temperatures. Maximum fruit output is typically attained with a night temperature of 18 C and a day temperature of 20 C, even though maximum growth is known to occur at a day and night temperature of roughly 25 C [29]. Different levels of temperature have an impact on a plant's chemical reactions and physical characteristics. In general, the growth rate of the various vegetable fruits increased as air temperature goes up. At the same plant, the fruit's biomass production increased when the temperature increased from 18 C to 25 C. Low temperatures have a direct effect on the organoleptic characteristics of vegetables. Less juice and a mealy flavor in the tomatoes are certain signs of low-temperature production. The majority of vegetables' quality is impacted by various temperature patterns. During crop production, consider the impact of temperature variations and contrast the results with crop production at a constant temperature. They discovered that significant temperature variations between day and night should be avoided since they can reduce crop quality. Furthermore, the opening of the cucumber can be brought on by extreme temperature variations linked to growth factors. Despite airflow, cooling, and shade, summertime greenhouse temperatures rise as a result of solar radiation. Fruits like tomatoes, cucumbers, and eggplants change in texture, color, and shape as a result of high temperatures [28].

Air Humidity

Air humidity has an impact on the water status and transpiration (water balance, transpiration cooling, and ion translocation) of hydroponic greenhouse plants. The most challenging environmental aspect to manage is humidity, which is also quite cost-effective, especially when heating. The relative humidity can be managed using a variety of techniques. The best technique to control relative humidity in cool weather is to gently open the exhaust window. Open your windows a little bit to let some of the heat and water vapor go. There are other different approaches that have been tried. Vapor pressure deficits between 0.2 and 1.0 kPa have no impact on crop development or growth. The results of numerous studies on the impact of vapor pressure deficit show that the average weight of tomato plants decreases when the vapor pressure deficit is low in hydroponic greenhouses. There was a decrease in the net accumulation of water in fruit when the hydroponic greenhouse's vapor pressure deficit increased from 1.0 to 2.5 kPa. High humidity levels have an impact on the quality of vegetables [28]. It is crucial to regulate the relative humidity within the greenhouse because it affects the plant's quality. Most crops commonly found relative humidity (RH) between 60 and 75 percent. The tomato seedlings cultivated on peat blocks exhibited limited development and increased water consumption due to the low ambient humidity. The period of a few hours after sunrise is when closed greenhouses experience the most dangerous high humidity levels because solar radiation that is transported into the inside speeds up plant transpiration. By raising RH, the macronutrient content of the plant's leaves dropped. When the plants had grown at high RH, the growth medium's level of macronutrient elements was lowest at the end of the experiment. N and K were the most impacted components. Due to excessive ventilation, the humidity level within the naturally ventilated greenhouses was very low. Relative humidity of 70 to 80 percent within the greenhouse can be controlled as being within a safe range. Normal plant growth takes place between 25 and 80 percent relative humidity, and the growth is positively connected with relative humidity. However, as most pathogenic spores develop at high relative humidity, too much of it is bad for plants [30].

CO₂

One of the most important environmental factors is CO₂ content, and interest in CO₂ enrichment has fluctuated over the duration of agronomy and agriculture history. Several studies on the effects of CO₂ enrichment have been conducted, and it has been found that as CO₂ enrichment in greenhouses grows, so do the plant's dry weight, height, number of leaves, and lateral branches. The rate of photosynthesis normally increases until it is constrained by another factor as an increase in CO₂ concentration accelerates the rate at which carbon is integrated into carbohydrates in the light-independent process. Increases in carbon dioxide concentration produce a rapid increase in the rate of photosynthesis, which finally reaches a plateau when the maximum rate of fixation is reached. This is because carbon dioxide is typically present in the atmosphere in relatively low quantities (approximately 0.04%). Therefore, it is possible to state that the relationship between CO₂ concentration and the photosynthetic rate is direct. Additionally, as CO₂ concentrations rise, other environmental factors (such as temperature and light) also rise. More research should be done on the CO₂ component to better understand how CO₂ enrichment influences the ideal amounts of 2 light, temperature, and air humidity [30] [28].

pH

Chemical characteristics like pH are important factors for the best growth of soilless crops. Depending on the crop type, different pH ranges are advised for soilless media. The pH of the

growth medium is influenced by irrigation and fertilization techniques, media component ratios, and the chemical makeup of the media particles. The availability and absorption of nutrients are significantly influenced by pH. The pH of the medium was optimal between 5.5 and 8.2 [28] [30].

2.2.5 Internet of Things (IoT)

The Internet of Things (IoT) describes the network of physical objects “things” that are embedded with sensors, software, and other technologies for the purpose of connecting and exchanging data with other devices and systems over the internet. These devices range from ordinary household objects to sophisticated industrial tools. With more than 7 billion connected IoT devices today, experts are expecting this number to grow to 10 billion by 2020 and 22 billion by 2025. Oracle has a network of device partners. Over the past few years, IoT has become one of the most important technologies of the 21st century. Now that we can connect everyday objects kitchen appliances, cars, thermostats, and baby monitors to the internet via embedded devices, seamless communication is possible between people, processes, and things. By means of low-cost computing, the cloud, big data, analytics, and mobile technologies, physical things can share and collect data with minimal human intervention. In this hyperconnected world, digital systems can record, monitor, and adjust each interaction between connected things. The physical world meets the digital world, and they cooperate. The development of information and communication technology (ICT) has consistently positively impacted social support, social connectivity, and social isolation, the development of which has established an unprecedented global network throughout human history. According to the World Telecommunication Union's worldwide guideline operation, the Internet of Things (IoT) is a set of sensors, computers, software, and other devices connected to the Internet. The Internet of Things (IoT) is about making "dumb" things "smart" by connecting them to each other and to the Internet. It enables remote sensing and control of physical objects, creating opportunities for more direct integration between the physical world and computer-based systems. Enables embedded devices with IoT sensors to connect and interact with each other via the Internet. Devices can be remotely monitored and controlled in real-time and can include anything from pumps, sheds, and tractors to weather stations and computers.

2.2.6 IoT-Based Monitoring:

An Internet of Things (IoT) platform is an on-premises software package or a cloud service (IoT platform as a service [PaaS]) that monitors, manages, and maybe controls different types of endpoints, frequently through apps that business units implement on the platform. The Ubidots IoT platform is utilized in this project. Students, manufacturers, and researchers may easily and securely construct IoT solutions with Ubidots. It is utilized for delivering data to the cloud from any Internet-enabled device, displaying that data, and setting off actions and alarms based on that data. To help you expand your data-driven business, Ubidots established the world's largest cloud network. With Ubidots, more than 40,000 applications currently connect the dots. A shared resource platform called Ubidots STEM was created to explore problem-solving at no cost or almost no expense. Ubidots STEM is only available for non-commercial applications and comes with 3 free devices.

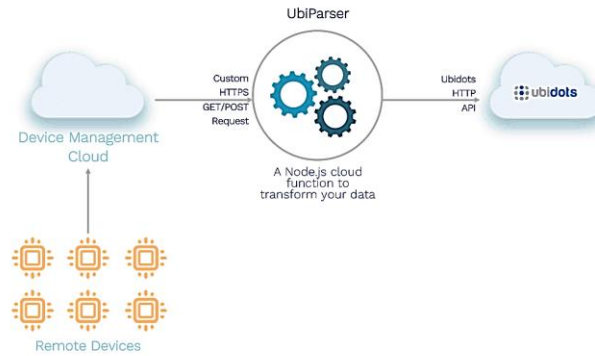


Figure 2.9: Ubidots Cloud Structure

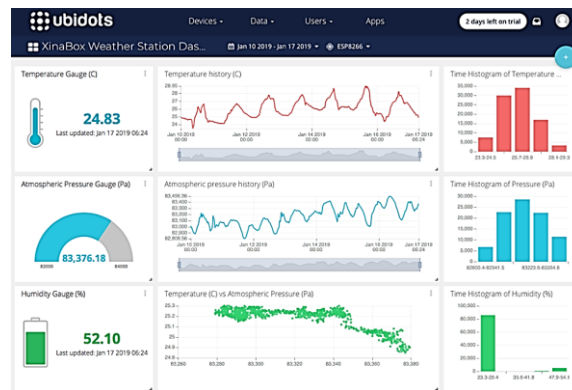


Figure 2.10: Ubidots Dashboard Interface

2.2.7 Embedded System

A microprocessor-based computer hardware and software system known as an embedded system is created to carry out a specific task, either independently or as a component of a larger system. An integrated circuit built to perform computing for real-time processes is at the heart of the system. From a single microcontroller to a group of connected processors with networks and peripherals, complexity can range from having no user interface to having intricate graphical user interfaces. Depending on the task for which it is created, an embedded system's complexity varies greatly. Applications for embedded systems include hybrid cars, avionics, digital watches, microwaves, and more. Embedded systems consume up to 98 percent of all produced microprocessors.

Field-programmable gate arrays (FPGA), GPU technology, gate arrays, application-specific integrated circuits (ASIC), and microcontrollers or digital signal processors (DSP) control embedded systems. These processing systems have integrated parts for handling mechanical and/or electrical interfaces. The firmware for embedded systems, which uses a minimal amount of computer hardware resources, is stored in read-only memory or flash memory chips. Peripherals, which connect input and output devices, allow embedded systems to communicate with the outside world.

The following elements make up an embedded system's fundamental structure:

- **Sensor:** A sensor takes physical measurements and turns them into electrical signals that may be read by an embedded systems engineer or any other electronic device. The quantity that was measured is stored in memory by a sensor.
- **A-D converters:** Analog-to-digital converters turn analog signals from sensors into digital signals.

ASICs and processors: ASICs and processors evaluate data to calculate output and store it in memory.

- **D-A Converter:** A device that converts digital data supplied to a processor into analog data.
- **Actuator:** An actuator saves the approved output after comparing the D-A Converter's output to the actual output that is stored.

2.3 Concepts

In this work, the monitoring system for hydroponic vertical farming is designed in such a way that the sensors and modules used in the entire farm can be clearly monitored. An IoT server named Ubidots is used for monitoring. Where the real-time data of the designed sensors are displayed and based on that data loads of the system can also be controlled. The data can also be stored on a remote server for future reference, sending messages to farm authorities in case of emergency. The data is stored in the system in case of any kind of interruption, and when the system is fixed, the data storage starts again from the last value. Thus, this work, in addition to improving the existing monitoring system in hydroponic vertical farming, makes the whole module more energy-saving and more easily portable than the models already developed.

2.4 Methods

There are two parts to this work first one is IoT-based monitoring which is shown in the figure 2.11 and the other is the embedded system-based automatic controlling part which is shown in figure 2.12. The monitoring part is responsible for collecting, storing, and visualizing data from the sensor panel of the system. The Arduino-based controlling part will receive data from sensors and automatically control the parameters of the hydroponic farm.

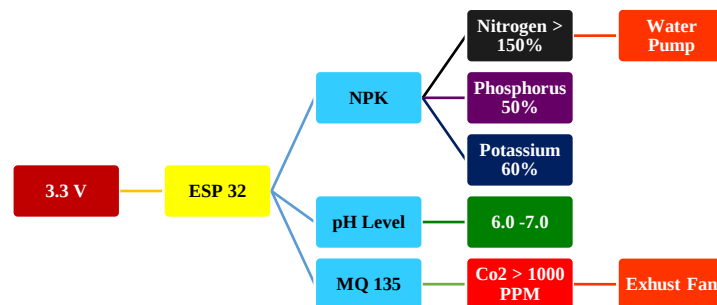


Figure 2.11: Monitoring with IoT Flowchart

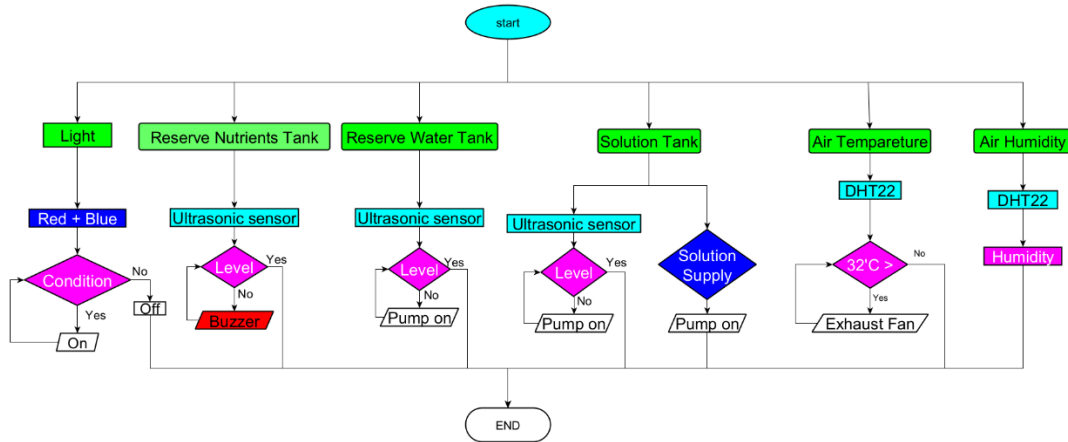


Figure 2.12: Automatic Controlling Flowchart

2.4.1 Structural Setup

The Nutrient Film Technique (NFT) system, which makes it possible to automate hydroponics easily and is a good method for hydroponics at home, is used to build the structure in this project. The building in this project was developed in 4 Steps.

