STRAWBERRY CULTIVATION MONITORING AND CONTROL IN A SMART VERTICAL AEROPONIC SYSTEM VIA BAYESIAN NETWORK THROUGH INTERNET-OF-THINGS

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Bachelor of Science in Electronics Engineering

Submitted by:

Firme, Crizar James A.

Mercado, Kelvin G.

Roble, Rica Joy B.

Suatengco, Ralph Emerson R.

Tamondong, Mary Queenie Joy R.

Velasco, Aya Yvonne S.

Adviser:

Engr. Mark P. Melegrito

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APPROVAL SHEET

This project study entitled **"STRAWBERRY CULTIVATION MONITORING AND CONTROL IN A SMART VERTICAL AEROPONIC SYSTEM VIA BAYESIAN NETWORK THROUGH INTERNET-OF-THINGS"**, has been approved and submitted by the following proponents:

Firme, Crizar James A.	Suatengco, Ralph Emerson R.
Mercado, Kelvin G.	Tamondong, Mary Queenie Joy R.
Roble, Rica Joy B.	Velasco, Aya Yvonne S.

In partial fulfilment of the requirements for the degree **of Bachelor of Science in Electronics Engineering** is hereby recommended for approval:

ENGR. MARK P. MELEGRITO
Project Adviser

ENGR. JOMER V. CATIPON
Panel Member

ENGR. AUGUST C. THIO-AC
Panel Member

ENGR. JESSICA S. VELASCO
Panel Chair

Accepted and approved in partial fulfillment of the requirements for the **Degree of Bachelor of Science in Electronics Engineering.**

ENGR. TIMOTHY M. AMADO
Head, ECE Department

ENGR. NILO M. ARAGO
Dean, College of Engineering

ABSTRACT

Due to the government-imposed Enhanced Community Quarantine during the pandemic, urban residents had trouble procuring food. Several studies have been conducted to increase a country's food sustainability from possibly catastrophic future disasters and tragedies. This study aims to introduce an automated vertical aeroponics setup to assist communities in cultivating their own food. Soil-less culture and vertical farming were identified as viable alternatives whereas aeroponics technology is one effective approach. This also includes a web application that monitors and governs the main cultivation data of strawberry plants gathered from the sensors and actuators. It also creates a predictive analytical model with a Bayesian network and a time series chart and was evaluated using the dataset gathered from the sensors. The predictive model in pH achieved 61.08% accuracy and 0.0929 mean absolute error, 29.14% accuracy and 0.086 mean absolute error for TDS level, 95.81% accuracy and 0.002 mean absolute error for air temperature, and 95.95% accuracy and 0.0022 mean absolute error for humidity. The Raspberry Pi 4 Model B acts as the microcontroller and the system was used to grow strawberries and compared it to the strawberries grown through traditional farming. It was found that strawberries from the system had a significantly faster growth cycle, reaching the harvesting stage in three months compared to the conventionally grown strawberries which is 5 months. Further, it was also found that strawberries in the system have higher yields and growth rate as the system was able to control the appropriate pH level, temperature, and humidity for the growth of the strawberries. The research did show significant progress when it comes to growing strawberries. However, it was not tested to grow other crops, as such it is advised for future researchers to attempt to grow other crops and modify the system as needed

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- **The Proponents**

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Chapter 1

THE PROBLEM AND ITS SETTING

1.1 Introduction

Food security plays a significant role in a country's economic and agricultural aspects. According to the Food and Nutrition Research Institute's (FNRI) Rapid Nutrition Assessment Survey (RNAS), 62.1% of Filipino families encountered food insecurity during the COVID-19 pandemic in the year 2020. About 56.3% of these households reported difficulty in obtaining food during the government-imposed Enhanced Community Quarantine (ECQ). Various factors contributed to this situation: lack of budget, restricted to non-existent public transit, job loss, no other family members to buy food from, and limited food shop options in the neighborhood. A strong indication that the country is still lagging in food sustainability.

The United Nations Philippines' policy (2021) had a proposal that current food systems must change to overcome and recover from potentially severe future unpredictable disasters and calamities. Several studies have been conducted to improve food sustainability and explore alternative ways to traditional farming in our country. While vertical farming is not a new agricultural technique, it is still stated as a need for urban food security. Produce grown vertically is typically cultivated in indoor climate-controlled facilities with precise environmental control for maximum efficiency. In vertical farming, crops are grown using aeroponics, irrigating with nutrient-rich air or mist.

To further improve the efficiency of aeroponics, the system can be automated. Developing a sensor network and generating a predictive analysis model using a Bayesian Network will allow the system to extend its capabilities, such as controlling and monitoring the important cultivation parameters, as one of the solutions for transforming food systems in the country.

1.2 Background of the Study

Aeroponics is a method of cultivating plants where the roots are suspended in the air while a fine mist of nutrients is delivered. Aeroponic cultivation techniques are modern agricultural planting techniques, and farmers have not been fully involved in planting until now since researchers mostly did it to conduct experimental studies.

Aeroponic planting systems are susceptible to several deficiencies, including nutrient distribution lines, inability to start water supply pumps, and automatic nozzle clogging, which necessitate specialized scientific or technical knowledge to prevent rapid plant death, damage, and frequent system failures. IoT connects people and things via the internet and stores data in the cloud for evaluation, allowing farmers to automate aeroponics. Many researchers use IoT to monitor aeroponics water level, pH level, temperature, flow, and light intensity, and it automatically controls and regulates critical parameters.

Aeroponics typically employs the mist sprinkler technique for nutrient delivery and root zone cooling. However, a study by Kanechi et al. (2017) uses dry fog instead. This research showed that cooling the ever-bearing strawberry's crown and root affected the fruit's growth. It also indicates that dry fog aeroponics increases photosynthetic activity, which boosts the growth, inflorescences, and fruiting of the ever-bearing strawberry.

According to the study of Janarthanan et al. (2017), the technique of growing plants using aeroponics is mechanically convoluted; it is vulnerable to malfunction. It requires accurate regulation and control of water and nutrients, leading to another study that developed cyberponics, a fully automated greenhouse system. This aeroponic system can monitor and regulate an interior environment and send the collected data over the internet to a server, which will process the data and display it to the user through a web interface, which will also be used to control the aeroponic system.

Monitoring the temperature, water level, pH and EC levels, humidity, and light intensity is necessary for an aeroponic system to function correctly. A study was conducted by Karuniawati et al. (2021) regarding the optimization of grow light control in an IoT-based aeroponic system. The data from this aeroponic system was analyzed with the help of a random forest classification algorithm and sensor fusion. The use of an algorithm distinguishes this study from the previous studies, as it will aid in decision-making and the formation of rules to monitor and regulate the specifications required for an aeroponic system.

As the years progressed, the aeroponics system evolved and advanced. A recent Indonesian project by Rahmad et al. (2020) implements an aeroponics control system where this system's main processing unit is a Lattepanda, and the LCD screen module displays temperature, light, and humidity sensor data. The system results are simulated using simulation software, and the experimental aeroponics control system results are evaluated using environmental factors. The results demonstrated that the system could be made more labor- and resource-efficient.

Smart farming produces higher-quality crops by making farms more intelligent in sensing their control parameters. The Internet of Things (IoT) can analyze massive amounts of data by connecting various devices. However, it is not enough to have Internet support and self-updating sensor readings for the data to be useful; it also needs self-sustainable agricultural production and analytics. This study by Farizan et al. (2021) analyzes the performance of SVR or support vector regression in predicting plant growth. The study's setup includes four different SVR models that will be measured and determined to benefit growth prediction in an aeroponic system significantly.

A thorough review of the studies reveals that the primary goal of this research is to improve the automation of aeroponics systems. The majority of these do not include a predictive analysis model, which is one of the objectives of the present study.

1.3 Research Gap

Most of the earlier research was geared toward developing an Internet of Things-based framework for smart farming applications. Few of these studies, however, have considered integrating an aeroponics farm with the IoT and employing an algorithm that performs data analytics to control the parameters that govern the growth of plants. Thus, the researchers decided to develop an automated Internet of Things (IoT) aeroponic farm that utilizes machine learning algorithms. The current study will employ fewer actuators, such as pumps, and grow lights than previous studies. In previous studies, temperature, humidity, and light intensity level were used as control parameters.

In contrast, the present study will utilize six control parameters, including temperature, humidity, water level, pH, EC, and light intensity. The present study will employ six sensors, including EC, pH, temperature, water level, humidity, and light intensity sensors, compared to the sensors used in previous studies, which primarily focused on the system's temperature and humidity level. These six sensors are required for the automation and regulation of the aeroponic system. In addition, for nutrient solution reservoirs, these studies only used clean or tap water; hence, the researchers will use rainwater harvesters.

The present study also aims to develop a Bayesian network-based predictive analysis model to automate a cultivation system suitable for strawberry growth.

1.4 Research Objectives

1.4.1 General Objective

This study aims to develop a smart vertical aeroponic system by integrating different sensors and actuators to automatically monitor and control the cultivation of strawberries via Bayesian Network through Internet-of-Things.

1.4.2 Specific Objective

The specific objectives are identified as follows:

1. Design and construct an indoor smart vertical aeroponic system setup with humidity, temperature, water level, light intensity, pH, and EC level sensors to monitor and control strawberry cultivation with sustainable water supply via rainwater harvesting and controlled using Raspberry Pi 4.
2. Gather sensor readings to perform data acquisition for the humidity, temperature, water level, light intensity, pH, and EC level on the IoT interface.
3. Generate a predictive analysis model using a Bayesian Network Classifier that will generate output decisions for automating the cultivation system suitable for strawberry growth.
4. Develop a web user interface that will serve as a graphical user interface for monitoring and control of the aeroponic system.

5. Compare the harvested strawberries from the smart aeroponic system to the traditional farming method using a T-test.

1.5 Significance of the Study

The economic effects of the pandemic are still being felt throughout the Philippines and its communities. This study can help address several issues, including poverty, health, unemployment, and the environmental impact of traditional high-carbon farming practices. Consequently, this study could significantly contribute to the following Sustainable Development Goals (SDG) of the United Nations: (2) Zero Hunger, (3) Good Health and Well-Being, (6) Clean Water and Sanitation, (8) Decent Work and Economic Growth, (9) Industry, Innovation, and Infrastructure, and (11) Sustainable Cities and Communities.

Additionally, this study aims to contribute to Section III, Agriculture, Aquatic and Natural Resources (AANR) under the Crops R&D Agenda of the Harmonized National Research and Development Agenda (HNRDA). The AANR supports the use of advanced and emerging technologies, together with our study focusing mainly on electronics and automation that aims to develop a product that significantly impacts this sector. This study also contributes to the Crop Production System Research, modernizing the industry and boosting agricultural efficiency, production, and competitiveness.

Furthermore, different cultivation methods have proven that soil isn't the only medium that can be used to grow plants. This smart vertical aeroponic system contributes significantly to the body's existing knowledge by using a more sustainable water supply and a Bayesian Network predictive analysis model to automate a strawberry farming system.

Lastly, this study will have a socio-economic impact by offering employment opportunities, building social bonds through interaction and community engagement, and bringing local produce into neighborhoods. It also significantly impacts impoverished communities as it saves resources, lowers the carbon footprint, and has a high production potential.

1.6 Scope and Limitations

This study will cover the design and development of a smart vertical aeroponic system that uses a predictive analysis model (Bayesian Network) with a sustainable water supply via a rainwater harvester in 294 C. Callejo St., Narra Road Las Brisas de Tagaytay, Mendez Crossing West, Tagaytay City. It will only focus on monitoring and correction of the temperature, humidity, water level, pH value, EC, and light intensity of the vertical setup greenhouse; automatic control of the pH and EC value of the nutrient solution to be applied to the roots of the plants and maintaining the required parameter values for a suitable environment for the growth of the strawberry crop. It will also use a solar panel for power management and a backup battery in case of power interruption.