- Setting Up PVC Pipes:** The first step in setting up the system is to drill holes into the 3-foot-long PVC pipe that will hold the net cups. To keep the net cup from falling inside, the holes that retain it are drilled. We used a total of 68 mm (2.7 in) high net cups for a 90 mm diameter PVC pipe for this system (3.5 in). The space between the cups is another crucial element. For plants to grow properly, there needs to be enough room between them. Furthermore, it depends on the kind of plant. For tomatoes, this technique maintains a 6 cm spacing. For the flowing water to reach all the plants and return to the water tank, one side of the PVC pipe is built with a water intake and a U loop on top.



Figure 2.13: Setting Up PVC Pipes

- Building the System Structure:** Plants, roots, growing medium, and water will be contained in PVC pipes that make up the system. Depending on the plants, the growth media, and the pipe's length, all of this may be rather hefty. Additionally, it may be the

heaviest if there is still water in the pipe. To withstand those loads, the structure is built using the same PVC pipes.



Figure 2.14: Building the System Structure

- **Setting Up the Reservoir:** Four buckets were used in this project to hold water; each will contain raw water, raw nutrients, reserve water, and solution water. To maintain water flowing through the system, water pumps will be managed using data from pH and NPK sensors. The level of the water tanks, where the water pump will stop when the water reaches a set height, has also been measured using ultrasonic sensors.



Figure 2.15: Setting Up the Reservoir

- **Transplant the Seedlings:** Various types of growth media are commonly used and tested. In this work, cocoa peat was used as the growing medium. Cocoa peat does a great job of keeping plants healthy due to its anti-fungal properties. It is also resistant to mold, which helps protect against disease and rot as the plant grows. Coconut is also slightly alkaline, and the pH is between 5.8 and 6.8. After planting, this cocoa peat is distributed around the seedlings in net cups.



Figure 2.16: Transplant the Seedlings

2.4.2 Control system

i. IoT-Based Control

Nowadays Internet of Things (IoT) is a very massively usable system. IoT system is used in various sector. IoT utilizes for smooth communication and control all over the world. Google cloud storage will use for better control. In this work, nitrogen (N), phosphorus (P), potassium (K), and pH levels in water and carbon dioxide (CO₂) as harmful gas around the farm are monitored and controlled through this IoT system. The flowchart of this control system is shown in above figure 2.4.1.

The three main macronutrients that plants need in large amounts for plant growth are NPK. All plant life requires these three nutrients, which also exist in nature. Due to their simplicity and low cost, NPK fertilizers are the most commonly available fertilizers. These three nutrients are most important for plants. The amount of each nutrient in the fertilizer is shown by the NPK figure A fertilizer labeled 150-112-82.5 would contain 150ppm nitrogen, 112ppm phosphorus, and 82.5ppm potassium. Monitoring and control of these factors are very important for the healthy growth of a tree. Basically, the NPK sensor will be in the normal water tank which will supply enough water to the entire farm and will accumulate again in that tank. In such a case, if there is a disturbance in the amount of nutrition in the water, the motor of the nutrient mixing tank will be on and continue to supply water until the amount of nutrition is stable.



Figure 2.17: NPK Control & Monitoring

For healthy plants and excellent harvests in soil and hydroponic gardening, ideal pH levels are essential. The maintenance of those ideal values necessitates regular, precise pH monitoring, particularly in soilless growth systems. Ideal pH values increase a plant's ability to absorb nutrients. These nutrients boost a plant's vitality and productivity in turn. The majority of vegetables grown in soil outdoors do well in a variety of soil pH conditions, often from mildly acidic (6) to neutral (7). With hydroponics, producers may precisely control pH levels to establish and sustain ideal circumstances. This prevents nutrient solutions that you give the plants from being wasted and results in healthier, more productive plants. Most plants require slightly lower pH levels when grown hydroponically than are advised for soil-based cultivation. With a high pH of 7, tomatoes grow nicely in the ground outside. Tomatoes grown under hydroponics thrive in more acidic environments, ideally with a pH of 6.0 to 6.5 [31]. They thrive in neutral (7.0) to slightly acidic (6.5) solutions when cultivated hydroponically.



Figure 2.18: pH Control & Monitoring

In the process of photosynthesis, plants employ carbon dioxide (CO_2), water, and sunlight to create sugar. Higher yields can be achieved by promoting earlier flowering, more

blooms, and improved plant growth by raising CO₂ concentrations above ambient (naturally occurring) values. On sunny days, raising CO₂ levels to 1,000 ppm can accelerate photosynthesis by about 50% compared to levels at ambient levels (340 ppm). As CO₂ is used by plants, its level can fall as low as 200 ppm, necessitating the use of supplementary CO₂ to maintain levels at or above ambient. The ideal CO₂ level in low-light situations is between 400 and 600 ppm. The best times of day to apply CO₂ are early in the morning and late at night. When utilizing high-quality CO₂, it is advised to use CO₂ concentrations of 800 to 1,000 ppm for tomato seedlings after the seedlings have become established [32]. Flue gas contaminants can harm young plants.



Figure 2.19: CO₂ Control & Monitoring

ii. **Lighting system**

Energy from light is utilized by plants to produce food through the process of photosynthesis. The only restriction when using artificial grow lights indoors is that they must be on for at least 18 hours every day to accurately mimic the effects of natural sunshine. To support your tomato plants indoors, artificial illumination is required. Because they are more affordable, energy-efficient, long-lasting, and don't heat up as much as the conventional High-Intensity Discharge grow lights used by large-scale hydroponic growers, look for full-spectrum LED grow lights. For optimal results, install LED grow lights no closer than 30 cm away from your indoor cherry tomatoes due to the little quantity of heat they emit. So RTC module is used for maintaining the light on time and off time inside the hydroponic system structure, which is another essential factor for the growth of a plant. On the farm, the LED light will be on at 5 AM, and at 9 PM light will be off. So, a total of 16 hours will be on the light and 8 hours will be off as rest time of the plant. Plant grow LED light Red (for fruiting and blooms) and blue color (for vegetative growth) to give necessary light intensity for the tomato plant to carry on photosynthesis [An AI Based System Design to Develop and Monitor a Hydroponic Farm].

iii. **Cooling System**

In a vertical farm, there are cultivated different types of vegetables and crops. Some of these plants need low temperatures, so the cooling module is playing a vital role in this

case. This system here used a cooling fan to control a certain temperature. When the DHT22 sensor gets an excessive temperature than the defined temperature value, the cooling fan is automatically on and it's still on till the temperature decreases from the defined temperature value. For tomato seedlings, the rated temperature is 10-25 degrees Celsius.

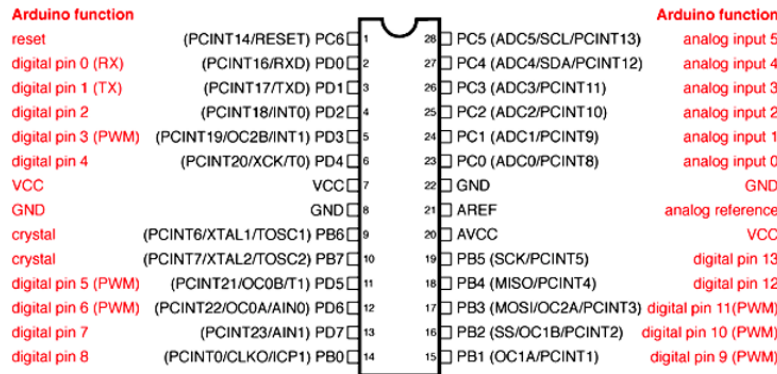


Figure 3.2: ATmega328 Pin Mapping [33]

Also, these microcontroller specifications are given below:

Descriptions	Features
Microcontroller	ATmega328
Operating Voltage	5V
Input Voltage (recommended)	7-12V
Input Voltage (limits)	6-20V
Digital I/O Pins	14 (of which 6 provide PWM output)
Analog Input Pins	6
DC Current for 3.3V Pin	50 mA
DC Current per I/O Pin	40 mA
SRAM	2 KB
Flash Memory	32 KB of which 0.5 KB is used by the bootloader
Clock Speed	16 MHz
EEPROM	1 KB

Table 3.1: Arduino Uno Microcontroller Specifications

Pin	Function	Type	Description
1	NC	NC	Not connected
2	IOREF	IOREF	Reference for digital logic V - connected to 5V
3	Reset	Reset	Reset
4	+3V3	Power	+3V3 Power Rail
5	+5V	Power	+5V Power Rail
6	GND	Power	Ground
7	GND	Power	Ground
8	VIN	Power	Voltage Input
9	A0	Analog/GPIO	Analog input 0 /GPIO
10	A1	Analog/GPIO	Analog input 1 /GPIO
11	A2	Analog/GPIO	Analog input 2 /GPIO
12	A3	Analog/GPIO	Analog input 3 /GPIO

13	A4/SDA	Analog input/I2C	Analog input 4/I2C Data line
14	A5/SCL	Analog input/I2C	Analog input 5/I2C Clock line

Table 3.2: Arduino Uno Analog pin specifications

Pin	Function	Type	Description
1	D0	Digital/GPIO	Digital pin 0/GPIO
2	D1	Digital/GPIO	Digital pin 0/GPIO
3	D2	Digital/GPIO	Digital pin 0/GPIO
4	D3	Digital/GPIO	Digital pin 0/GPIO
5	D4	Digital/GPIO	Digital pin 0/GPIO
6	D5	Digital/GPIO	Digital pin 0/GPIO
7	D6	Digital/GPIO	Digital pin 0/GPIO
8	D7	Digital/GPIO	Digital pin 0/GPIO
9	D8	Digital/GPIO	Digital pin 0/GPIO
10	D9	Digital/GPIO	Digital pin 0/GPIO
11	SS	Digital	SPI Chip Select
12	MOSI	Digital	SPI1 Main Out Secondary In
13	MISO	Digital	SPI Main In Secondary Out
14	SCK	Digital	SPI serial clock output
15	GND	Power	Ground
16	AREF	Digital	Analog reference voltage
17	A4/SD4	Digital	Analog input 4/I2C Data line (duplicated)
18	A5/SD5	Digital	Analog input 5/I2C Clock line (duplicated)

Table 3.3: Arduino Uno Digital pin specifications [33]

Ultrasonic sensors

The Ultrasonic sensors use ultrasonic waves to measure distances to objects. Here the Vcc must be connected to 5V. Arduino Uno sends a control signal to the Trig pin. Arduino Uno receives a signal from the Echo pin. The Arduino Uno calculates the distance based on the duration of the pulse. The ultrasonic sensor automatically emits ultrasonic waves. After hitting an obstacle, the ultrasonic wave reflects back. Ultrasonic sensors detect reflected waves and measure their travel time. In this project, an ultrasonic sensor is used to measure the reserve water tank level, nutrients tank level, and solution tank level. The ultrasonic sensor is shown in figure 3.3 [34].



Figure 3.3 Ultrasonic sensor

Water pump

Water is limited here, so a water pump circulates it. And another purpose is to use the water pumps for automated adding reserve water, and raw water, supplying the hydroponics solution to the entire system, and mixing the solution well. There are two types of water pumps. One is a 12 V DC water pump and another is a 6 V DC water pump. The 12V DC water pump is shown in figure 3.4 and the 6V DC water pump is shown in figure 3.5.