The study limits itself to only using Sweet Charlie runners, a day-neutral strawberry plant, as it can sustain the average temperature of the location in which the system is to be deployed. Plants other than strawberries will not be part of the study.

1.7 Definition of Terms

- **Accuracy (Machine Learning) -** refers to the measure of how a model correctly predicts or classifies the data points in a dataset.
- **Aeroponics** - Aeroponics is a type of hydroponics in which plants are grown without the use of soil or aerated solutions. Instead, they are sprayed with air or misted with water droplets.
- **Analog TDS Sensor Meter -** The concentration of dissolved solids in a liquid solution may be determined using an analog TDS (Total Dissolved Solids) sensor meter. It works on the premise that an electric current flowing through a liquid with dissolved particles would produce a detectable electrical conductivity.
- **Analog Signal Isolator -** A tool used to electrically separate and safeguard analog signals transported between two different systems or circuits is known as an analog signal isolator. It is frequently employed in industrial applications to avoid signal interference, ground loops, and possible equipment damage.
- **Automated Aeroponics System -** An innovative planting and cultivation method that is a combination of soil-less plant growing techniques, together with advanced automation technologies. In this system, plants are hung in the air, and the misting gives them the nutrients and solution they need to sustain their root's nourishment. Automation components such as actuators, sensors, and control software used to control, monitor, and regulate environmental parameters such as temperature, humidity, nutrient delivery, and lighting.
- **Automation** - It involves technology and system use to perform tasks without human interference. Its objectives are error reductions, efficiency improvements,

and workflow optimizations by replacing or intensifying human labor with software and machines.

- **Automatic Transfer Switch** - This is an electrical device that is used to automatically switch the power source from the primary power up to the backup power source. It ensures the smooth flowing of electricity and uninterrupted power transfer in the event of a power outage or other electrical issues. It also provides power to essential loads during the disruption of critical electrical operations.
- **Bayesian Network -** A joint probability distribution may be represented in a Bayesian network, which is a minimal, adaptable, and comprehensible way. Since directed acyclic graphs allow the representation of causal relationships between variables, they are also a helpful tool in knowledge discovery. Often, data is used to utilize a Bayesian network.
- **Control** - A practice of modulating and adjusting different environmental parameters, such as the nutrient delivery, and other factors, to improve the growth and progress of strawberry plants in the cultivation system.
- **Controlled Environment -** It is a setting in which environmental sensors such as humidity, light, and air quality are manipulated deliberately, and controlled to generate optimal conditions for specific purposes.
- **Cultivation -** It refers to the process of nurturing the crops involving different activities such as soil preparation, seed planting, providing specific solutions, and water, managing pest control, and ensuring to make it easier for plants to grow, develop, and eventually be harvested for various purposes, including food production, ornamental use, medicinal use, or other specific objectives. Humans

actively influence how plants develop by cultivating them, which enables planned and intentional agricultural or horticulture techniques.

- **Dataset -** a grouping of structured or ordered data that is frequently saved and examined as a single entity. Depending on the dataset's nature and intended use, it may contain a variety of information kinds, such as text, photos, audio, and video.
- **Day-neutral Strawberry Plant** - This is a kind of strawberry plant that bears fruit and blooms regardless of the length of the day. It is generally accepted day/night temperatures at or above 29°C (85°F) are the upper limit at which day-neutral strawberries will produce flowers.
- **EC Level -** often referred to as Electrical Conductivity Level, this term describes the measurement of a solution's capacity to carry electrical current. It serves as a gauge for the number of dissolved ions, minerals, and salts that are present in the solution overall. It offers useful details on the salinity and nutrient content of a solution, which have an immediate influence on the availability and uptake of nutrients by plants, as well as the general quality and appropriateness of water for different uses.
- **Farming** - Is the practice of growing plants and animals for the reasons of food, medicinal plants, fiber, and other consumable products used by humans. It has different ways such as planting, cultivating, nurturing, harvesting, and processing agricultural products. Modern farming adapts technological advancements such as engineering, machinery, precision agriculture, automation, and sustainable practices to have efficiency, productivity, and sustainability.

- **Fruit-bearing crops** - refer to agricultural plants or fruit-producing plants. These plants are grown expressly so that their fruits may be collected and consumed.
- **Greenhouse** - a building created specially to provide a growing environment for plants. It is often composed of translucent materials that permit sunshine to enter and trap heat within, such glass or plastic. A greenhouse's main function is to give plants regulated environments so they can flourish and lengthen their growth seasons.
- **Grow lights** - are artificial lighting systems created specially to provide plants the right amount and type of light for healthy development. They are frequently used in greenhouses, indoor gardens, and other controlled areas where there may be little or restricted natural sunshine. Red and blue light, which are crucial for plant development, are among the light wavelengths that grow lights emit and are good for photosynthesis.
- **Indoor Farming** - describes the activity of producing plants and raising crops in regulated, confined spaces. It includes creating ideal growth conditions for plants without relying on conventional soil-based techniques or natural sunlight by using technologies like artificial lighting, climate control systems, hydroponics, or aeroponics. Indoor farming makes it possible to cultivate plants all year long, regardless of the exterior climate, and it gives the ideal control over things like temperature, humidity, light, and nutrient levels. This strategy lowers the use of chemical herbicides and pesticides, optimizes resource efficiency, and uses less water.

- **Internet-of-Things** - designates a network of interconnected physical things, gadgets, and sensors that have internet connectivity built into them so they can gather and share data. It enables communication between these gadgets and people, simplifying information sharing and enabling remote control, automation, and monitoring.
- **Monitoring** - A practice of observing actively and data gathering on various parameters and variables associated with the cultivation of strawberries. These factors may include such as temperature, nutrient concentrations, humidity, and the plants growth progress.
- **MQTT** (Message Queuing Telemetry Transport) - is a lightweight messaging protocol developed for effective communication between devices and applications. The system uses a publish-subscribe paradigm, whereby one device or application may publish messages to a topic and another device or application can subscribe to that subject to receive the messages.
- **pH level** - this is essential in figuring out whether a solution is appropriate for a certain application. For instance, in agriculture, the pH of irrigation water or soil impacts the amount of nutrients that plants can access, which in turn affects plant growth and health.
- **Sensors -** Sensors are components or objects that detect, measure, and then transform physical, chemical, or environmental characteristics into quantifiable signals or data. It operates by transforming the physical amount perceived into an electrical signal or data that can be processed, evaluated, and used for a variety of system functions, including feedback, monitoring, control, and decision-making.

- **Sensor Data Fusion** - To provide data that individual sensors functioning independently are unable to produce, sensor data fusion optimally combines the advantages of several sensors and measurement techniques.
- **Smart Farming** - An agricultural technique that utilizes data optimization and technology for farming practices, enriching efficiency, and upgrading crop yields of the plants. Technologies such as sensors, drones, GPS, data analytics, and satellite imagery smart farming gathers and assess soil conditions data, the health of the crops, patterns of the weather, and other pertinent parameters. Smart farming's goal is to increase the yields of the plants, sustain their growths, and make a profit by harnessing the utilization of technologies employed and its data-driven insights.
- **Smart Vertical Aeroponic System** - The vertical design makes the most of available space and enables effective plant stacking in a regulated setting. The "smart" component suggests the incorporation of automation, sensing, and monitoring technologies to improve the system's efficacy and efficiency.
- **Solar Power** - uses the power of the sun as a sustainable and renewable energy source. Photovoltaic (PV) panels or solar thermal collectors are commonly used in solar power systems to transform sunlight into useful energy.
- **Strawberry Cultivation** - pertains to the practice of raising strawberry plants in order to harvest strawberries. Throughout the growth season, it needs close observation and upkeep, which includes routine trimming, the removal of any fruit that is damaged, and protection from bad weather.

- **Telemetry -** The practice of gathering, measuring, and transmitting data from distant or inaccessible sites for monitoring, analysis, and control is referred to as telemetry. Data collection on numerous factors, including temperature, pressure, humidity, motion, and other physical or environmental variables, is done by using sensors, instruments, or devices.
- **Vertical Farming -** Crops are grown vertically in layers that are piled one on top of the other. It is a kind of controlled environment agriculture (CEA) that uses just electric illumination to produce crops on more than one level in fully insulated, indoor facilities.

Chapter 2

REVIEW OF RELATED LITERATURE

2.1 Aeroponics

In an aeroponic system, plants are grown in a controlled environment without the need of soil or other growing medium but are receiving all the necessary nourishment. This method involves misting or spraying nutritional solution onto plant roots that are suspended in the air. This method requires a relatively lower amount of water input per unit of planted area, which makes it a method that is both safe for the environment and environmentally friendly (Tunio et al., 2020).

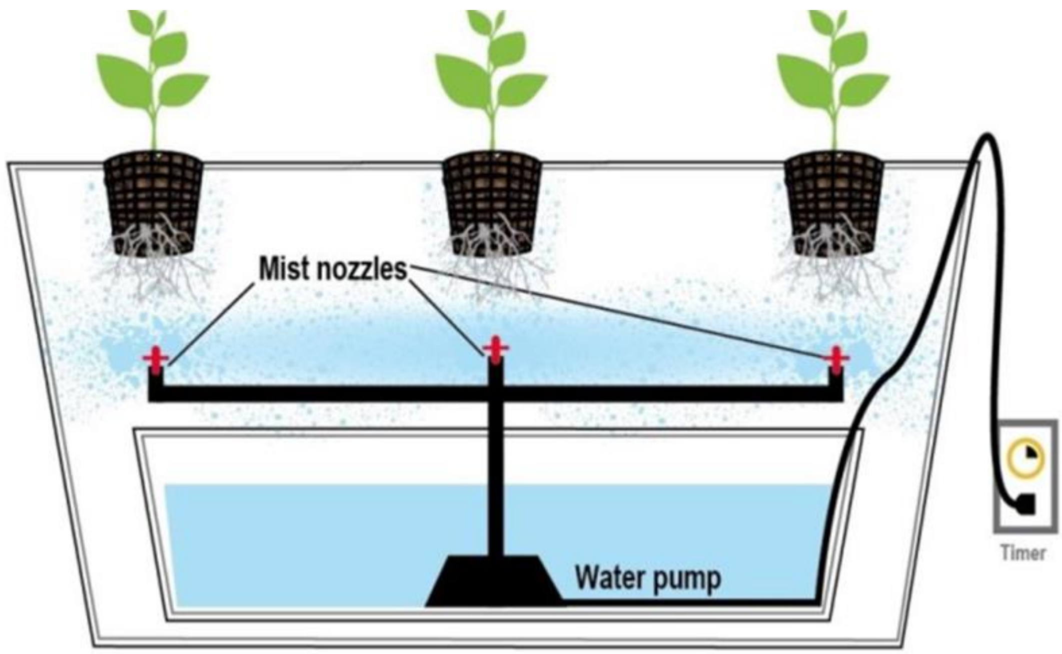


Figure 2.1 Aeroponic System

Figure 2.1 shows an example illustration of an aeroponic system highlighting the use of nozzles and water pump.

2.1.1 Vertical Farming

The vertical farming concept was presented with the intention of "building upwards" to increase the amount of agricultural land. To save water and eliminate soil, vertical farming includes growing crops inside of buildings (like a skyscraper or an empty warehouse) (M. Salim Mir et al., 2022). The vertical farming strategy aims to boost efficiency. Typical features include computerized air-temperature and humidity management, solar panel lighting fixtures and heating, and adjustable 24-hour LED illumination. Additionally, recycled water is gradually used in addition to rainfall or water from a desalination facility (Benke & Tomkins, 2017).

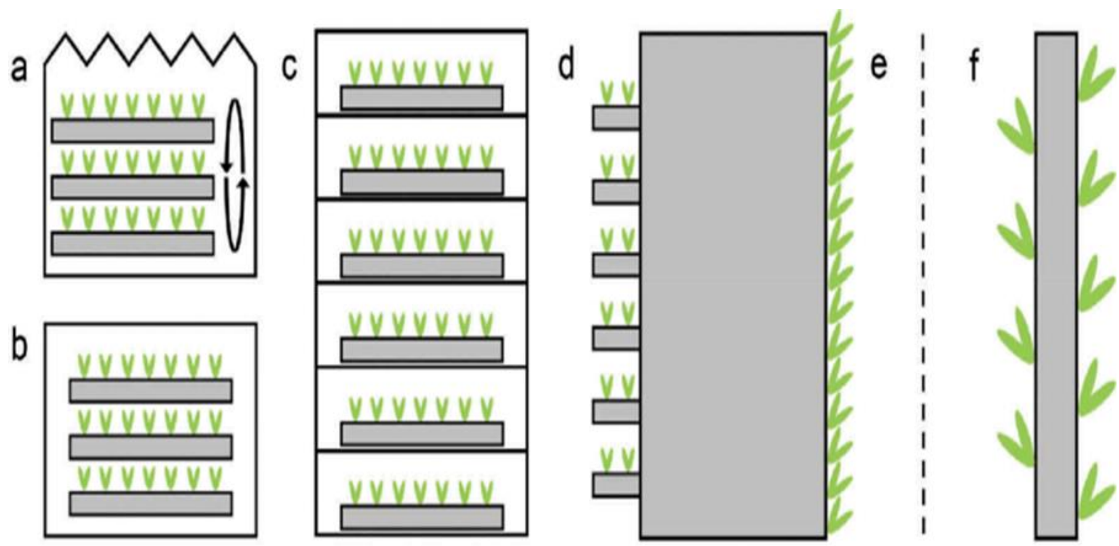


Figure 2.2 Representation of Vertical Farm

The representation of the vertical farm is presented on Fig. 2.2. It shows a multi-layer production of shelves. By this, the plants are allowed to be grown vertically.

2.1.2 Automated Aeroponic System for Smart Farming via IoT

With the advancement of technology, IoT has received much attention from industry and academia. IoT technology has been used to create smart homes, smart cities, and autonomous cars. Traditional agriculture, on the other hand, is still waiting for major advances in networking technology, particularly in IoT. Thus, many researchers and engineers have been working towards the application of IoT technology to the advancement of agriculture. Over time, researchers have been able to use IoT to create a smart farming solution that can be used in a variety of farming systems, such as hydroponics and aeroponics.

In relation to aeroponic systems and IoT technology, relevant works have been published, and many different designs and applications for a smart farming system have been proposed. Rahman et al. presented an indoor farming system concept based on the farming technique called aeroponic, in a controlled environment using Arduino and various measuring sensors. The proposed system is an automated urban indoor farming structure with the integration of technologically advanced instruments that will help supply fresh produce to a certain number of people not actively involved in gardening and without the need for soil and manual watering. The proposed system also has a web service that can be used to check the status of the system. The sensor threshold value is set in the program. The program specifies the sensor threshold value. To meet system requirements, this program will use sensor data to operate output actuators, such as the light bulb and the fan. By lowering power consumption, complexity, and offering a variable form to maintain an aeroponic atmosphere, the study was able to overcome the flaws (Rahman et al., 2019).

Table 2.1 Summary of Previous Studies in Automated Aeroponic System for Smart Farming via IoT

Author	Year	Title	Relevant Findings	Relationship to VSAFS
Rahman, Ferdousi Ritun, et al.	2019	Automated Aeroponics System for Indoor Farming using Arduino	With the proper maintenance of the environment with the system we were able to uphold a better growth compared to traditional farming with soil.	Both studies are aimed at developing an automatic aeroponics system.
Fitrianto Rahmad, Iwan Tanti, et al.	2020	Automatic Monitoring and Control System in Aeroponic Plant Agriculture	Results show that the system can be more efficient in saving labor and increasing the economic value of the product.	Both studies focus on developing an automatic aeroponics system.
Stephen C. Kerns Joong-Lyul Lee	2017	Automated Aeroponics System Using IoT for Smart Farming	Application that helps farmers increase the production of organic crops in a smart farming system.	Both studies will use IoT.

The connection between the related research and the project is summarize in Table 2.1. The results indicate that there are similarities in the usage of IoT and automating the aeroponics system.

S. Kerns et al. (2017) presented an automated aeroponic system using IoT devices. The researchers have used the Raspberry Pi Zero to gather information from a water pump and a dosing pump which are controlled by the sensors to add water and nutrients. The proposed system was designed to monitor and control the environmental factors required for optimal agricultural needs. The researchers also implemented a mobile application and service platform for an IoT device so that users can monitor and control the Aeroponics system remotely.

2.1.3 Automated Aeroponic System using Dry-Fog

Dry fog hydroponics is an aeroponics technique. It is a technique that involves spraying a very fine mist-like nutrient solution with an average droplet diameter of 10 meters or more in the root zone of the aeroponic system.

Kanechi et al. (2017) presented a new aeroponic system utilizing a dry-fog spray fertigation system for establishing ever-bearing strawberry production. This aeroponic system needs less water than most and keeps the root zone temperature lower due to the principles of dry-fog evaporation. The results of the study showed that dry-fog aeroponics kept the root zone and crowns cooler than the surrounding air temperature by up to 5°C. Based on the results, the researchers concluded that the dry-fog spray fertigation was an effective method for both supplying and cooling the root zone at the same time. Furthermore, the study also concluded that strawberry plants grown with the dry-fog method have enhanced photosynthetic activity, producing more inflorescences and fruiting.

Table 2.2 Summary of Previous Studies in Automated Aeroponic System using Dry-Fog

Author	Year	Title	Relevant Findings	Relationship to VSAFS
M. Kanechi, Y. Hikosaka, C. Fukuda et al.	2017	Ever-bearing strawberry culture using a new aeroponic system with dry-fog spray fertigation during the summer	Cooling the plant parts (crown and root) of ever-bearing strawberry affected the growth behavior.	Both studies will need an appropriate cooling method for the plant's growth.
Y. Hikosaka, M. Kanechi, M. Sato et al.	2015	Dry-fog Aeroponics Affects the Root Growth of Leaf Lettuce (*Lactuca sativa* L. cv. Greenspan) by Changing the Flow Rate of Spray Fertigation	Changing the flow rate of the dry-fog in the rhizosphere can affect the growth and physiological activities of leaves and roots.	Both studies use fog aeroponics.

According to Table 2.2, the relationship between the research both assess the optimum cooling strategy for plant development.

Hikosaka et al. (2015) presented a study about the growth traits and physiological functions of lettuce roots and leaves grown in dry-fog aeroponics at various flow rates of the nutrient dry-fog. The researchers concluded that the flow rate had an impact on the number of dry-fog particles that clung to the surface of the roots as well as the shoot and root development of leaf lettuce plants. The roots had strong branching, root hairs, and a high respiration activity as they grew and evolved in an aerobic dry-fog environment. These roots may be chosen in order to improve the plant's capacity for absorbing water and nutrients, meet the evapotranspiration requirement adequately, and boost photosynthetic rate and stomatal conductance. In light of this, dry-fog aeroponics is regarded as an efficient growing strategy to encourage plant development.

2.2 Sustainable Aeroponics System

Aeroponics has the potential to have a significant impact on impoverished communities due to its practices of conserving resources and high yield potential. Aeroponic cultivation is considered "controlled environment agriculture," which means that it addresses environmental issues by simulating an "ideal" growing environment in a closed space. The aeroponic system presented in the study will be sustainable since it has grow lights to supplement sunlight during rainy seasons and a solar backup in case of a power outage.

2.2.1 Grow Lights

A significant challenge for fruit-bearing crops like strawberries is controlling their light spectral composition to regulate flowering. Prisca et al. (2022) have demonstrated that the day-neutral strawberry accessions Fragaria vesca 'Yellow Wonder' YW5AF7 and 'Hawaii-4' can be induced to produce flowers and fruits by various light treatments. This project was done under both long- and short-day photoperiods by using blue (449 nm) and far-red (740 nm) light in the background of the sunlight-like photosynthetic active radiation (PAR). Based on the findings, blue light throughout the night and far-red light for 24 hours were the best times for flower induction. These light treatments overrode the photoperiodic regulation of blooming. Both light treatments increased blooming, increasing fruit yield while having little to no impact on vegetative plant development.

Table 2.3 Summary of Previous Studies in Aeroponics System Grow Lights

Author	Year	Title	Relevant Findings	Relationship to VSAFS
Meyer Prisca, Verlent Maarten, Van Doorsselaere Jan, Nicolai Bart, Saeys Wouter, Hytonen Timo, De Coninck Barbara, Van de Poel Bram	2022	Blue and far-red light control flowering time of woodland strawberry (Fragaria vesca) distinctively via CONSTANS (CO) and FLOWERING LOCUS T1 (FT1) in the background of sunlight mimicking radiation	The optimal periods for flower induction were during the night under blue light and 24 hours under far-red light.	Both studies will use blue/red light LEDs for the aeroponic system.
Majid Esmaeilizadeh, Reza Malekzadeh Shamsabad, Hamid Reza Roosta, Piotr Dąbrowski, Marcin Rapacz, Andrzej Zieliński, Jacek Wróbel, Hazem M. Kalaji	2021	Manipulation of light spectrum can improve the performance of photosynthetic apparatus of strawberry plants growing under salt and alkalinity stress	CO2 absorptions are significantly increased in red and blue/red light.	For the aeroponic system, both studies will utilize blue/red LEDs.

Table 2.3 depicts the behavior of plant development under various grow light colors. Blue/red grow lights were shown to be the most effective.

Plant development and metabolic processes are affected by light quality. Strawberries are also known to be sensitive in terms of alkalinity stress which could cause a reduction in the quantity of flowers and inflorescences, as well as interveinal chlorosis. Esmaeilizadeh et al. (2021) experimented with the effects of various light spectra on strawberries *(cv. Camarosa)* plants under salt and alkalinity stress. As a control, blue light with a peak at 460 nm, red light with a peak at 660 nm, blue/red light with a peak at 1:3, white light with a peak at 1:1, and ambient light were employed. The study's findings imply that using various light spectra might attenuate the negative impacts of salt and alkaline stress on strawberry plants' ability to photosynthesize. Under salt stress, red and blue/red light significantly increased CO_2 absorption, while under alkaline stress, only red light significantly changed its magnitude.

2.2.2 Solar Powered

Utilizing solar power is one way to improve the aeroponic system. Solar energy is one of the renewable energy sources that is universally available for no cost. Solar energy is cost-effective, environmentally friendly, and farmer friendly. Using PV cells, solar energy can be stored as electrical energy in batteries for use in power generation. The solar-powered aeroponic system was made to grow high-value crops, and if the main power source fails, it can be used as a backup power source (Hancock, 2017).

Table 2.4 Summary of Previous Studies in Solar Powered Aeroponic System

Author	**Year**	**Title**	**Relevant Findings**	**Relationship to VSAFS**
Hancock R.	2017	Water and Energy Conservation Grow System: Aquaponics and Aeroponics with a Cycle Timer	The study determined that in addition to a solar-powered system, an aeroponics system requires a cycle timer to provide the proper feeding schedule for optimal plant growth and size.	Both studies use solar powered aeroponic systems.
Ramalingannanavar, N. et al.	2020	Design, Development and Evaluation of Solar Powered Aeroponic system	Technical evaluation of the system in the present case indicated that the 120W SPV module can provide 95.12 – 111.8W for Raichur climatic conditions and roots.	In both studies, solar-powered aeroponic systems are utilized.