Figure 3.4: 12V Water pump



Figure 3.5: 6V Water pump

NPK Sensor

The NPK sensor measures nitrogen, phosphorus, and potassium content. The hydroponic solution's nutrients can be determined by it. The sensor can be buried in the soil for a long time. To ensure long-term operation, the probe is rust-resistant, electrolytic-resistant, and salt & alkali corrosion-resistant. Chemical reagents are not required for the sensor. It can be used with any microcontroller since it is the fastest response speed, high measurement accuracy, and good interchangeability. Due to its Modbus Communication port, the sensor cannot be used directly with the microcontroller. To connect the sensor to the microcontroller, there needs to be a Modbus Module such as RS485/MAX485. There is the use of a Modbus Module MAX485 sensor which is shown in figure 3.7. Sensors operate on 9-24V and consume very little power. There are use 12V for this sensor. Approximately 2% of the accuracy of the sensor can be achieved. It can measure nitrogen, phosphorus, and potassium up to 1 mg/kg (mg/l). It is possible to make an Arduino-based NPK meter or any other cloud IoT-based nutrient content monitoring system using this NPK sensor. This sensor measures the nutrient solution level and automatically controls the nutrient level. The NPK sensor is shown in figure 3.6. [35].



Figure 3.6: NPK sensor

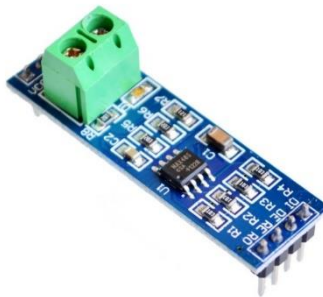


Figure 3.7: MAX 485 module

pH sensor

Water and other liquid substances can be accurately measured using a potential hydrogen sensor (pH). The negative logarithm of the concentration of H^+ ions is known as pH. The concentration of hydrogen ions in a solution is described by the pH scale, which also serves as a measurement for the solution's acidity or basicity. The pH scale is a range of 0 to 14, with 7 representing neutral. If a pH value of above 7 denotes a base, while a pH value of less than 7 indicates an acidic substance. There are two electrodes on pH probes one is a sensor electrode and another is a reference electrode that measures the hydrogen-ion activity in a solution. By measuring the voltage generated by ions exchanging, a pH meter converts the voltage into a pH value that can be read. A pH electrode is a passive sensor, so there is no need for an excitation source such as voltage or current. It is classified as a bipolar sensor because its output swings above and below its reference point. Depending on the pH of the solution being measured, it produces a voltage output. This is a Laboratory Grade sensor and it needs a 3.3 to 5.5V power supply and grounding. This sensor measurement accuracy is ± 0.1 at $25^\circ C$, and its working temperature range is 5 to $60^\circ C$. In this project, this pH sensor is used for monitoring and controlling the hydroponic solution pH level. This pH sensor is shown in figure 3.8. [36].



Figure 3.8: pH sensor

MQ 135 sensor

The MQ135 Gas Sensor detects a wide range of gasses, including carbon dioxide (CO_2), ammonia (NH_3), sulfur (S), benzene (C_6H_6), and other hazardous gasses. The MQ135 gas sensor is highly sensitive to ammonia, sulfur dioxide, and benzene steam, as well as smoke and carbon dioxide. In addition to the analog output pin, this gas sensor also has a digital output pin. The digital pin goes high when the level of these gasses in the air exceeds a threshold limit. The measuring range of this gas sensor module is 10 to 1000 Ppm. There is the use of this sensor for measuring the air quality and for automatic controlling purposes. The MQ135 sensor is shown in figure 3.9. [37]



Figure 3.9: MQ 135

Exhaust fan

An exhaust fan is typically installed in a kitchen or bathroom to remove stale, muggy, or dirty air. By removing unwanted odors, moisture, smoke, and other pollutants from the air, exhaust fans work. Exhaust fans operate by pulling hot or muggy air out of restricted space and letting fresh air in from somewhere else (perhaps a doorway or vent) to replace it. A ducting system is used to transport the warm air that is extracted by an exhaust fan outside. Exhaust fans can be divided into two types. The first type of fan is an axial fan, which looks like a propeller and draws air straight through it. Another type is centrifugal fans, which are shaped like squirrel cages and exhaust air at a 90-degree angle. There are the use of this axial type exhaust fan controls the air quality by removing CO₂ or other pollution in the air. The axial exhaust fan is shown in figure 3.10.



Figure 3.10: Exhaust Fan

DHT22

The DHT22 is a basic, low-cost digital temperature and humidity sensor. It uses a capacitive humidity sensor and a thermistor to measure the surrounding air and spits out a digital signal on the data pin (no analog input pins are needed). There is only one data pin for Arduino and a 3.3 to 6V DC power supply and also a ground pin. There are using a 5V power supply for this sensor. The DHT22 is suitable for a variety of harsh applications because of its small size, low power consumption, and long transmission distance (20m). In addition to being more expensive, and also it is higher specifications. It measures temperatures from -40 to +80 degrees Celsius with ± 0.5

degrees accuracy. Moreover, this sensor measures humidity better, from 0 to 100% with 2-5% accuracy. This sensor sensitivity or resolution is 0.1degree Celsius and humidity is 0.1%RH. There is use this sensor for measuring the air temperature and humidity and also for automatic controlling purposes. The DHT22 sensor is shown in figure 3.11. [38].



Figure 3.11: DHT22

Light (green, blue)

A plant's growth is impacted by light in three ways: photosynthesis, photorespiration, and photoperiodism. For the majority of greenhouse vegetable crops, light intensities between 50000 and 70000 lux are optimal. In photoperiodism, light plays a second role, and in a plant's response to the day-night cycle [26]. Most vertical farms use very effective Light-Emitting Diodes (LEDs), with customized bulbs that use only the red and blue light spectra, which are best for maximizing plant development. For that reason, there are to use red and blue LED. The red LED is shown in figure 3.12 and the blue LED is shown in figure 3.13.



Figure 3.12: Red LED



Figure 3.13: Blue LED

LDR sensor

Photoresistors are also known as light-dependent resistors (LDRs). High-resistance semiconductors are used in LDR. Photons give electrons energy when they hit the device. Since the LDR sensor does not require an external voltage source to function, it is a passive sensor. When light of varying intensity falls on it, it acts as a variable resistor, changing its resistance accordingly. LDR is a higher resistance when the light level is decreased. Also, LDR gives a lower resistance when the light level increases. The LDR is shown in figure 3.14.



Figure 3.14: LDR

ESP 32

The ESP32 is a series of low-cost, low-power systems on a chip with integrated dual-mode Bluetooth and Wi-Fi. Espressif Systems developed the ESP32 chip. By integrating Wi-Fi, Bluetooth, and Bluetooth LE, modules are truly versatile and can target a wide range of applications. The use of Wi-Fi ensures a wide range of connectivity. This chip creates its own wireless network which is ESP32 Soft-Access Point. This Wi-Fi network can be accessed by other devices. A station is set up for the ESP32 client. As a result, it can connect to the wireless network of the ESP32 server. By reducing the communication stack overhead on the main application processor, it may operate both independently and as a slave to a host MCU. There are 48 pins on this chip, which can be used for a variety of functions. All ESP32 development boards cannot expose all pins, and some pins cannot be used. This chip is used to send sensor data to the Arduino IoT cloud server. The ESP32 is shown in figure 3.15.

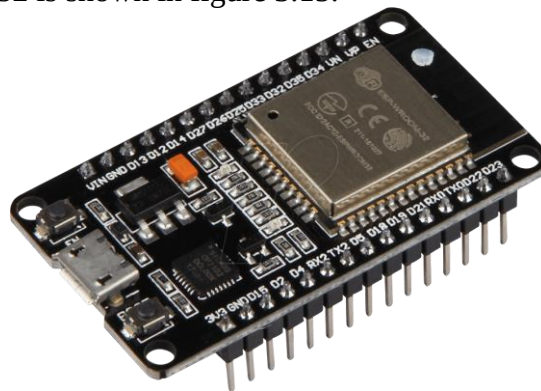


Figure 3.15: ESP 32

Relay

A 5V relay controls a high-current using a low-current signal in an automatic control circuit. Electromagnetic induction is the basis of relay operation. By applying some current to the electromagnet, a magnetic field is created. An electromagnet is created by the copper coil and iron core in a relay. The coil begins to attract contact when DC current is applied to it. Relays are energized by this process. When the supply is cut off, it returns to its original position. Relays are de-energized by this process. A relay signal has an input voltage between 0 and 5 volts. There is the use of this relay for automatic switching purposes. The relay module is shown in figure 3.16.



Figure 3.16: Relay

Power supply

There is a 12V 5A DC power supply to power up the entire system. This power supply input voltage is 230V AC and the output is 12V 5A DC. The power supply is shown in figure 3.17.



Figure 3.17: Power Supply

PVC Pipe

Here is to use PVC pipe to create the whole structure in this project. The entire hydroponic structure builds on this PVC pipe which is shown in figure 3.18.



Figure 3.18: PVC Pipe

Pipe

There are to use these soft and flexible PVC pipes which is shown in figure 3.19 supply the solution to the entire system. Also, supply the groundwater to the reserve tank, reserve water supplies the solution tank, and nutrients supply the solution tank.



Figure 3.19: Soft and Flexible PVC Pipe

Water Bucket

There are to use this plastic bucket which is shown in figure 3.20 for storing the solution, and reserve water, groundwater, and nutrients.



Figure 3.20: Plastic Bucket

One Time Cup

There are to use this one-time cup which is shown in figure 3.21 for planting the plant. After planting the plant this cup is fixed to the structure and then the solution supply to this cup. The plant will automatically absorb the nutrients.



Figure 3.21: One-time Cupe

3.2 Simulation

This hardware system is divided into two parts one is an IoT-related monitoring part and another is without an IoT-related automatic controlling part. The entire system of automatic controlling parts is simulated on Tinkercad but the rest of the parts are not simulated because of the limitation of the library file. The Tinkercad interface is shown in figure 3.22.

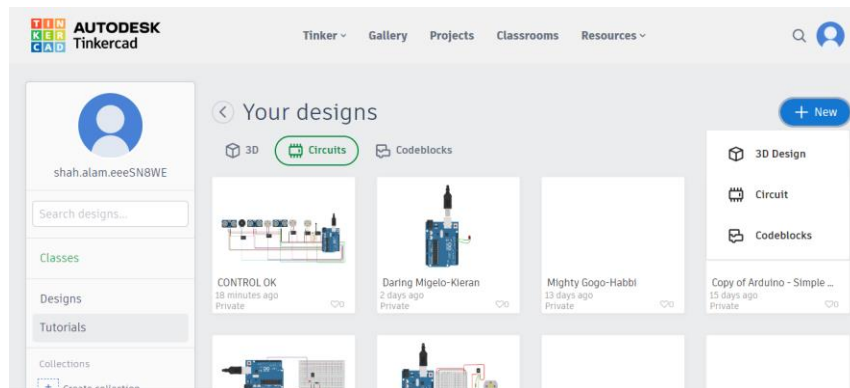


Figure 3.22: Tinkercad Interface

The simulation circuit diagram of the controlling part is shown in Figure 3.23.

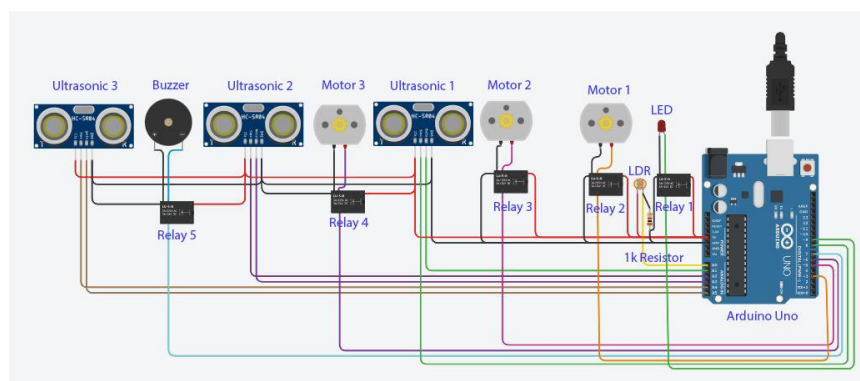


Figure 3.23: Automatic Control Simulation Circuit Diagram

In this portion, here is the use of three DC motors first one is to supply the hydroponics solution to the entire system. The second one is the use to supply raw water into the reserve water tank. And the last one is the use to supply the reserve water into the solution tank. This component counts from right to left. The hydroponics solution supply pump is on all the time which is shown in Figure 3.24 and there is use a red box mark indicator.