Table 2.4. Illustrates that studies have employed solar power for Aeroponic systems, which will be the same the setting with VSAFS for its efficiency and as a backup power source.

According to a study conducted by Ramalingannanavar et al., (2020), using solar panels can serve as an alternative power source for the aeroponic system. In this system, the crop shoot portion is exposed to natural or artificial light. Important growth chamber parameters, including temperature and relative humidity, are optimally maintained. This method of cultivation reduces water consumption to a greater extent than conventional soil agriculture. The study's technical analysis of the system showed that the 120W SPV module can produce between 95.12 and 111.8W in Raichur's climate.

2.2.3 Rainwater Harvester

Rainwater harvesting is the practice of collecting, storing, transporting, and purifying rainwater from rooftops, parks, roads, etc. for future use. Rainwater collection is an efficient method of water conservation. The purpose of Jurga et al.'s (2021) study was to determine whether a rainwater harvesting system could adequately meet the water needs for hydroponic lettuce cultivation indoors in Wroclaw, Poland. In a 300-square-meter room, the hydroponic cultivation of vertically grown lettuce was evaluated. The rainwater harvesting calculation considered the capacity of the tank for the water to be collected. Yield after spillage (YAS) algorithm was used to simulate the operation of the water storage. It was clear that the suggested method might function as a relief system for the water supply network. The harvesting system for the chosen vertical farming indoor hall provides an average of 35.9% of the water required and permits an annual water savings for the cultivation of 146,510 L.

To further improve the advancement of agricultural technology, a study by Kumar and Prasaath (2021) demonstrated that the crops grown, and farm needs were the aspects considered to automate the monitoring of a farm field. In addition to this, collection of rainwater or rainwater harvesting improves the system since it saves even more resources and reduces labor cost.

Table 2.5 Summary of Studies in Rainwater Harvesting

Author	Year	Title	Relevant Findings	Relationship to VSAFS
A. Jurga, A. Pacak, D. Pandelidis, and B. Kaźmierczak	2021	A long-term analysis of the possibility of water recovery for hydroponic lettuce irrigation in an indoor vertical farm	This study shows how to design a rainwater harvester to account for future climate change.	Both studies will incorporate rainwater harvesting.
N. K. Kumar and T. S. Prasaath	2021	Field Monitoring and Rain Water Harvesting Automation Using Internet of Things	The study reveals that the rainwater harvester can be automated using the internet of things.	Both research studies will include rainwater harvesting.
S. Zhang, J. Zhang, T. Yue, and X. Jing	2019	Impacts of climate change on urban rainwater harvesting systems	The study determined the suitability of a rainwater harvesting process to achieve the water requirements for hydroponic lettuce cultivation indoors.	Both research studies will include rainwater harvesting and determine their sustainability.

Previous research has demonstrated the effectiveness of rainwater collection, as shown in Table 2.5. Rainwater collection plays a vital part in demonstrating the project's sustainability.

In addition, many cities, including Beijing and Shenzhen, are promoting rainwater harvesting (RWH) as an adaptation to climate change strategy to alleviate water supply and drainage constraints in urban areas. A study by Zhang et. al. (2019) suggests that the design of RWH systems should consider the conditions of future climate changes to meet the standard of sustainable water saving and rainwater management.

2.3 Environmental Sensor

Environmental sensors are sensors that measure the environmental conditions of the system, such as temperature, humidity, light, air pressure, air quality, and etc. Consequently, an environmental sensor aids in the monitoring of environmental factors that result in the collection and analysis of a whole amount of data that may be utilized for farming, energy conservation, water management, and irrigation.

2.3.1 Temp/Humidity Sensor

The job of a temperature sensor is to record, monitor or notify the changes in temperature by measuring its surrounding climate and converting that collected information into electronic data. While a humidity sensor detects humidity in its environment and converts that input into an electrical output.

An example of an entry-level digital temperature and humidity sensor is the DHT22. It monitors the humidity and temperature of the surrounding air using a capacitive humidity sensor and a thermistor, and then outputs a digital signal on the data pin, removing the need for analog input inputs.

Temperature regulation is required in the aeroponic system to make the plants reach full maturity as quickly as possible. This holds true for both the nutrient solution and the surrounding air (“Sensor Fusion”, 2022). Humidity is an important factor in aeroponic systems for successful plant growth and development. However, changes in relative humidity have a significant impact on plant growth. Humidity affects plant physiological functions and contributes to disease problems. Furthermore, it is very easy to control and maintain humidity in the growth.

2.3.2 Water Level Sensor

A water level sensor detects an abnormally high or low liquid level in a fixed container. The design of a sensor water brick is to detect water and can be used to identify rainfall, water level, and even liquid leaks.

2.3.3 pH Sensor

A pH sensor is a scientific instrument that measures acidity and alkalinity in water and other liquid substances with precision.

One example of a pH sensor is the PH-4502C pH sensor module. It is a device that allows measuring the pH with the help of a probe, which is the one that takes the reading (electrode E201) through the BCN connector.

The pH of the aeroponic solution has a significant impact on nutrient availability and plant uptake. Strongly acidic solutions present a competitive environment for H+ and other mineral nutrients that are necessary for plant uptake. According to the results, pH 6.0 was evaluated as optimum for strawberry aeroponic cultivation, resulting in better quality fruits. Furthermore, the pH of a nutrition solution should be maintained within a small range, often between 5.5 and 6.5, to provide the greatest availability of vital nutrients to aeroponic plants (Akon 2019).

2.3.4 EC Sensor

The electrical conductivity sensor (EC sensor) is a device that measures electrical conductivity in a solution and is commonly used in aquaculture and water quality assessment. Electrical conductivity indicates the strength of a nutrient solution. Plants receive nutrients dissolved in water. All nutrients are salts with a positively charged cation and a negatively charged anion. Fertilizer salt breaks into cations and anions in the nutrient solution given to the plant, allowing it to conduct electricity; a higher nutrient content signifies a greater magnitude of electrical ions and a higher electrical conductivity (EC). The EC level of 1.5 considerably induced the best yield contributing attributes of marketable fruit number, individual fruit weight, and overall fruit yield. The EC level of 1.5 ds m^{-1} was determined to be optimal for most of the features and influenced plant vegetative growth (Akon et al., 2018).

2.3.5 Light Intensity Sensor

A photoelectric device called a light sensor turns the observed light energy (photons) into electrical energy (electrons). The intensity and quality of light not only provide energy, but also allow for a wide range of morphological and physiological-related responses during plant growth (Tunio et al., 2020).

Table 2.6 Summary of Previous Studies in Environmental Sensors of Aeroponics

Author	Year	Title	Relevant Findings	Relationship to VSAFS
M. Tunio *et al.*	2020	Potato production in aeroponics: An emerging food growing system in sustainable agriculture for food security	In countries with insufficient natural resources, the aeroponics system can be utilized effectively for the production of additional vegetables with the help of different sensors.	Both studies focus on developing an automatic aeroponics system using different environmental sensors.
M. R. Akon	2019	The influence of nutrient solution p H on growth and yield of strawberry plants grown in aeroponic system	Based on the results of the study, pH 6.0 was better than pH 3.0, 4.0, 5.0, and 7.0 for most growth and yield contributing parameters.	Both studies monitor the pH level of the strawberry plant in an aeroponics system.
M. R. Akon, S. Ahsan et al.	2018	Effect Of Electrical Conductivity On Growth And Yield Of Strawberry Cultivated In Aeroponic System	Electrical conductivity in nutrient solution 1.5 ds m-1 could be followed to increase the fruit production of strawberry cultivation in the aeroponic system.	Both studies measure the electrical conductivity (EC) of strawberry plants grown in an aeroponic system.

As indicated in Table 2.6, the inclusion of environmental sensors has been mentioned in relevant research and is considered as part of the project.

The BH1750FVI (or BH1750) is one example of a light intensity sensor. The incident light intensity is measured by a calibrated digital light sensor IC, which then translates the result into a 16-bit digital value. Direct digital output is provided via the BH1750FVI sensor.

An I2C interface can be used to access the sensor output. The measurement unit is lux, and it can measure ambient light intensity. It's simple to connect this module to an Arduino.

2.4 Actuators

Actuators are the devices that, upon receiving a control command, cause a change in a physical system by generating force, motion, etc. It is a mechanism that causes movement. Typically, actuators are utilized alongside a power supply and a coupling mechanism. The power unit delivers AC or DC power at the specified voltage and current rating. The solenoid valve, DC fan, pump, and LED lights will be utilized as actuators in the present study's aeroponics system.

2.4.1 DC Fan motor

Direct current (DC) motors convert electrical energy into mechanical energy by absorbing direct current. Electromagnetism causes a machine to rotate when DC motors are used. A DC motor's rotation is aided by an inductor (electromagnet) that generates a magnetic field. A DC fan is a fan powered by direct current and utilizing a DC motor. Similar to AC axial fans, DC axial fans and DC cross flow fans are also available. DC axis flow fans are widely used for ventilation, electronic device cooling, computer ventilation, etc.

2.4.2 Mister

In contrast to conventional spraying apparatus, a fogger delivers the chemical as fog. This is the most efficient way to spray or apply certain chemicals. These specialized foggers and the small droplets generated within the fog are then either slowly blown over the plants or fed into an enclosed space where the roots are contained. This method of delivering ultra-low volumes of nutrients and water for hydration and supplementation is impressive in its efficiency and simplicity. In this environment, plants tend to absorb the maximum amount of nutrients required for growth and survival. This is due to the fog's ability to permeate and seep into every nook and cranny of the crops, unlike spraying, thereby ensuring a constant supply and complete delivery to all the plants so that they grow uniformly (Hikosaka et al., 2015).

2.4.3 Pump

A pump is a mechanical device for transferring liquids from one location to another. This hydraulic device increases the pressure of a fluid from low to high and moves the fluid from low to high pressure. Pumps propel liquid by converting the liquid's mechanical energy into pressure energy (hydraulic energy). One example of a pump suitable for an aeroponics system is a peristaltic liquid pump, in which only the tube part touches the water. Since only the inner bore of the tube connects the fluid, it eliminates the risk of the pump contaminating the liquid or the fluid contaminating the pump.

2.5 Nutrient Solution

Nutrient optimization is the most crucial aspect in soilless culture, such as aeroponics, to produce high-quality, high-yield crops and fruits. Growing various plants in aeroponics requires a person to supply all of the necessary elements for the plants to grow correctly. Every crop has a unique nutritional demand. The needed nutrient solution should have a comprehensive structure of primary, secondary, macro, and micronutrients. All these nutrients must be in proper proportions for the plants. Nitrogen, phosphorus, and potassium are the major nutrients. Magnesium, calcium, and sulfur are examples of secondary nutrients (Grower Today, 2021).

Aeroponic nutrition solutions are usually more concentrated than traditional solutions. This indicates the amount of liquid required in an aeroponic system is less than that needed for a traditional system. The proper nutrition solution recipe for the aeroponics plants is critical to their growth. Furthermore, it is essential to know the needed nutrient solution for a specific type of plant and the appropriate nutrient level for the plant's growing requirements.

2.6 Strawberry Runners

Most strawberry varieties produce runners, also known as stolons. These runners will eventually form roots and form a clone plant. Once these adventitious roots have established themselves in the soil, the runners begin to dry out and shrivel. As a result, employing strawberry plant runners for replication makes it extremely simple to produce extra plants. Strawberry cultivation can be effective at optimum day temperatures of 22 to

25 °C and ideal night temperatures of 7 to 13 °C, according to Imran et al. (2022). It spreads through runners, a natural form of dissemination. It is more effective to employ runners as propagation material than seeds. The study also states that the most significant disadvantage of using store brought strawberry seed is the user does not know the viability and germination percentage of the seed.

The first and most important aspect of cultivating strawberries is selecting strong and healthy runners. According to Madan's article, to grow a runner, one must choose a strong runner close to the mother plant to grow and remove other runners from the plants. After a few times, these runners will grow roots that will make touch with the soil. Before cutting for propagation, ensure proper roots in the runner; otherwise, it may fail to develop into a new plant. Then, using a hairpin, u-shaped clips, or wire, secure the runner in the soil. The plantlet grows and produces enough root to support its growth after four to six weeks of pegging (TechnicalAgri, 2021).

Table 2.7 Summary of Studies of Strawberry Runners

Author	Year	Title	Relevant Findings	Relationship to VSAFS
Imran, Kazimi, Pratap	2022	Effects of various growing media, as well as jeevamrit, on the growth and production of strawberry: A review	The use of runners as propagation material is more efficient than the use of seed propagation.	This study shows that strawberry runners is much faster to propagate for the aeroponics system.

Table 2.7 compares the propagation of seeds and runners for the aeroponic method and reveals that runners are more effective than seed growth.

2.7 Sensor Data Fusion

Sensor fusion is the process of combining sensor data with data from other sources to generate information with less uncertainty than would be possible if these sources were used separately. Sensor fusion includes several algorithms and methods such as the Kalman Filter, Bayesian Network, etc. (Liu et al., 2016).

Based on the Bayes theorem, a Bayesian network is a probabilistic graphical tool that assesses the conditional dependence structure of a set of random variables: P(A|B) = P(B|A) P(A) P(B) (Liu et al., 2016).

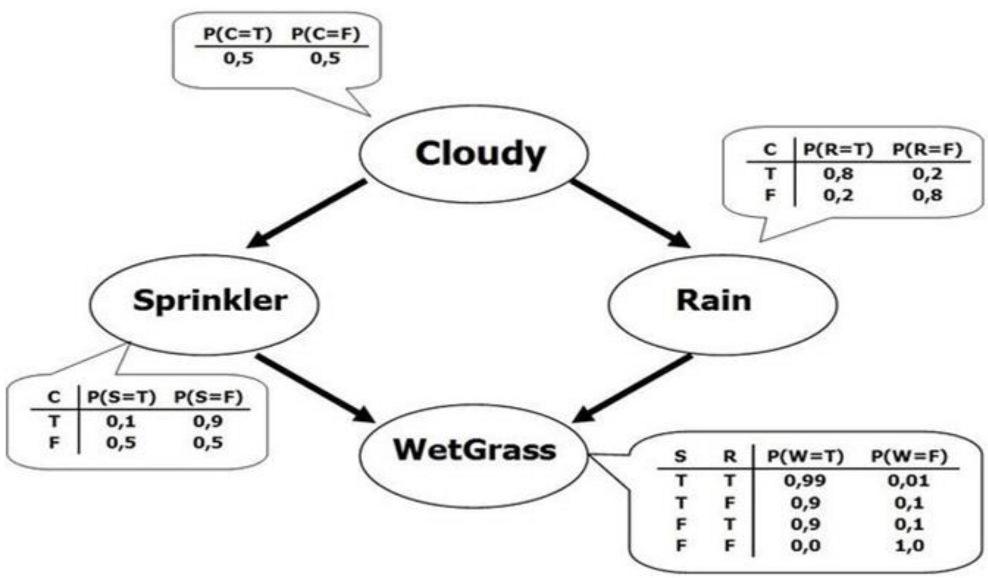


Figure 2.3 Bayesian Network Representation

Figure 2.3 depicts a Bayesian Network representation in which the nodes in the graph represent variables and the edges reflect conditional dependencies between variables.

Using sensors connected to the Raspberry Pi, Asha Hagargund (2021) demonstrated a Bayesian theorem-based plant health care system. The study was conducted on the health care of one particular rose plant. The study uses a Bayesian model for inferring the suitability of the climate, taking a significant number of likelihoods with sensor readings. With the relevant information on environmental elements like temperature, humidity, and soil moisture, this strategy will prevent overwatering and suggest the ideal time of watering to the user. The study concluded that using a Bayesian approach makes the system efficient at handling the health care of the Rose plant by reducing the redundant calculation for suitability of climate sensor readings.

Table 2.8 Summary of Studies in Sensor Data Fusion

Author	Year	Title	Relevant Findings	Relationship to VSAFS
Hagargund, Asha G	2021	Bayesian inference and Internet of Things based plant health care	Designed an IoT based smart rose plant health care which effectively monitors the need and amount of water required for the rose plant.	Both studies use the Bayesian Inference algorithm.
M. I. Alipio, et. al	2017	A smart hydroponics farming system using exact inference in Bayesian network	The use of exact inference in Bayesian Network aids in producing high-quality crops.	Bayesian Inference is utilized in both studies.

Table 2.8 shows the previous research that used Bayesian Network Inference shown its credibility in assessing the likelihood of alternative combinations of values for the variables.

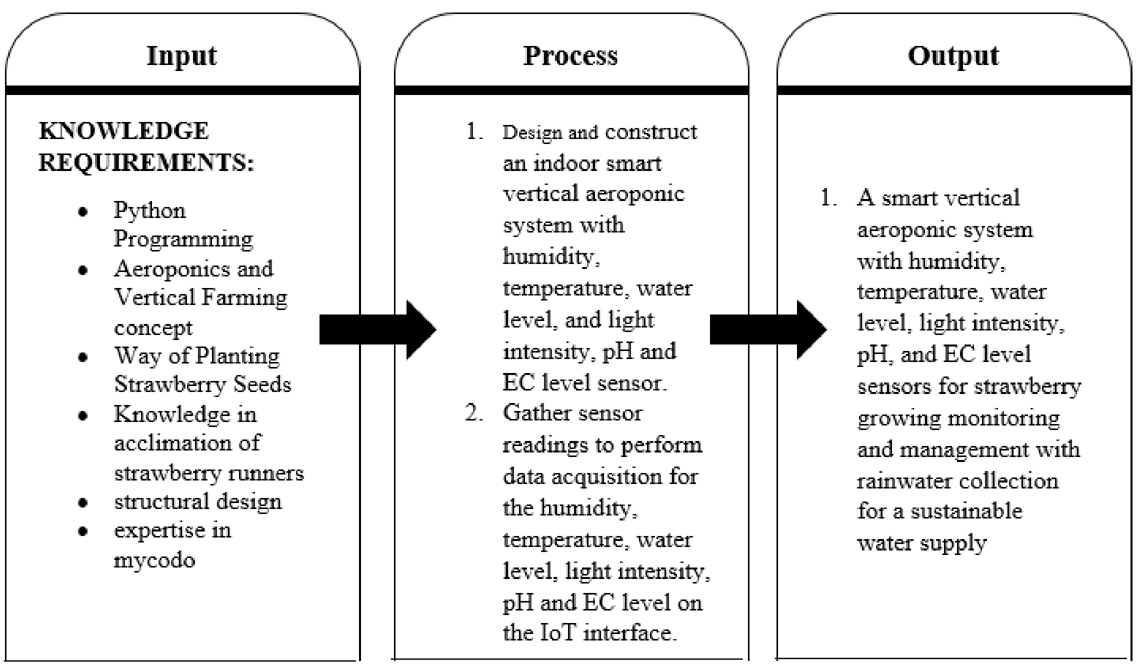
A smart hydroponic farming system created by Alipio et al. (2017) uses Bayesian network inference to automate the process of growing plants. In order to establish an atmosphere that is conducive to plant development, sensors and actuators have been integrated. A Bayesian network was created using the information acquired by the sensors to draw conclusions for autonomous control. Two web interfaces were created for the monitoring and controlling of the system one is for the automatic control and the other one is for the manual control. The study concluded that automatic control has a higher yield of crop than manual control.

Chapter 3

METHODOLOGY

3.1 Research Design

A developmental research design will be used in this study. It is a design where the researcher performs a systematic study regarding the designing, developing, and evaluating of instructional programs, processes, and products that shall fall under the criterion of consistency and effectiveness (Alipio et al., 2017). This will aid the researchers in designing and developing their target vertical smart indoor strawberry aeroponics system. An experimental research design will also be used in this study. This design will provide the researchers with a variable that can be manipulated, measured, calculated, and compared and enable the researchers to conduct the study in a controlled environment (Alipio et al., 2017). The researchers will then be able to compare the results to the conventional method of strawberry cultivation to assess the impact of varying the various factors on the growth of strawberries in the lowlands.



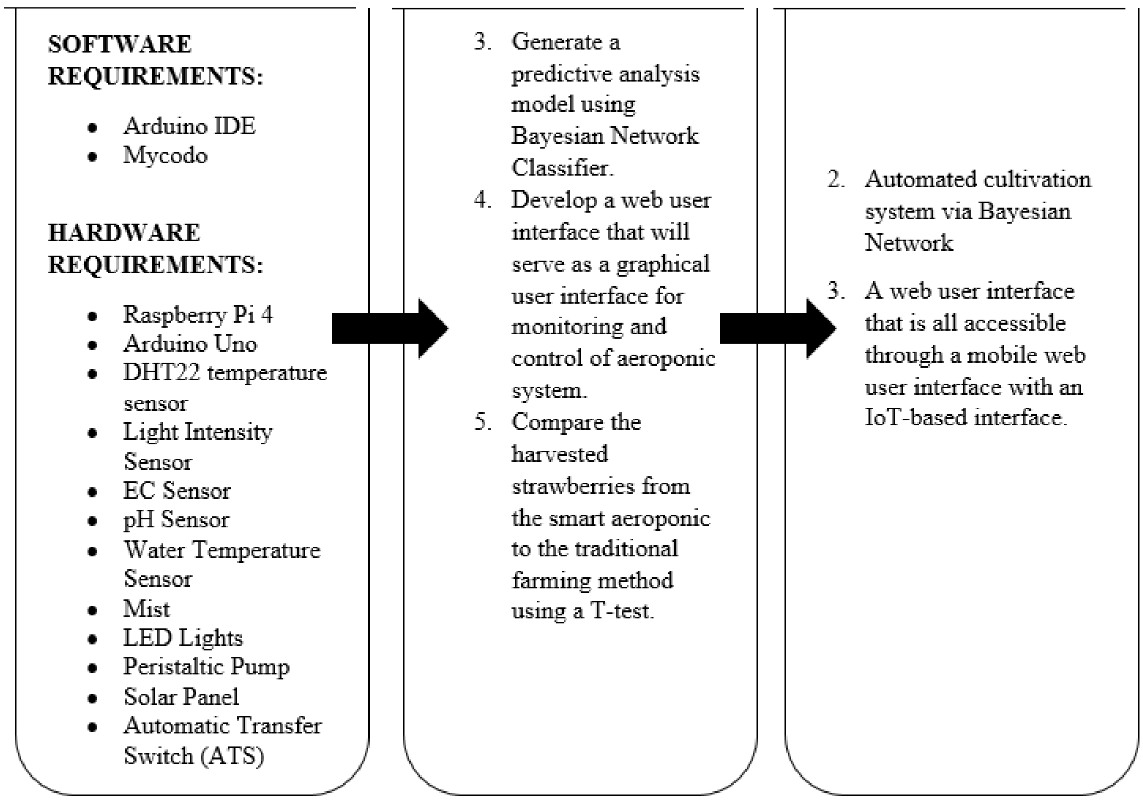


Figure 3.1 IPO of the System

The figure shown above is the Input-Process-Output (IPO) of the system. The input will be gathering the environmental parameters using the attached sensor. The data from these sensors will be collected and sent to the IoT platform to generate a Bayesian network model. Finally, the data in the cloud will be displayed via a user interface in a time series chart that will make the entire indoor smart aeroponic system accomplished.