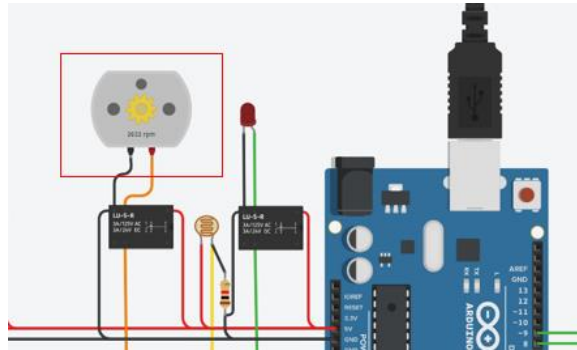


Figure 3.24: Hydroponics solution pump on

There is the use of three ultrasonic sensors for monitoring and automatic controlling of the reserve water tank level, raw nutrients tank level, and hydroponics solution tank level. The first one is the use to monitor reserve water tank levels. Once the water level is above 20cm then the DC water pump will automatically on as shown in figure 3.25. This water pump is on until then the level rich up to below 10cm. When this water level is below 10 cm then the water pump is automatically off as shown in figure 3.26.

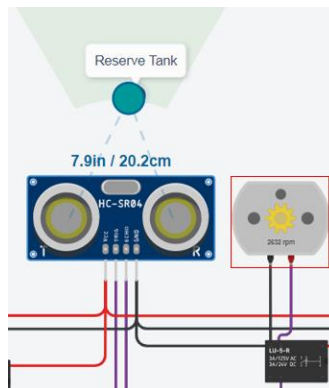


Figure 3.25: Ground Water pump is automatically on.

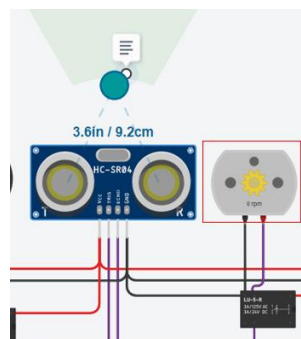


Figure 3.26: Ground Water pump is automatically off.

The second one is the use to monitor hydroponics solution tank levels. Once the solution level is above 20cm then the reserve water pump will automatically on as shown in figure 3.27. This reserve water pump is on until then the level rich up to below 10cm. When this solution level is below 10 cm then the reserve water pump is automatically off as shown in figure 3.28.

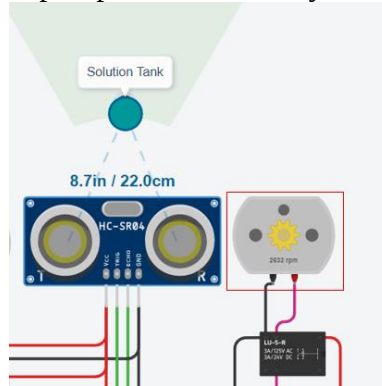


Figure 3.27: Reserve Water pump is automatically on

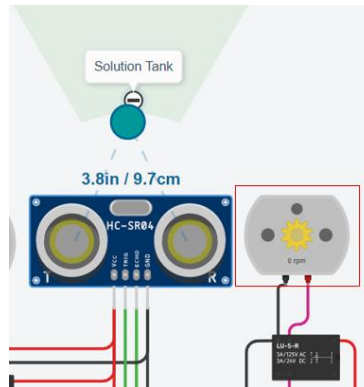


Figure 3.28: Reserve Water pump is automatically off

The third one is the use to monitor nutrient tank levels. Once the nutrient level is above 20cm then the buzzer will automatically on as shown in figure 3.29. This buzzer is on until then the level rich up to the below 10cm. When this nutrient level is below 10 cm then the buzzer is automatically off as shown in figure 3.30.

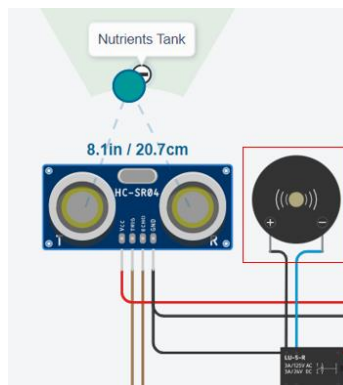


Figure 3.29: Buzzer is Automatically on

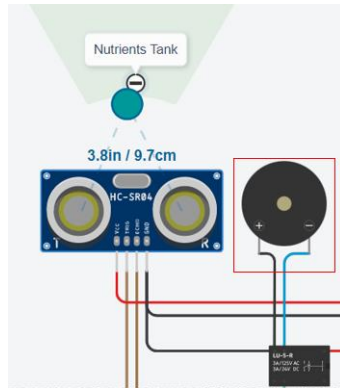


Figure 3.30: Buzzer is Automatically off

There are also used LDR for controlling the light. If sunlight falls into the LDR then this LDR is decrease its resistance and an Arduino HIGH the PIN 09. This PIN 09 is connected to a relay and this relay work as a magnetic switch. When an Arduino PIN 09 is high then the relay is also on and the light is automatically on. However, if sunlight does not fall into the LDR then this LDR is increasing its resistance, and an Arduino LOW the PIN 09. As a result, the relay is off and also light is automatically off. Without sunlight, the simulation is shown in figure 3.31. As a result, the light is off. With sunlight, the simulation is shown in figure 3.32. As a result, the light is on.

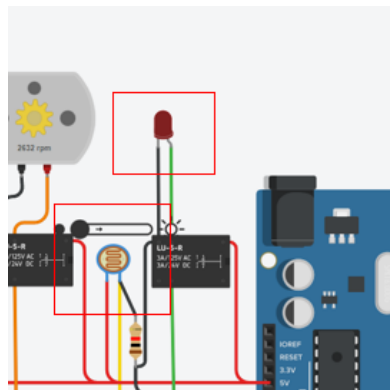


Figure 3.31: Light Control using LDR without sunlight

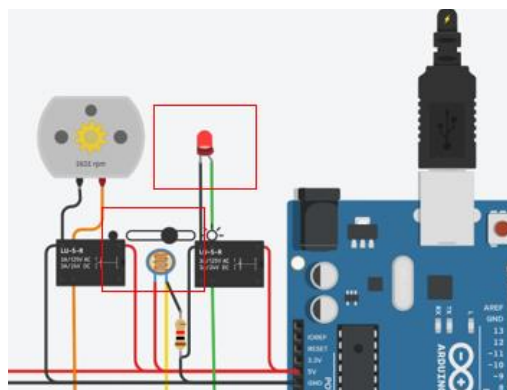


Figure 3.32: Light Control using LDR with sunlight

3.3 Implementation

3.3.1 IoT System

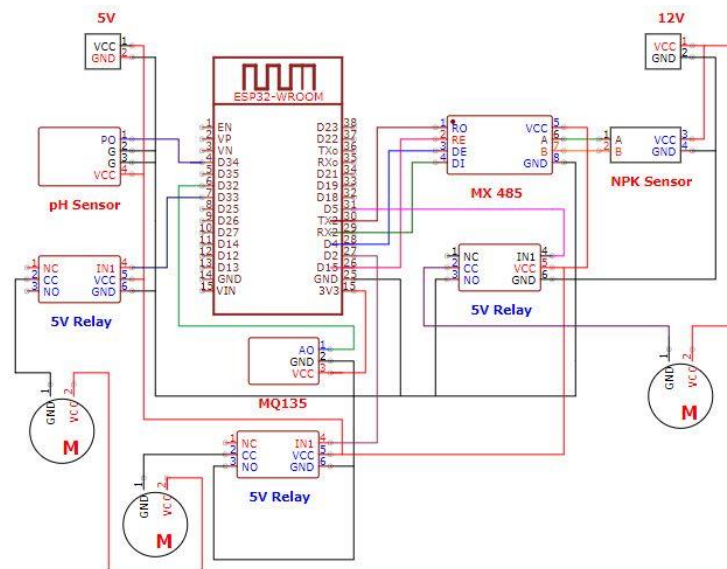


Figure 3.33: Circuit Diagram of IoT-based monitoring and control System

The ESP32 module is powered by a 3.3-5V DC supply. For this, here a 5V charging adapter is used. A 12V AC-DC adapter is used here to power up the entire load. Also, in this controlling part, five 3V relays are used here for controlling the power of the cooling fan, exhaust fan, and water pump.

- At first, all sensors, loads & relay GND pins are connected in series with the ESP32 module.
- To power, the pH Sensor uses an external 5V DC supply from the adapter. The output pin of the pH Sensor module was connected to the 34 of ESP32 which is used as an analog pin.
- To control the water pump according to the value of pH, a 5V DC relay is connected to the ESP32 board pin 33, and with the changes in pH value, the water pump is turned on or off.
- To power, the NPK Sensor also uses an external 12V DC supply from the adapter, and to power MAX 485 module, the VCC pin is connected with the 3.3V pin of the ESP32 board. The output pin of the NPK Sensor module was connected to the 34 of ESP32 which is used as an analog pin. Sensor pins A & B are connected with the same pin of the MAX 485 module. The MOD pin (RO, DI) of the MAX 485 module is connected with the 17 & 16 pins of the ESP32 board, and the RE & DE pins are connected with the 4 & 15 pins of the ESP32 board.
- To control the water pump according to the value of nitrogen, a 5V DC relay is connected to the ESP32 board pin 5 and with the changes in nitrogen value, the water pump is turned on or off.

- The MQ135 gas sensor is powered up with the connection of the VCC pin and the Vin pin of the ESP32 board. Here Vin pin is supplied 5V DC to the sensor. The sensor data pin is connected to pin 32 of the ESP32 board.
- To control the exhaust fan according to the value of CO₂, a 5V DC relay is connected to the ESP32 board pin 23, and with the changes in CO₂ value, the exhaust fan is turned on or off.

3.3.2 Embedded System

A circuit diagram of the automatic controlling without an IoT is shown in figure 3.34.

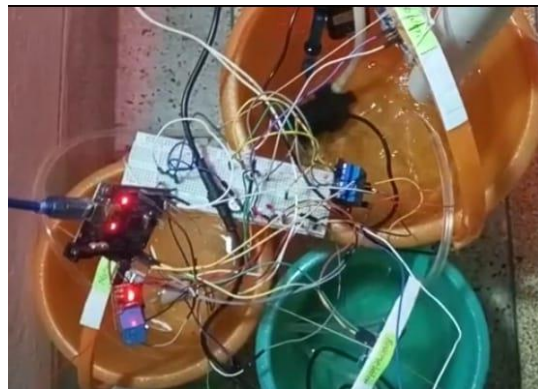


Figure 3.34: Embedded system-based Implemented Circuit Diagram.

- A 12V adapter is used here to power up the entire system. Also, in this controlling part, five 5V relays are used here for controlling the light and motor power.
- First of all, all relay VCC and GND pins and all ultrasonic sensors VCC and GND pins are to connect to the Arduino 5V and GND pins.
- Then relay 1 data pin to connect to the Arduino pin 9. Then 12V LED positive pin is connected to the relay 1 NO pin. And relay 1 CO pin is to connect to the positive pin of the power supply. Then LED negative pin connects to the GND of the 12V power supply. And then one LDR pin connects to the 5V of the Arduino pin and another LDR pin connects to the 1k resistor. Another pin of 1k resistor connects to the GND pin of relay 1.
- Next, the relay 2 data pin connects to the Arduino 3 pin, the relay 2 NO pin connects to the positive pin of motor 1, and the relay 2 CO pin is to connect to the positive pin of the power supply. Then motor 1 negative pin connects to the GND of the power supply.
- The relay 3 data pin is to connect to the Arduino 5 pin, the relay 3 NO pin connects to the positive pin of motor 2, and the relay 3 CO pin is to connect to the positive pin of the power supply. Then motor 2 negative pin connects to the GND of the power supply. Then ultrasonic 1 trig pin connects to the Arduino 8 pin and the echo pin connects to the Arduino A1 pin.