3.2 Research Process Flow

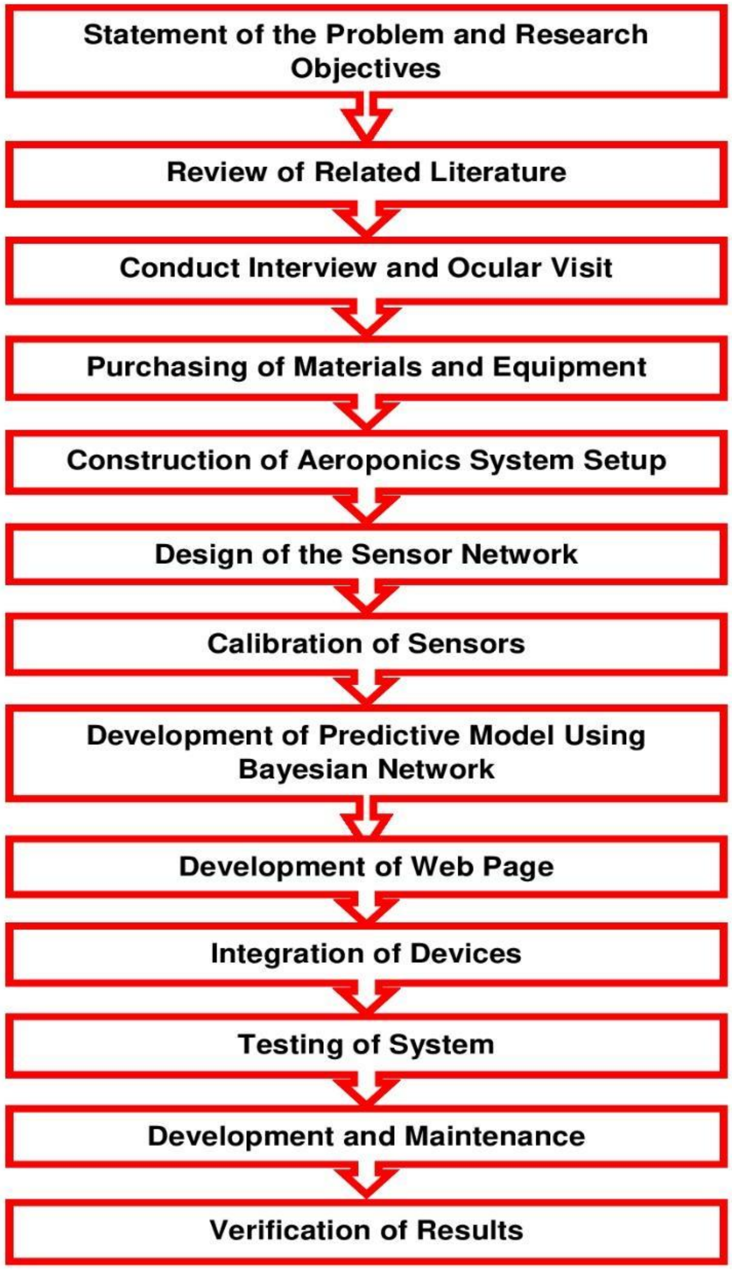


Figure 3.2 Process Flow Chart of the Research

Figure 3.2 depicts the study's flow process. The first step is formulating a problem statement and establishing the study's objectives to determine its purpose. After identifying the research objective, a review of the relevant literature provides researchers with insight into what other research has accomplished to identify the research gaps. After planning, the researchers will be able to design and conceptualize the aeroponic system setup by visiting the deployment site. The next step is to canvas and purchase all the materials and equipment needed. The researchers will then calibrate the required sensors and install the aeroponics system. Next, construct the aeroponic greenhouse and design and install the sensor network. After installing all the required sensors and actuators, the researchers will calibrate the sensors and implement the Bayesian Network. This algorithm will produce a decision and predictive model that will assist the aeroponic system in identifying and correcting incorrect parameter values. The next step is to create a mobile-accessible web user interface that can be used to monitor the gathered data. The software and hardware will now be implemented for it to be synchronized. After integrating all the devices, the researchers will test the system's working flow to monitor and correct system and chamber deficiencies. The results are checked in the last step of the research process to see if the study's objectives were accomplished.

3.2.1 Aeroponics System Flowchart

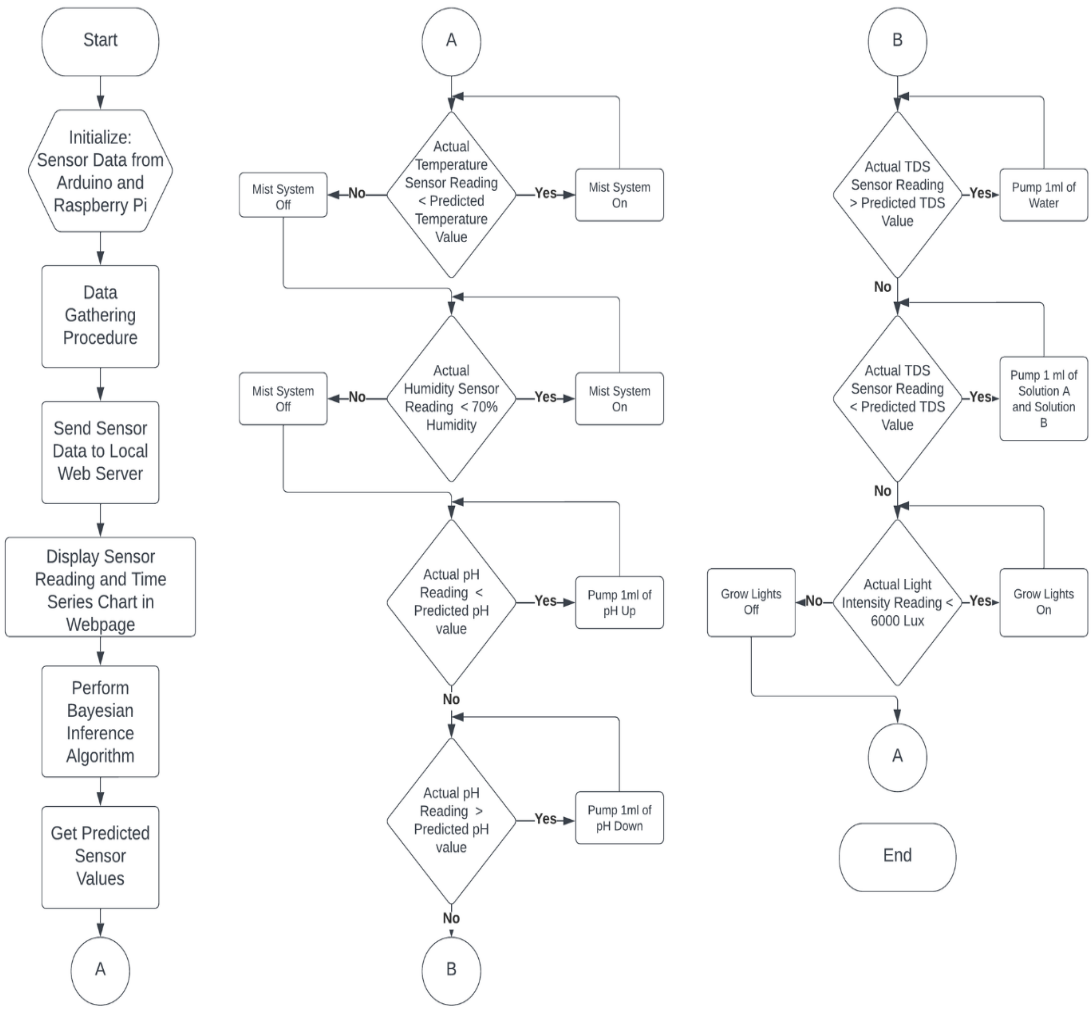


Figure 3.3 Aeroponics System Flowchart

Figure 3.3 depicts an overall graphical representation of the aeroponics system's operation and displays how the sensor data will be utilized and transmitted to the local web server. This flowchart also illustrates how the Bayesian algorithm was employed in the study to aid in decision-making by assessing the collected data and applying it to the aeroponics system.

3.2.2 Block Diagram

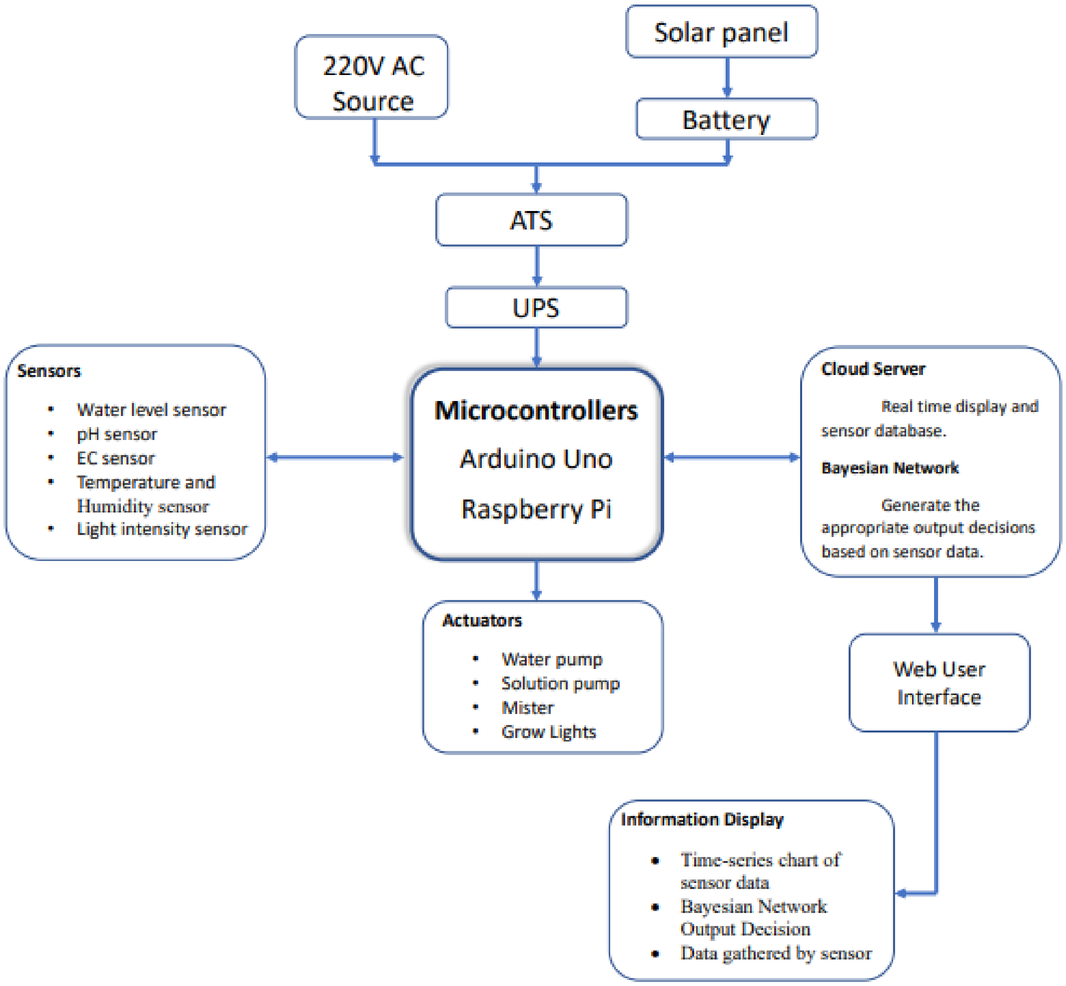


Figure 3.4 Block Diagram

Figure 3.4 demonstrates the significance of the microcontroller in the aeroponics system using a block diagram from the study. It illustrates the microcontroller's connection with the sensors, actuators, UPS, and cloud server. Each block connected by a line aids researchers in understanding the relationship between each block and visualizing the study's functional perspective.

3.3 Design and Construct an Indoor Smart Vertical Aeroponic System Setup with Humidity, Temperature, Water Level, Light Intensity, pH, and EC Level Sensors to Monitor and Control Strawberry Cultivation with Sustainable Water Supply via Rainwater Harvesting and Controlled using Raspberry Pi 4.

The aeroponic system requires very little space and is thus ideal for urban agriculture. Recycling the nutrient solution prevents water loss and conserves 95% of water. As a result, plants are healthier and grow faster.

3.3.1 Purchasing of Sensors, Actuators, and other Materials

Acquire the appropriate materials, sensors, and actuators to construct the indoor aeroponic system setup. The researchers will need a light intensity sensor, pH level sensor, temperature and humidity sensor, water level sensor, and electrical conductivity sensor for the sensors. Further, the actuators are the mister, peristaltic pump, and red and blue grow lights. The additional materials are pipes for the tower, a container to serve as the water reservoir, a Raspberry Pi 4, phosphorous-based pH down and pH up solutions, nutrient solutions, and strawberry runners to complete the system.

3.3.2 Project Components

The project utilizes several key components, including a Raspberry Pi 4, an Arduino Uno a pH sensor meter, a temperature and humidity sensor, a TDS sensor meter, a water level sensor, a light intensity sensor, grow lights, a peristaltic pump, misting nozzles and solar energy materials.

3.3.2.1 Raspberry Pi 4

Figure 3.5 Raspberry Pi 4 (8gb)

The Raspberry Pi 4 Model B 8GB is a powerful single-board computer that plays a central role in this study. This versatile device functions as the brain of the smart vertical aeroponic system, allowing for the seamless integration of numerous sensors and actuators. The Raspberry Pi 4's increased memory capacity of 8GB enables it to efficiently process large amounts of sensor data and implement complex algorithms for the Bayesian Network. It enables precise control of environmental factors such as temperature, humidity, light intensity, water level, pH, and nutrient content in order to maximize strawberry growth. Its small size, low power consumption, and programmability make it an ideal component for building an innovative IoT-based solution that supports sustainable and efficient strawberry cultivation practices in a smart aeroponic system.

3.3.2.2 Arduino Uno

Figure 3.6 Arduino Uno

The Arduino Uno microcontroller is used to read both digital and analog sensor data readings. The Arduino Uno gather the data from the sensors (pH, EC, light intensity, air temperature and humidity, water level, and water temperature) and send it to the Raspberry Pi 4 using serial communication

3.3.2.3 Environmental Sensors

Various environmental sensors can be employed to monitor and maintain optimal growing conditions for plants. Here are some common environmental sensors used in aeroponics systems:

a. pH Sensor Meter for Arduino (Df Robot)

Figure 3.7 pH Sensor Meter

This sensor is designed particularly to measure the pH level of the nutrient solution in the smart vertical aeroponic system, a crucial parameter for optimizing strawberry cultivation. The IoT-integrated pH sensor provides real-time data on the acidity of the nutrient solution, enabling the Bayesian Network to make informed decisions for precise system control. This sensor contributes to the effectiveness of the smart aeroponic system in enhancing strawberry growth and yield by providing optimal pH conditions.

b. AM2302 (DHT22) Temp & Humidity Sensor

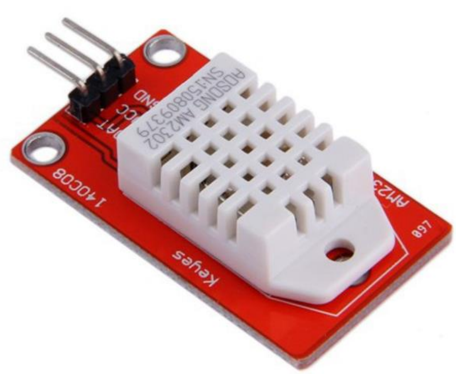


Figure 3.8 Temperature and Humidity Sensor

This sensor is designed to measure both temperature and humidity levels within the smart vertical aeroponic system, thereby providing vital environmental data for optimizing strawberry cultivation. By integrating the DHT22 sensor into the IoT infrastructure, temperature, and humidity readings in real-time are gathered, allowing the Bayesian Network to make informed decisions for precise control of the cultivation environment. With the precise monitoring capabilities of this sensor, the smart aeroponic system can maintain the ideal climate conditions required for sustainable and efficient strawberry growth, substantially contributing to the study's success.

c. Analog TDS Sensor Meter

Figure 3.9 Analog TDS Sensor Meter

The IoT-integrated Analog TDS Sensor Meter provides real-time data on the mineral content of the nutrient solution, enabling the Bayesian Network to make data-driven decisions for precise control of the cultivation environment

d. Water Level Sensor

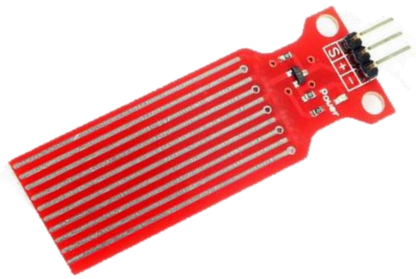


Figure 3.10 Water Level Sensor

This sensor is designed to measure the water level in the smart vertical aeroponic system, playing a crucial role in guaranteeing an efficient and sustainable water supply for strawberry cultivation. The Water Level Sensor, which is integrated into the IoT infrastructure, provides real-time data on the water levels, enabling the Bayesian Network to make informed decisions for precise irrigation system control.

e. Light Intensity Sensor

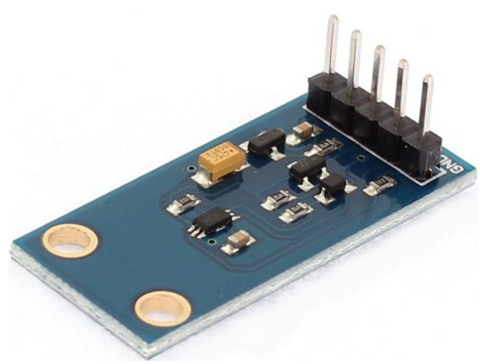


Figure 3.11 Unsoldered Gy-30 Bh1750fvl

The Unsoldered GY-30 BH1750FV1 is a light intensity sensor module designed for precise and dependable ambient light level measurement. It is frequently employed in a variety of applications, including intelligent vertical aeroponic systems for precise monitoring and control of light conditions. This sensor is designed particularly to measure light intensity levels within a smart vertical aeroponic system, thereby providing crucial data for optimizing strawberry cultivation

3.3.2.4 Grow Lights

Figure 3.12 LED Grow Lights (Red and Blue)

These concentrated artificial lighting systems are designed to supplement natural sunlight in the smart vertical aeroponic system, providing optimal light conditions for the growth of strawberries. Integrating with the Internet-of-Things (IoT) framework, grow lights can be remotely monitored and controlled to provide the precise light intensity and photoperiod required for the various phases of strawberry cultivation. The grow lights play a vital role in establishing a controlled and sustainable cultivation environment, substantially contributing to the success of the research study and its potential for future smart farming applications.

3.3.2.5 Peristaltic Pump

Figure 3.13 Peristaltic Pump

This specialized pump is intended to deliver precise and controlled quantities of nutrient solution to the smart vertical aeroponic system, thereby ensuring optimal strawberry nutrition. By precisely modulating nutrient supply, the peristaltic pump plays a crucial role in promoting sustainable and efficient strawberry cultivation, thereby maximizing plant growth and yield.

3.3.2.6 Misting Nozzles

Figure 3.14 Adjustable Misting Nozzle

Misting nozzles are devices designed to emit a thin mist or spray of water or other liquids into the atmosphere. These nozzles create minuscule droplets by pressurizing the liquid and forcing it through a tiny orifice. Due to the high velocity of the liquid as it departs the nozzle and fragmentation into fine particles, the misting effect is created. Misting nozzles are utilized in a variety of applications, such as outdoor cooling systems, agricultural irrigation, greenhouse humidity control, pollution suppression, and industrial processes. They provide an efficient method for dispersing water in the form of a fine mist, which can aid in reducing ambient temperatures, humidifying the air, and uniformly watering plants in controlled environments such as vertical aeroponic systems. Misting nozzles are a valuable tool for increasing comfort, productivity, and plant growth in a variety of environments due to their adaptability and efficiency.

3.3.2.7 Solar Energy Materials

Solar energy materials can be utilized to provide sustainable and renewable power for various components. Here are some solar energy materials commonly used in aeroponics systems:

a. **Solar Panel**

Figure 3.15 50 Watts Solar Panel

A solar panel, also known as a photovoltaic (PV) panel, is a device that uses the photovoltaic effect to convert sunlight into electricity. Multiple solar cells constructed from semiconducting materials, such as silicon, absorb photons from sunlight and generate an electron flux. This renewable energy source is used to power the smart vertical aeroponic system, ensuring its operation is sustainable and environmentally favorable. By utilizing solar energy, the intelligent aeroponic system can operate independently, reducing reliance on conventional power sources and promoting energy efficiency.

b. Solar Controller

Figure 3.16 Solar Controller

In solar energy systems, a solar controller, also known as a solar charge controller or regulator, is an essential component. Its primary purpose is to govern and regulate the flow of electricity between the solar panels and the batteries. The solar controller prevents overcharging and injury to the battery bank by ensuring that the batteries receive the optimal charge and voltage levels from the solar panels. In addition, it protects the battery system from over discharge and overvoltage situations, thereby maximizing the system's efficiency and lifespan.

c. Inverter

Figure 3.17 Solar Inverter (50 watts)

Inverters are indispensable components of solar power systems and other renewable energy applications. It is responsible for converting the direct current (DC) electricity produced by solar panels or batteries into alternating current (AC) electricity, which can be used to power domestic or commercial electrical devices. There are various varieties and sizes of inverters, including grid-connected, off-grid, and hybrid inverters. In systems connected to the main electrical grid, grid-tied inverters enable excess electricity to be fed back into the grid.

d. Solar Battery

Figure 3.18 Solar Battery (40 AH)

Numerous solar power installations incorporate solar batteries, also known as solar energy storage systems or solar battery banks. It is used to store excess electricity produced by solar panels during periods of high sunlight for use when solar panels are not producing electricity, such as at night or during inclement weather. Solar batteries typically utilize lead-acid, lithium-ion, or other advanced battery technologies to store the excess energy as chemical energy. These batteries can be repeatedly discharged and recharged, making them an essential component for off-grid, hybrid, and reserve power solutions.

e. Automatic Transfer Switch

Figure 3.19 ATS

Automatic Transfer Switch (ATS) is an electrical device used to automatically transfer power sources in the event of a power outage or other electrical problems. ATS is typically utilized in hybrid solar energy systems that combine solar power with grid power or emergency generators. When solar power or battery power is insufficient, or in the event of a power outage, the ATS will autonomously switch the electrical load from the solar source to the main electrical grid or a backup generator. When solar power is available or when the batteries are sufficiently charged, the ATS transfers the load back to solar/battery power.

3.3.3 Acclimation of Strawberry Runners

The researchers will initially germinate the Sweet Charlie seeds; after 60 days, the strawberry seeds will develop into strawberry runners. Before transferring the strawberry runners to the aeroponics tower, the strawberry runners must undergo the acclimatization process. The acclimatization period will take between two and three weeks. The first part of the acclimatization process is the resting period, during which the plant recovers from different environmental circumstances. The second phase is the stress test, during which the strawberry runners will acclimate to the local temperature of the deployment region by being exposed to severe temperatures to achieve their stability. The third stage is adaptation, which comprises the process of altering the plant's natural nutrient uptake requirements. The next step in the aeroponics method is transplanting, which involves transferring the modified plant to a new planting media. The key to a successful strawberry runner acclimation is when the plant develops aerial roots, which shows the plant's readiness for an aeroponics system.