- The ultrasonic 2 trig pin connects to the Arduino A2 and the echo pin connects to the Arduino A3 pin. Then relay 4 data pin connects to the Arduino pin 6. Relay 4 CO pin connects to the positive pin of the power supply and relay 4 NO pin connects to the positive pin of motor 3. Then motor 3 negative pin connects to the GND pin of the power supply.
- The ultrasonic 3 trig pin connects to the Arduino A4 and the echo pin connects to the Arduino A5 pin. Then relay 5 data pin connects to the Arduino pin 7. Relay 5 CO pin connects to the positive pin of the power supply and relay 7 NO pin connects to the positive pin of the buzzer. Then buzzer GND pin connects to the GND pin of the power supply.
- The DHT22 temperature & humidity sensor is powered up with the connection of the VCC pin and the 5V pin of the Arduino UNO board. The sensor data pin is connected to pin 10 of the Arduino UNO board.
- To control the cooling fan according to the value of temperature, a 5V DC relay is connected to the Arduino UNO board pin 11 and with the changes in temperature value, the cooling fan is turned on or off.

CHAPTER FOUR

RESULT AND DISCUSSION

Introduction

This chapter contains the implementation result of the Arduino Uno-Based Automated Controlling System and IoT-Based Control and Monitoring System. As well, as the analysis of the data that is recorded from different sensors in the monitoring system using Ubidots and results of both the monitoring and the controlling parts and details observations of the project.

4.1 Arduino Uno-Based Automated Controlling System

After assembling the controlling part all sensors are to check as per the design. As per the condition the solution supply motor 1 is on, as shown in Figure 4.1. and Arduino IDE serial monitor data is shown in figure 4.2.

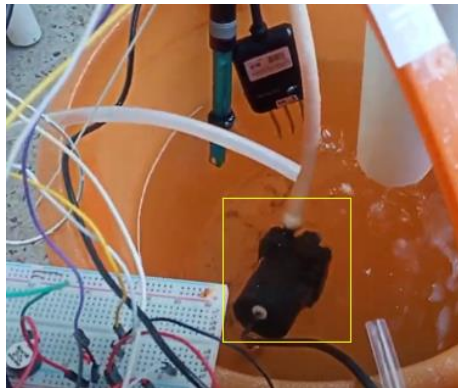


Figure 4.1: Solution Pump is on

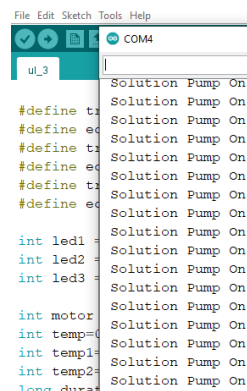


Figure 4.2: Arduino IDE Serial Monitor Data

In this project firstly control the light using a ds3231 sensor. DS3231 is a timer sensor but there are facing some problems with this sensor that is once electricity is gone then this sensor is

automatically reset for that reason DS3231 sensor is counting the time from the beginning. The DS3231 implementation circuit diagram is shown in figure 4.3. There is a DS 3231 sensor implemented only for 30 sec because electricity is interrupted so many times and there is no use power backup in this project. Initially light is off as shown in figure 4.4. when the time is 05 sec then the light is automatically on as shown in figure 4.5. And after 30 sec light is automatically off which is shown in figure 4.6. Arduino serial monitor data is shown in figure 4.7

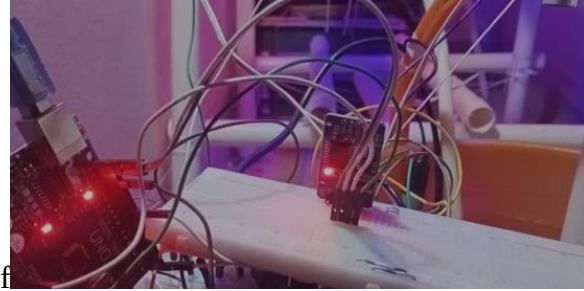


Figure 4.3: Implementation Circuit Diagram of DS3231



Figure 4.4: Initially Light is Off

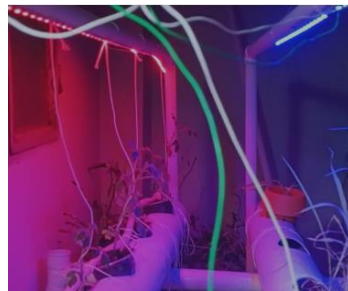


Figure 4.5: Light is on when Time is 5 sec



Figure 4.6: Light is off when time is 30 sec

```

sketch_oct10a$
#include <DS3231.h>

int Relay = 4;

DS3231 rtc(SDA, SCL);
Time t;

const int OnHour = (0,0,5);
const int OffHour = (0,0,35);

void setup() {
  00:00:02 Light Off
  00:00:03 Light Off
  00:00:04 Light Off
  00:00:05 Light On
  00:00:06 Light On
  00:00:07 Light On
  00:00:08 Light On
  00:00:09 Light On
  00:00:10 Light On
  00:00:11 Light On
  00:00:12 Light On
  00:00:13 Light On
  00:00:14 Light On
  00:00:15 Light On

```

Figure 4.7: Arduino Serial Monitor Data for DS3231

Electricity is interrupted so many times that reason light control system switch to LDR. Light control by the LDR circuit diagram is shown in figure 4.8 And the LED is on when sunlight falls into the LDR, shown in Figure 4.9. The LED goes off when LDR goes to darkness, shown in Figure 4.10. and the Arduino IDE serial monitor data is shown in figure 4.11.

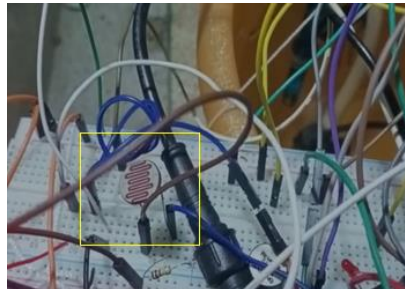


Figure 4.8: Light Control by the LDR Implementation Circuit Diagram



Figure 4.9: LED is On When LDR is in Light Mode

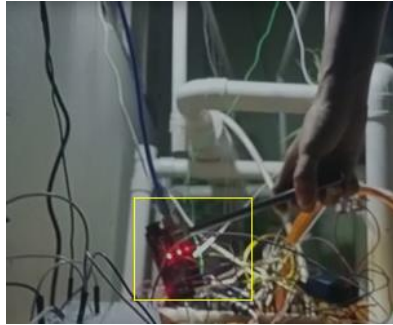


Figure 4.10: LED is On When LDR is in Dark Mode

<pre> sketch_oct10a \$ #include <DS3231.h> int Relay = 4; DS3231 rtc(SDA, SCL); Time t; const int OnHour = (0,0,5); const int OffHour = (0,0,35); void setup() { </pre>	<pre> 00:00:02 Light Off 00:00:03 Light Off 00:00:04 Light Off 00:00:05 Light On 00:00:06 Light On 00:00:07 Light On 00:00:08 Light On 00:00:09 Light On 00:00:10 Light On 00:00:11 Light On 00:00:12 Light On 00:00:13 Light On 00:00:14 Light On 00:00:15 Light On </pre>
---	---

Figure 4.11: Arduino IDE Serial Monitor Data for LDR

There are use the ultrasonic sensor for measuring the water level of the tank. The ultrasonic sensor is fixed on the top of the water bucket for that reason ultrasonic measuring distance decreasing means the level is going up. On the other hand, the ultrasonic measuring distance increasing means the level is going down. So, if the reserve water level is below 20 cm, then the groundwater pump is on, as shown in figure 4.12. and this groundwater pump goes off when the water level is rich by 10 cm. which is shown in figure 4.13. and Arduino serial monitor data as shown in figure 4.14.



Figure 4.12: Ground Water Pump is on



Figure 4.13: Ground Water Pump is off

```

File Edit Sketch Tools Help
COM4
ul_3
#define ts Ground Water Pump On
#define ed Ground Water Pump On
#define ts Ground Water Pump On
#define ed Ground Water Pump On
#define ts Ground Water Pump On
#define ed Ground Water Pump On
#define ts Ground Water Pump On
#define ed Ground Water Pump On
int led1 = Ground Water Pump On
int led2 = Ground Water Pump On
int led3 = Ground Water Pump Off
int motor = Ground Water Pump Off
int temp0 = Ground Water Pump Off
int temp1 = Ground Water Pump Off
int temp2 = Ground Water Pump Off

```

Figure 4.14: Ground Water Pump Serial Monitor Data

As per the condition if the solution level is below 20 cm, then motor 3 is on as shown in figure 4.15 and this motor 3 goes off when the solution level is rich 10 cm. as shown in figure 4.16. and Arduino serial monitor data as shown in figure 4.17.

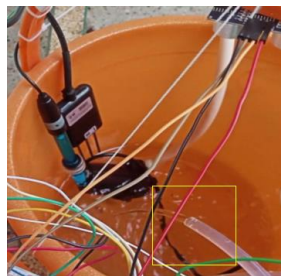


Figure 4.15: Motor 3 is on

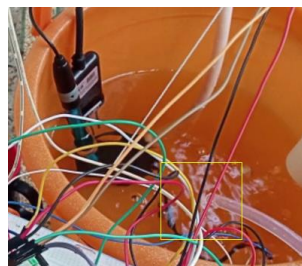


Figure 4.16: Motor 3 is off

```

File Edit Sketch Tools Help
COM4
ul_3
Reserve Water Pump On
#define t Reserve Water Pump On
#define e Reserve Water Pump On
#define t Reserve Water Pump On
#define e Reserve Water Pump On
#define t Reserve Water Pump On
#define e Reserve Water Pump On
#define t Reserve Water Pump On
#define e Reserve Water Pump On
int led1 = Reserve Water Pump On
int led2 = Reserve Water Pump On
int led3 = Reserve Water Pump Off
int motor = Reserve Water Pump Off
int temp = Reserve Water Pump Off
int temp1 = Reserve Water Pump Off
int temp2 = Reserve Water Pump Off
long durat Reserve Water Pump Off

```

Figure 4.17: Arduino Serial Monitor Data for Reserve Water Pump

Next, as per the condition if the nutrient level is below 20 cm, then the buzzer is on as shown in figure 4.18. This buzzer goes off when the nutrient level is rich 10 cm, as shown in Figure 4.19.



Figure 4.18: Buzzer is on



Figure 4.19: Buzzer is off

4.2 IoT-based Monitoring, Controlling, and Data Storing System

The output pin of the pH Sensor module was connected to the 34 of ESP32 which is used as an analog pin. To control the water pump according to the value of nitrogen, a 5V DC relay is connected to the ESP32 board pin 33, and with the changes in pH value, the water pump is turned on or off. For tomato seedlings, the pH level should be 6.5-7. So, when the pH Level is rise from the rated level of 7, the reserve tank water pump will be on. And, when the pH Level is below 7, then the reserve tank water pump will be off.



Figure 4.20: pH Level Monitor & Control

The output pin of the NPK Sensor module was connected to the 34 of ESP32 which is used as an analog pin. To control the water pump according to the value of nitrogen, a 5V DC relay is connected to the ESP32 board pin 5. For tomato seedlings, the NPK level should be 150-50-60. So, when nitrogen is below the rated level of 150, the nutrient tank water pump will be on. And, when the nitrogen Level is equal to 150, then the nutrient tank water pump will be off.

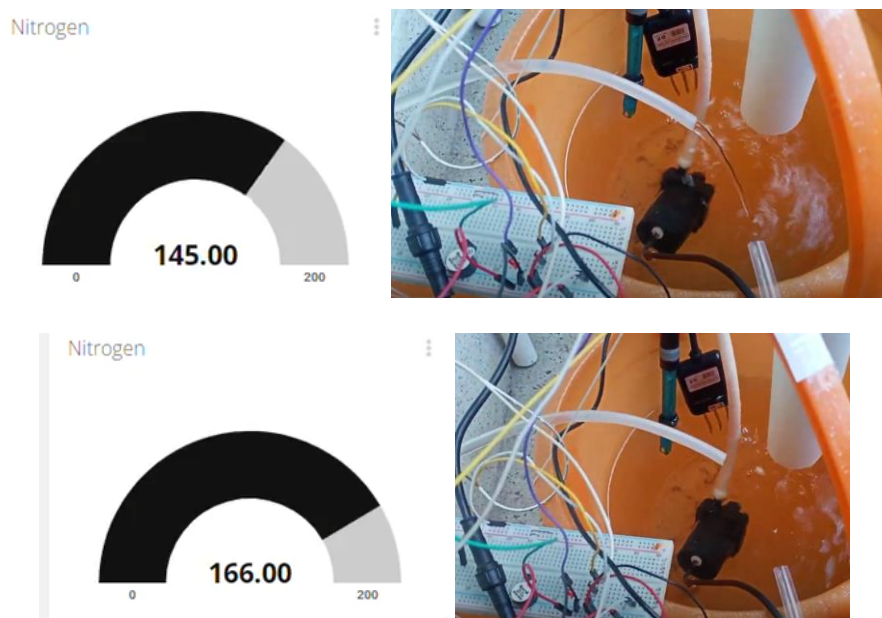


Figure 4.21: NPK Level Monitor & Control

The sensor data pin is connected to pin 32 of the ESP32 board. To control the exhaust fan according to the value of CO₂, a 5V DC relay is connected to the ESP32 board pin 23, and with the changes in Co2 value, the exhaust fan is turned on or off. For tomato seedlings, the CO₂ level should be 800-1000. So, when the CO₂ level is rise up from the rated level of 1000, the exhaust fan will be on. And, when the CO₂ Level is between 1000, then the exhaust fan will be off.

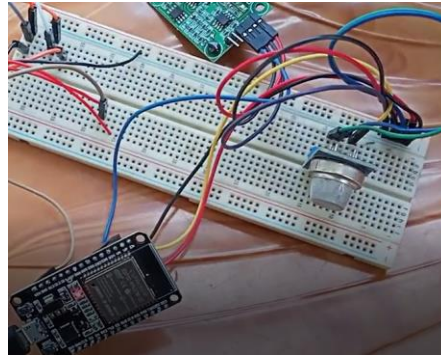


Figure 4.22: Implementation Circuit Diagram of MQ135



Figure 4.22: CO₂ Level Monitor & Control



Figure 4.23: CO₂ and pH Level Monitor on Ubidots.

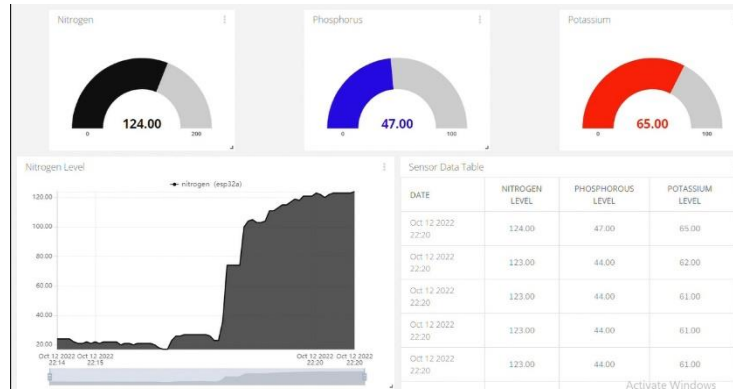


Figure 4.24: System monitor for nutrition levels in Ubidots Cloud Server.

4.3 Data Analysis

In the IoT system, we got the three-sensor data called pH, NPK & CO₂ from this hydroponic system. This data was measured only for cherry tomatoes. As the IoT cloud here used Ubidots, where the sensors' data can be stored & download in an Excel file. To check the system's accuracy, seven days of real-time data took from the cloud storage. These data are the per-day average data of the sensors. After collecting this data, it's understandable that the system accuracy is 80-90%.

Day No	CO ₂ (PPM)	pH	Nitrogen	Phosphorus	Potassium
01	814	6.7	145	43	57
02	900	7	135	40	55
03	890	6.4	150	51	60
04	950	6.8	136	50	56
05	867	6	155	52	63
06	935	6.6	145	45	58
07	1015	7.1	150	52	62

Table 4.1: Per day average value of the IoT-controlled sensors

4.4 Cost Analysis

In the Argo market, there are several types of hydroponic systems that exist based on their system quality & product quantity. Also, their prices depend on customer demand & system requirements respectively. The Green Savers [39] sells a system called 'Hydro Max NFT System' at the price of 16,000 BDT. Where included in their system are 72 Regenerative Plants (Tomato, Basil, Lettuce, Cucumber, etc.), a 30L Nutrient Tank, an Air Pump, Submersible Pump, 72 Net Pots, an Analog Timer, 1 Measuring Dropper, a pH-Down Solution, Nutrient Solution A & B (For 1 Crop Cycle). Another hydroponic selling site Krishi Mela [40] sells its system at the price of 10,500 BDT including 32 Regenerative Plants (Tomato, Basil, Lettuce, Cucumber, etc.), a 30L Nutrient Tank, an Air Pump, a Submersible Pump, 32 Net Pots, an

Analog Timer, 1 Measuring Dropper, a pH-Down Solution, Nutrient Solution A & B (For 1 Crop Cycle). Both of these sites are just selling the initial hydroponic components. But the customer also needs the control & user-friendly monitoring system for their hydroponic farm, which is not provided by these sites. In this proposed system, these features are included with the initial hydroponic components at the price of 18,500 BDT (Table 4.2). With the use of this system, the customer can also control & monitor the most important parameter (pH, NPK, CO₂) for indoor hydroponic farming. As well as the other controlling systems can also be controlled automatically, which makes this whole system completely user-dependent free.

Sensor list	Quantity	Price	Price
DHT22	1	398	398
LDR	1	10	10
Ultrasonic Sensor	3	118.18	354.54
Buzzer 5V	2	15	30
MQ-135	1	200	200
Arduino Uno (China)	1	900	900
LED Light	60	3	180
5 Volt Relay	6	70	420
ESP 32	1	550	550
RTC Module	1	400	400
NPK sensor	1		8000
Structure	1	2000	2000
pH sensor	1	2200	2200
Supply pump (5+1)	5	450	450
Pipe	30 feet	300	300
Seed cup	30	150	150
Wire		500	500
MAX485 Module	1	400	400
Tank	4	500	500
Seed (tomato)	1	30	50
Nutrient solution	1+1	250	250
Adapter 12V	1	250	250
TOTAL		18,500	

Table 4.2: Total Budget of the Implemented System

4.5 Impacts

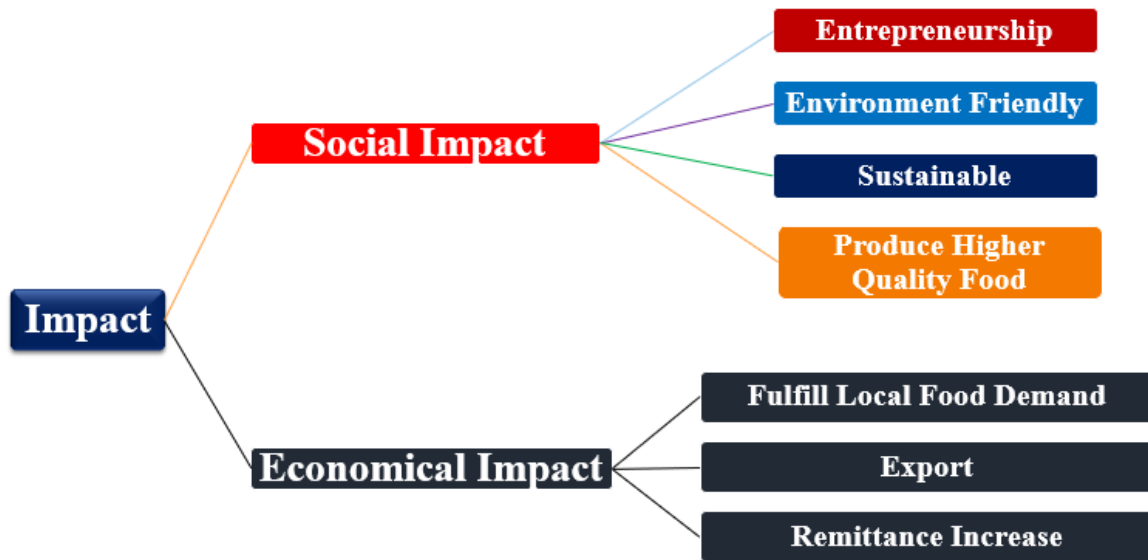


Figure 4.25: Impact Flowchart Diagram the of this Project

4.4.1 Social Impact

Smart indoor hydroponic agriculture with the help of automation and sensor technology impacts society in the following way [41]

- **Entrepreneurship and Employment:** Emerging smart technology is creating opportunities for entrepreneurs who desire to venture into vertical farming with lower levels of investment. Such technologies are enabling indoor farming projects to be set up in relatively small spaces using energy-efficient processes that recycle and reuse the resources deployed in the system. For instance, the new generation of LED lights is replicating the same intensity of light with significantly lower energy requirements. Similarly, cloud computing, SAAS (Software as a Subscription Service), and the Internet of Things are enabling automation without investing heavily in computer systems. The hydroponic farming system will provide locals with both year-round and temporary employment options. The employees will have the chance to train and develop their abilities in the new high-tech farming. This is a clear way to empower people to be a part of the change needed and take ownership of their local communities [42].
- **Environmental Impact:** hydroponic farming can have a lower more environmental impact than conventional farming if the correct energy mix is used. The Advanced Hydroponic Farm uses 90% less water for irrigation than traditional farming methods for herbal crops and between 40% and 60% less for

other vegetable crops, which improves irrigation water usage efficiency and frees up additional water for agricultural growth. For the same number of crops, especially those produced in layers, 50% less land is required. Any accessible type of land may be used; there is no requirement for soil or weeds, and the nutrients in the soil are used more efficiently. In comparison to traditional farming, this farming approach increases the area that may be planted and yields safe goods with increased output. Pesticide and fertilizer usage must be reduced by 60% since plants are growing indoors. By removing soil (there is no requirement for harmful chemicals to protect plants in this way). IPM is used to cut back on chemicals.

- Within a hydroponic farm or other building, hydroponic plants may be readily confined. As a result, they are protected from many of the issues that traditional farmers struggle to solve and even create their microclimates. They don't have to be treated with a variety of pesticides and aren't at the mercy of pests [42].
- **Sustainability:** Hydroponics is an incredibly sustainable way of growing the food needed to feed a growing population. Due to the fact that hydroponic plants are cultivated inside, they can flourish in locations where conventional farms are ineffective. As a result, we may reduce the carbon emissions caused by shipping our favorite fruits and vegetables across the country or around the world by bringing local products to areas where fresh produce is in short supply. Since the water used in the system may be recycled several times, the approach even utilizes far less water than conventional growth techniques. In order to compete with traditional agriculture without having to rely entirely on renewable energy, hydroponic farming still has a long way to go. This technique resulted in considerable reductions in food waste as well as transportation-related energy, packaging, and fuel needs. the chance to convert part of the present agricultural areas into carbon sinks through afforestation, as well as the reduced emissions caused by the absence of agricultural equipment and fertilizers [43].
- **Produces Higher Quality Food:** Food that naturally ripens on the plant usually contains more nutrients and tastes better. These vegetables may be cultivated in almost any place as hydroponic gardens have their own microbiomes. As a result, they may be harvested when they are at their ripest because they won't travel very far to get to the homes and establishments where they will be consumed.

4.4.2 Economic Impact

The main economic impact of hydroponic farming is its speed compared to field-based farming and the fact that you may harvest considerably more in a year than you would under normal circumstances. Farmers may supply seasonal goods to the market whenever they choose by growing their own vegetables in a controlled environment without having to worry about the harvesting season. The nutritional content of your produce rises with little time between planting and harvest, giving you the most value

for your money. Since the atmosphere is already managed, hydroponic farming also saves money on the expense of purchasing insect control or chemical weed killer. Because the fastest-growing crops required less labor, the indoor hydroponic farming system fulfilling the local food demand as well as can export the food and remittance increases.

- **Produces Higher Yields:** Because hydroponics demands that items be produced in a controlled environment, farmers may grow their crops all year long, harvest them four times a year, and deliver the maximum nutritional value possible.
- **Require Less Labor:** Because hydroponics doesn't require tilling, weeding, applying herbicides and insecticides, or other labor-intensive farm tasks, it puts less of a burden on workers and can be readily handled with a lot less man-hours. This decreases the expense of growing crops while also freeing up time for other activities. A tiny hydroponic greenhouse may really be run wholly by one part-time employee.
- **Fulfill Local Food Demand:** A significant amount of energy utilization may be eliminated with hydroponics. Where conventional farms could never prosper, hydroponic farming may be set up. This indicates that they can meet local food demands without wasting resources on transportation or doubtful preservation techniques. Because of the reduction in waste and improvement in freshness, high-quality products may now be grown locally, even in urban settings, and given to the community.
- **Export and remittance increase:** since in the indoor hydroponic farm, all environmental conditions are monitored and controlled, it ensures the maximum and fastest growing crops can be cultivated and harvested the crops over the year. Healthy crops have immense export potential after meeting local food needs which increases the remittance.

4.5 Ethical point of view

Ethical farming refers to the practice of producing food in a way that protects the environment, public health, communities, and animal welfare. As a result, ethical farms are more socially and ecologically conscious since they are dedicated to supplying society with food while maintaining the ability of future generations to do the same. Everyone benefits from such a movement, and buying goods that have been ethically and responsibly produced at the grocery store is a simple way to support this transformation in the business. It will ensure the family is fed only the best meals in addition to supporting the ethical treatment of farmed crops and farming practices. These are only a few advantages of ethical farming, and ethical horticulture has the ability to address a lot more issues in the real world. Hydroponic indoor farming is the most ethical farming system to feed food ethically. On the other hand, some people are using this indoor hydroponic farming system to grow and sell drugs in the city area. Recently at Mohammadpur and Gulshan in Bangladesh, a person is arrested because of growing Kush, and

other high-end drugs using the indoor hydroponic farming system, which is an unethical use of hydroponic farming [44]. This proposed implemented indoor NFT hydroponic system is designed for monitoring and controlling all environmental mental parameters to cultivate cherry tomato plants. The main purpose of this project is to design the monitoring and controlling part of an automated hydroponic farm, which is completely ethical. This system will ensure to the provision of fresh and chemical-free food, public health, sustainability, and reduce global warming.

CHAPTER FIVE

CONCLUSION AND FUTURE WORK

5.1 Main Achievement

Benefits of This Project

The benefits of vertical farming include its independence from environmental factors like temperature, humidity, fertilizer, pH, etc. Compared to conventionally grown vegetables and herbs, vertical farms use more energy, but they also utilize fewer resources including water, fertilizers, arable land, and pesticides. Here is used less water to grow tomato plants compared to traditional farming.

Opportunities for Urban Areas

Growing crops in urban areas provide an opportunity to boost the local economy by creating jobs and the food supply. It reduces the cost of transferring a load of food grains from rural to urban regions and reduces the amount of spoiling that takes place there. The amount of fossil fuel used to transport farm products from rural areas to cities is also significantly reduced.

Remotely Monitor

This project is successfully run and controlled automatically and also monitor all the parameter from anywhere as per the design. The system mainly has two parts one is the monitoring part such as pH, NPK, air temperature, air moisture, and CO₂, which are monitored successfully and sent all the data to the IoT platform at the Ubidots where all this data is shown as a graphical representation.

Automatic Control

And another is controlling parts such as reserve water level monitoring and control, solution level monitoring and control, nutrient level monitoring and control, and light monitoring and control are successfully working.

5.2 Scope of Further Development

In this project still much scope to develop further. For the cost limitation, can't implement everything as per the design. Like, there is could not be developed a fully automatic control system. The entire system is fully functional but the temperature is not being controlled as a result tomato plant is not growing well. Several points can be developed still now such as temperature control, the use of renewable energy for the entire system, and the use of machine learning for automatic disease detection, and power backup that is described below:

Temperature Control

Temperature is an important factor for every plant. Different levels of temperature have an impact on a plant's chemical reactions and physical characteristics. In general, the growth rate

of the various vegetable fruits increases as the air temperature is raised. At the same plant, the fruit's biomass production increased when the temperature rose from 18 C to 25 C. Low temperatures have a direct effect on the organoleptic characteristics of vegetables. Less liquid and a mealy flavor in tomatoes are certain signs that they were produced at a low temperature. So, it needs to control the temperature for mass agriculture production. In the future, this system can be integrated cooler to control the air temperature and water temperature [28].

Use Renewable Energy for the Entire System

There is also can be the use of renewable energy (such as PV cells, and wind energy) for the entire system. In this vertical farming system, all subsystems need power such as the water pump, cooling system, monitoring system, and lighting system in this all subsystems can be to use renewable energy. This is to minimize the carbon footprint and be energy-efficient, cost-effective, sustainable, and environmentally friendly.

Use Machine Learning for Prediction

There can be the use of machine learning for the prediction of nutrient levels (NPK), plant disease detection, and classification, the deep learning convolutional neural network (DLCNN) model also can be integrated into this system.

Power Backup

There is no use of any power backup for cost limitation during the absence of electricity. So, in the future can be used as power backup (e.g., lithium-ion battery cell or generator) for the entire system.

REFERENCES

- [1] M. H. N. S. M. Saad, "State of the Art of Urban Smart Vertical Farming Automation System: Advanced Topologies, Issues and Recommendations," *Electronics*, vol. 10, p. 40, 2021.
- [2] A. V. L. a. M. J. Beacham, "Vertical farming: a summary of approaches to growing skywards.," *The Journal of Horticultural Science and Biotechnology*, vol. 94, no. 3, p. 277, 2019.
- [3] A. A. S. S. N. K. R. a. H. A. Ullah, "Cost effective smart hydroponic monitoring and controlling system using IoT," *Intelligent Control and Automation*, vol. 10, no. 04, p. 142, 2019.
- [4] A. T. S. F. M. a. M. V. Richa, "Recent advances and perspectives in the treatment," *Reviews in Environmental Science and Bio/Technology*, vol. 19, no. 04, p. 945, 2020.
- [5] S. B. H. P. R. a. O. A. Tagle, "Development of an indoor hydroponic tower for urban farming," in *In Proceedings of the 6th DLSU International Conference on Innovation and Technology Fair*, Manila, Philippines, 2018.
- [6] P. a. M. P. Bhuvaneswari, "SMART INDOOR VERTICAL FARMING MONITORING USING IoT," *Journal of Contemporary Issues in Business and Government*, vol. 27, p. 3, 2021.
- [7] M. P. L. G. A. & G. A. G. Pascual, "Vertical Farming Using Hydroponic System: Toward a Sustainable Onion Production in," in *Open Journal of Ecology*, 2018.
- [8] L. I. & G.-M. F. C. Trejo-Tellez, "Nutrient Solutions for Hydroponic System," in *IntechOpen*, 2012.
- [9] S. A. A. M. Y. M. Saaid M.F, "Automated pH controller system for hydroponic cultivation," in *Computer Application & Industrial Electronics*, 2015.
- [10] R. S. a. K. H. K. S. Adhau, "Design of fully automated low cost hydroponic system using LabVIEW and AVR microcontroller," in *IEEE International Conference on Intelligent Techniques in Control, Optimization and Signal Processing*, 2017.
- [11] S. S. I. B. J. A. R. A. Z. S. Zulkarnay Z, "An overview on pH measurement technique and application in biomedical and industrial process," in *Biomedical Engineering*, 2015.
- [12] A. M. N. M. Y. N. Saaid M.F, "A development of an automatic microcontroller system for Deep," in *Signal Processing and its Applications (CSPA)*, 2013.
- [13] M. N. Pantasen N, "Ontology-Based Nutrient Solution Control System for Hydroponics," in *Instrumentation, Measurement, Computer, Communication and Control*, 2011.
- [14] M. F. S. A. & M. A. M. S. A. I. M. Y. Saaid, "Autimated pH Controller System for Hydroponic Cultivation," in *Langkawi*, s.n., 2015.
- [15] G. T. F. a. T. Y. Michael, "Development of Automated Monitoring System for Hydroponics Vertical Farming," in *In Journal of Physics: Conference Series*, 2021.
- [16] R. a. L. C. Lukito, "Development of IoT at hydroponic system using raspberry Pi," in *TELKOMNIKA (Telecommunication Computing Electronics and Control)*, 2019.
- [17] M. C. A. D. J. a. F. R. Alipio, "A smart hydroponics farming system using exact inference in Bayesian network," in *In 2017 IEEE 6th Global Conference on Consumer Electronics (GCCE)*, 2017.
- [18] O. D. R. R. S. M. A. a. A. D. Samijayani, "Hybrid Zigbee and wifi wireless sensor networks for hydroponic monitoring," in *In 2020 International Conference on Electrical, Communication, and Computer Engineering (ICECCE)*, 2020.
- [19] K. R. B. N. M. W. G. R. Q. R. M. G. A. R. L. F. Q. C. G. a. J. S. Lean, "HyLo: Implementation of LoRaWAN in an Automated Hydroponics System," in *In 2021 IEEE International Conference on Mobile Networks and Wireless Communications (ICMNWC)*, 2021.

- [20] S. D. S. H. S. C. S. a. S. K. Rathod, "LoRa Technology Based Hydroponic Farm Monitoring System," in In 2021 2nd International Conference on Smart Electronics and Communication (ICOSEC), 2021.
- [21] G. A. S. a. S. G. Muralimohan, "Design and Development of IoT based Hydroponic Farming Setup for Production of Green Fodder," NVEO-NATURAL VOLATILES & ESSENTIAL OILS Journal| NVEO, pp. 4325-4340, 2021.
- [22] Y. a. A. L. Chin, "Vertical farming monitoring system using the internet of things (IoT)," in In AIP Conference Proceedings, 2017.
- [23] N. C. V. C. I. V. H. a. H. R. Bakhtar, "IoT based hydroponic farm," in In 2018 International Conference on Smart Systems and Inventive Technology (ICSSIT), 2018.
- [24] M. J. S. I. M. a. N. A. Kamarulzaman, "Monitoring System of Hydroponic Using Solar Energy," Journal of Electronic Voltage and Application, vol. 2, no. 1, pp. 26-37, 2021.
- [25] D. Farming, "Greenhouse MANAGEMENT," Greenhouse MANAGEMENT, 25 January 2016. [Online]. Available: <https://www.greenhousemag.com/article/hydroponics-provides-major-water-savings/>.
- [26] E. Vinje, "Planet Nature - Research Center," Planet Nature, 3 July 2018. [Online]. Available: <https://www.vegetables.bayer.com/au/en-au/resources/growing-tips/cultivation-insights/managing-light-and-co2-for-tomatoes-in-protected-culture.html#:~:text=Under%20low%2Dlight%20conditions%2C%20the,when%20using%20high%20quality%20CO2%20..>
- [27] M. S. M. R. M. R. M. a. S. M. Salam, "Quality of tomato (*Lycopersicon esculentum* Mill.) as influenced by boron and zinc under different levels of NPK fertilizers," Bangladesh Journal of Agricultural Research, vol. 35, no. 3, pp. 475-488, 2010.
- [28] F. Khan, "A review on hydroponic greenhouse cultivation for sustainable agriculture," International Journal of Agriculture Environment and Food Sciences, vol. 2, no. 2, pp. 59-66, 2018.
- [29] S. P. A. a. V. N. Khan, "Hydroponics: Current and future state of the art in farming," Journal of Plant Nutrition, vol. 44, no. 10, pp. 1515-1538, 2020.
- [30] M. K. A. A. S. A.-K. F. H. J. H. F. R. M. Chowdhury, "Design, construction and testing of iot based automated indoor vertical hydroponics farming test-bed in qatar," Sensors, vol. 20, no. 19, p. 5637, 2020.
- [31] S. Nozad Mahmood, "Gsm interaction based real time climate change monitoring technique," Kirkuk University Journal-Scientific Studies, vol. 13, no. 2, pp. 1-17, 2018.
- [32] M. P. S. a. M. E. Martin, "Exploring the environmental performance of urban symbiosis for vertical hydroponic farming," Sustainability, vol. 11, no. 23, p. 6724, 2019.
- [33] A. U. R3, 2022. [Online].
- [34] "HC-SR04," Ultrasonic Sensor, 14 November 2014. [Online]. Available: <https://datasheetspdf.com/pdf/1380136/ETC/HC-SR04/1>.
- [35] "Wireless Soil NPK Sensor," netvox, [Online]. Available: <http://www.netvox.com.tw/um/R72632A01/R72632A01datasheet.pdf>.
- [36] "DFROBOT," pH Meter, [Online]. Available: https://wiki.dfrobot.com/PH_meter_SKU__SEN0161_.
- [37] "ALLDATASHEET," MQ135, [Online]. Available: <https://www.alldatasheet.com/datasheet-pdf/pdf/1307647/WINSEN/MQ135.html>.
- [38] "ALLDATASHEET," DHT22, [Online]. Available: <https://www.alldatasheet.com/datasheet-pdf/pdf/1132459/ETC2/DHT22.html>.

- [39] "Green Sever," 2022. [Online]. Available: [https://www.thegreensavers.org/hydroponics#:~:text=BDT%2016%2C000%2B&text=\(Tomato%2C%20Basil%2C%20Lettuce%2C%20Cucumber%20etc.\),-30L%20Nutrient%20Tank](https://www.thegreensavers.org/hydroponics#:~:text=BDT%2016%2C000%2B&text=(Tomato%2C%20Basil%2C%20Lettuce%2C%20Cucumber%20etc.),-30L%20Nutrient%20Tank).
- [40] F. International, "Krishi Mela," 03 February 2019. [Online]. Available: <https://krishimela.com.bd/shop/hydroponic-nft-system-set-1-farmtech/>.
- [41] G. G. P. a. B. R. Patil, "Smart agriculture system based on IoT and its social impact," *International Journal of Computer Applications*, vol. 176, no. 1, pp. 0975-8887, 2017.
- [42] N. a. M. O. Iron, "Environmental and social impact assessment," *Assessment*, 2013.
- [43] R. C.-K. A. a. S. C. Milestad, "The Högdalen urban farm: A real case assessment of sustainability attributes," *Food Security*, vol. 12, no. 6, pp. 1461-1475, 2020.
- [44] T. Report, "RAB nabs one for growing, selling Kush, other high-end drugs from Gulshan," *THE BUSINESS STANDERED*, 2 August 2022. [Online]. Available: <https://www.tbsnews.net/bangladesh/crime/rab-nabs-one-growing-selling-kush-other-high-end-drugs-gulshan-469870>.

APPENDIX

IoT System Code:

```
#include "UbidotsEsp32Mqtt.h"
#include "PubSubClient.h"
#include "Wire.h"
#include <WiFi.h>
#include <SoftwareSerial.h>
#include "MQ135.h"
#define SensorPin 34 // D34 connected to the ph sensor

float ph;
float pH_Value;

uint8_t DE = 4;
uint8_t RE = 15;

int pinOut = 35; //variable to name the pin for the relay - Nitrogen

const char *UBIDOTS_TOKEN = "BBFF-sMkhZgMgxSQKo4CZblNSpI1tgcKLLC"; // Put here
your Ubidots TOKEN
const char *WIFI_SSID = "Shohoz"; // Put here your Wi-Fi SSID
const char *WIFI_PASS = "Bangladesh2022"; // Put here your Wi-Fi password
const char *DEVICE_LABEL = "esp32";
const char *VARIABLE_LABEL1 = "PH"; // Put here your Device label to which data will be published
const char *VARIABLE_LABEL2 = "AirQuality Value";
const char *VARIABLE_LABEL3 = "Nitrogen";
const char *VARIABLE_LABEL4 = "Phosphorous";
const char *VARIABLE_LABEL5 = "Potassium";

const int PUBLISH_FREQUENCY = 5000; // Update rate in milliseconds
unsigned long timer;

uint8_t analogPin_MQ135 = 32; // Pin used to read data from D35 for MQ135

///..... MQ135 - Air Quality .....///

float MQ135_value;
int Ex-Fan = 23; //5V Relay
int Threshold = 1000; //CO2 Detect
```

```

Ubidots ubidots(UBIDOTS_TOKEN);

//const byte code[] = {0x01, 0x03, 0x00, 0x1e, 0x00, 0x03, 0x65, 0xCD};
const byte nitro[] = {0x01,0x03, 0x00, 0x1e, 0x00, 0x01, 0xe4, 0x0c};
const byte phos[] = {0x01,0x03, 0x00, 0x1f, 0x00, 0x01, 0xb5, 0xcc};
const byte pota[] = {0x01,0x03, 0x00, 0x20, 0x00, 0x01, 0x85, 0xc0};

byte values[11];
SoftwareSerial mod(17,16); //For ESP32

/*****
    Auxiliar Functions
*****/

void callback(char *topic, byte *payload, unsigned int length)
{
    Serial.print("Message arrived [");
    Serial.print(topic);
    Serial.print("] ");
    for (int i = 0; i < length; i++)
    {
        Serial.print((char)payload[i]);
    }
    Serial.println();
}

/*****
    Main Functions
*****/

void setup()
{
    // put your setup code here, to run once:
    Serial.begin(115200);
    //ubidots.setDebug(true); // uncomment this to make debug messages available
    ubidots.connectToWifi(WIFI_SSID, WIFI_PASS);
    ubidots.setCallback(callback);
    ubidots.setup();
    ubidots.reconnect();
    timer = millis();

    ///..... MQ135 - Air Quality .....///
    pinMode(Ex-Fan, OUTPUT);
    pinMode(analogPin_MQ135, INPUT);

```

```

///..... NPK .....///
mod.begin(9600);
pinMode(RE, OUTPUT);
pinMode(DE, OUTPUT);
delay(3000);

pinMode(5, OUTPUT); //Nitrogen Control

}

void loop()
{
  ///.....pH Sensor.....///

  pH_Value = analogRead(SensorPin);
  Serial.print(pH_Value);
  Serial.print(" | ");
  float voltage = pH_Value * (3 / 4095.0);
  ph = (3 * voltage);
  Serial.println(ph);
  delay(500);

  ///..... Air Quality .....///

  MQ135_value = analogRead(analogPin_MQ135);    // read analog input pin A5
  Serial.print("AirQuality Value: ");
  Serial.println(MQ135_value, DEC);

  if (MQ135_value > Threshold) //Threshold = 420; From CO2.Earth web...
  {
    digitalWrite(greenLED, LOW);
    Serial.println("Alert!!!");
    delay(2000); // wait 2000ms
  }

  else
  {
    digitalWrite(greenLED, HIGH);
    Serial.println("Normal");
    delay(500); // wait 500ms
  }

  ///..... NPK .....///

```

```

byte val1,val2,val3;

if (val1 > 150.0)
{
digitalWrite(pinOut, HIGH); // if the temperature reaches 30°C or above, close the circuit
}

else
{
digitalWrite(pinOut, LOW); // otherwise, open (break) the circuit
}


// put your main code here, to run repeatedly:
if (!ubidots.connected())
{
ubidots.reconnect();
}
if ((millis() - timer) > PUBLISH_FREQUENCY) // triggers the routine every 5 seconds
{
float pH_Value= analogRead(SensorPin);
float voltage = pH_Value*(3/4095.0);
ph =(3*voltage);
ubidots.add(VARIABLE_LABEL1, ph);

float MQ135_value = analogRead(analogPin_MQ135);
ubidots.add(VARIABLE_LABEL2, MQ135_value);

val1 = nitrogen();
delay(250);
ubidots.add(VARIABLE_LABEL3, val1);

val2 = phosphorous();
delay(250);
ubidots.add(VARIABLE_LABEL3, val2);

val3 = potassium();
delay(250);
ubidots.add(VARIABLE_LABEL4, val3);

ubidots.publish(DEVICE_LABEL);
timer = millis();
}
ubidots.loop();
}

```

```

byte nitrogen(){
  digitalWrite(DE,HIGH);
  digitalWrite(RE,HIGH);
  delay(10);
  if(mod.write(nitro,sizeof(nitro))==8){
    digitalWrite(DE,LOW);
    digitalWrite(RE,LOW);
    for(byte i=0;i<7;i++){
      //Serial.print(mod.read(),HEX);
      values[i] = mod.read();
      Serial.print(values[i],HEX);
    }
    Serial.println();
  }
  return values[4];
}

```

```

byte phosphorous(){
  digitalWrite(DE,HIGH);
  digitalWrite(RE,HIGH);
  delay(10);
  if(mod.write(phos,sizeof(phos))==8){
    digitalWrite(DE,LOW);
    digitalWrite(RE,LOW);
    for(byte i=0;i<7;i++){
      //Serial.print(mod.read(),HEX);
      values[i] = mod.read();
      Serial.print(values[i],HEX);
    }
    Serial.println();
  }
  return values[4];
}

```

```

byte potassium(){
  digitalWrite(DE,HIGH);
  digitalWrite(RE,HIGH);
  delay(10);
  if(mod.write(pota,sizeof(pota))==8){
    digitalWrite(DE,LOW);
    digitalWrite(RE,LOW);
    for(byte i=0;i<7;i++){
      //Serial.print(mod.read(),HEX);
      values[i] = mod.read();
      Serial.print(values[i],HEX);
    }
  }
}

```

```
    Serial.println();  
  }  
  return values[4];  
}
```

Arduino Code

```
#define trigPin1 8  
#define echoPin1 A1  
#define trigPin2 A2  
#define echoPin2 A3  
#define trigPin3 A4  
#define echoPin3 A5  
#include <DHT.h>  
#define DHTTYPE DHT22  
  
int light=9;  
  
int led1 = 5;  
int led2 = 6;  
int led3 = 7;  
  
int motor = 3;  
int temp=0;  
int temp1=0;  
int temp2=0;  
  
int DHTPIN = 10;  
DHT dht(DHTPIN, DHTTYPE);  
  
int pinOut = 11; //variable to name the pin for the relay  
  
long duration, distance, FIRSTSensor,SECONDSensor,THIRDSensor;  
void setup()  
{  
  Serial.begin (9600);  
  pinMode(trigPin1, OUTPUT);  
  pinMode(echoPin1, INPUT);  
  pinMode(trigPin2, OUTPUT);  
  pinMode(echoPin2, INPUT);  
  pinMode(trigPin3, OUTPUT);
```

```

pinMode(echoPin3, INPUT);
  pinMode(light,OUTPUT);
  pinMode(A0,INPUT);

pinMode(led1, OUTPUT);
pinMode(led2, OUTPUT);
pinMode(led3, OUTPUT);

  pinMode(motor, OUTPUT);

  dht.begin();
  pinMode(7, INPUT);
  pinMode(6, OUTPUT);

}

void loop()
{

  SonarSensor(trigPin1, echoPin1);
  FIRSTSensor = distance;
  SonarSensor(trigPin2, echoPin2);
  SECONDSensor = distance;
  SonarSensor(trigPin3, echoPin3);
  THIRDSensor = distance;
  digitalWrite(motor, HIGH);

  //raw water
  if(FIRSTSensor<20 && temp==0){
    digitalWrite(led1, LOW);
    temp=1;
  }
  else if(FIRSTSensor<=20 && temp==1){
    digitalWrite(led1, LOW);
  }
  else if(FIRSTSensor>20)
  {digitalWrite(led1, HIGH);
  temp=0;
  }
  // FOR NUTRIENT
  if(SECONDSensor<10 && temp1==0){
    digitalWrite(led2, LOW);
    temp1=1;
  }
  else if(SECONDSensor<=20 && temp1==1){
    digitalWrite(led2, LOW);
  }

```

```

}
else if(SECONDSensor>20)
{digitalWrite(led2, HIGH);
temp1=0;
}
// FOR SOLUTION
if(THIRDSensor<10 && temp2==0){
digitalWrite(led3, LOW);
temp2=1;
}
else if(THIRDSensor<=20 && temp2==1){
digitalWrite(led3, LOW);
}
else if(THIRDSensor>20)
{digitalWrite(led3, HIGH);
temp2=0;
}
int a = analogRead(A0);

if(a>500)
{
digitalWrite(light,HIGH);
}
else
{
analogWrite(light,LOW);
}

float hm = dht.readHumidity();
Serial.print("Humidity ");
Serial.println(hm);
delay (2000);

float temp = dht.readTemperature();
Serial.print("Temperature ");
Serial.println(temp);

if (temp > 32.0)
{
digitalWrite(pinOut, HIGH);// if the temperature reaches 30°C or above, close the circuit
Serial.println("Cooling Fan On");
}

else

```

```
{  
digitalWrite(pinOut, LOW); // otherwise, open (break) the circuit  
Serial.println("Cooling Fan Off");  
  
}  
  
}  
void SonarSensor(int trigPin,int echoPin)  
{  
digitalWrite(trigPin, LOW);  
delayMicroseconds(2);  
digitalWrite(trigPin, HIGH);  
delayMicroseconds(10);  
digitalWrite(trigPin, LOW);  
duration = pulseIn(echoPin, HIGH);  
distance = duration * 0.034 / 2;  
}  

```