3.3.4 Construction of Aeroponic System Setup

The construction of the aeroponics system setup employs tower farms and a vertical farming strategy. The vertical Aeroponic tower is constructed out of PVC pipes and measures 6 feet in height, 4.3 feet in length, and 1.48 feet in width. The entire system is contained within the greenhouse. The system utilized horticultural foam and pool noodles as the growing medium and a 1.64 ft x 1.15 ft x 1.64 ft plastic container as the reservoir. The nutrient solution is sprayed from a reservoir using mister with fine mist. Consequently, a solar panel and a rain harvester system was installed on the greenhouse's roof and connected to the water tank.

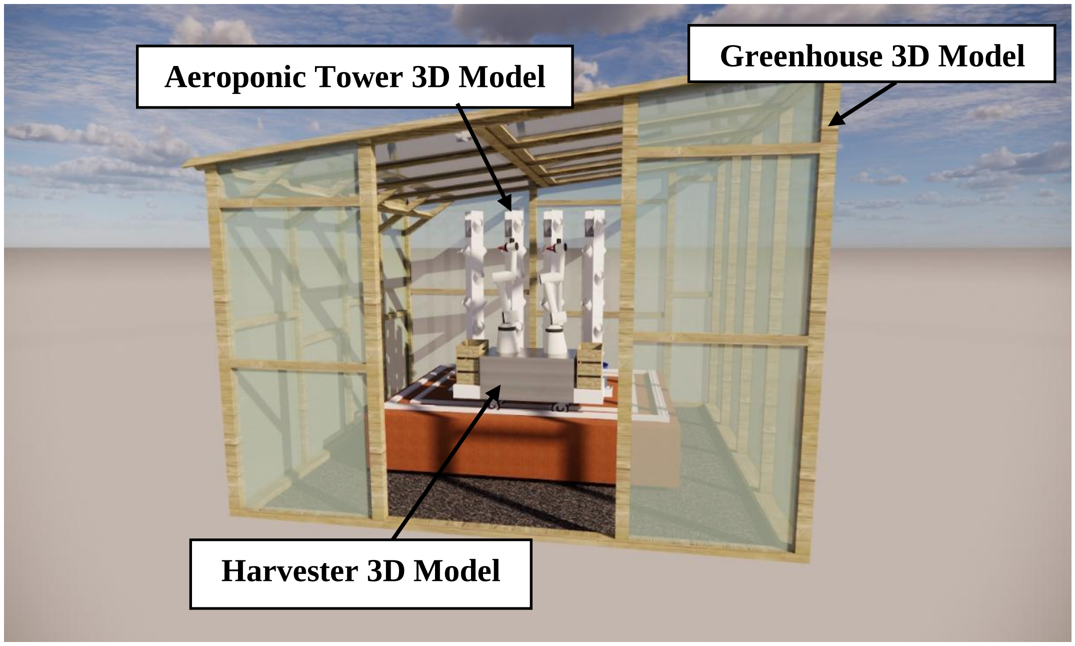


Figure 3.20 Green House 3D Model Set-up of the Aeroponics Tower (Front View)

Figure 3.20 displays the front view of the 3D model of the initial design of the Aeroponic system within the greenhouse.

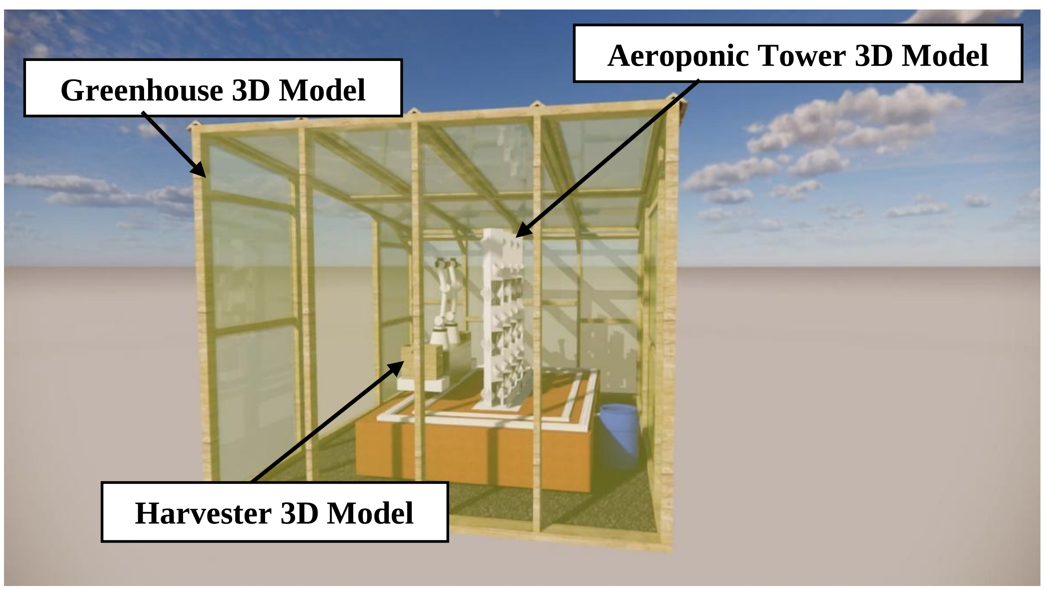


Figure 3.21 Green House 3D Model Set-up of the Aeroponics Tower (Side View)

Figure 3.21 shows the side perspective of the 3D model of the initial design for the Aeroponic System within the greenhouse

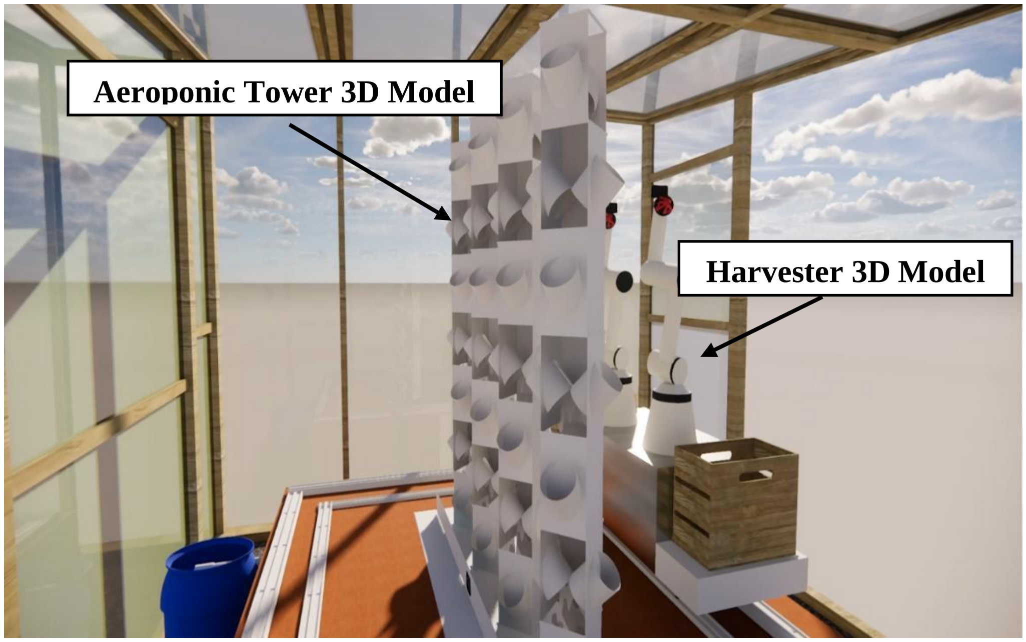


Figure 3.22 Aeroponics Tower 3D Model Set-up (Side View)

Figure 3.22 provides a considerably more detailed view of the aeroponic tower configuration as a 3D model, which represents its original design.

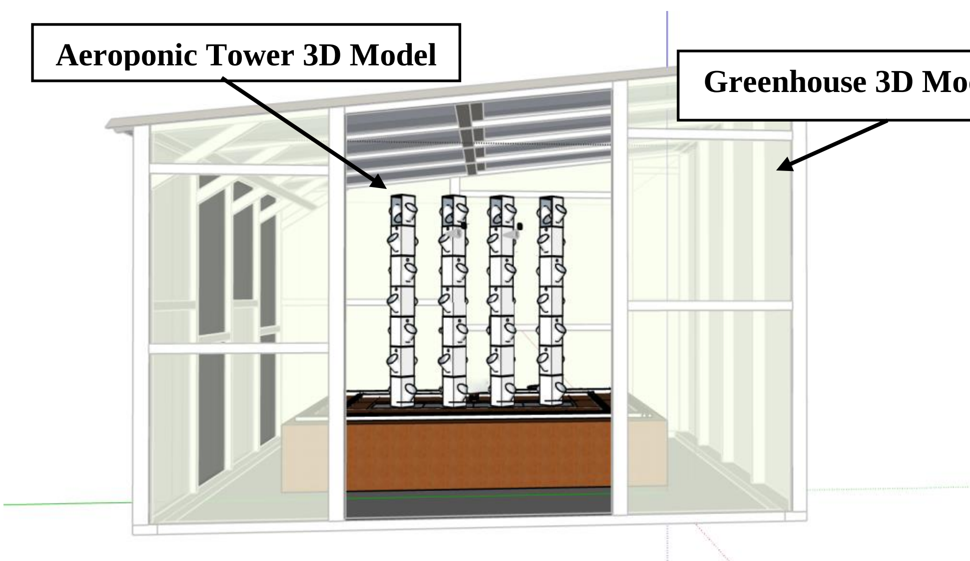


Figure 3.23 Aeroponics Tower 3D Model Set-up (Front View)

Figure 3.23 shows the front view of the entirety of the project with the aeroponic system situated inside the greenhouse

3.3.5 Calibration of sensors

Table 3.1 Strawberry Required Parameters

Parameters	Value
pH	**5.5 to 6**
TDS	**500 to 800 ppm**
Water Temperature	**18 to 25 degrees Celsius**
Greenhouse Temperature (inside the greenhouse environment)	**18 to 25 degrees Celsius**
Light level intensity	**>6000 lux**
Average level of humidity	**60 to 75 percent**

As observed in Table 3.1, are the suggested standard sensing values for each parameter, as validated by relevant past research.

As mentioned by Akon (2019) and Akon et al. (2018), each sensor has recommended sensing value ranges where each parameter should be satisfied for a climate that promotes strawberry growth.

3.3.6 Integration of Sensors and Actuators with Raspberry Pi 4 inside the Greenhouse

Six different sensors are integrated with Raspberry Pi 4, which collects data on various aspects of plant development. These sensors assess the water level (WL), pH level (PH), electrical conductivity (EC), temperature (T), relative humidity (RH), light intensity (LI), and water temperature (WT). The EC, pH, temperature, water level, and humidity sensors are directly probed into the reservoir. These will gauge the nutritional solution’s current level and concentration. The light intensity sensor is mounted on the tower to keep track of incoming light, which is also integrated inside the greenhouse.

3.3.7 Installation of Rainwater Harvester

For water sustainability, the researchers will install a rainwater harvester as the main source of water for the indoor aeroponics system.

3.4 Gather Sensor Readings to Perform Data Acquisition for the Humidity, Temperature, Water Level, Light Intensity, pH, and EC level Sensors on the IoT Interface

The various data from the sensors connected to the microcontroller will be sent over to the Raspberry Pi 4 using serial connection and will be stored in the Raspberry Pi database.

3.4.1 Collect Data from the Sensors.

The sensors pH, EC, temperature, relative humidity, light intensity, water level that are calibrated and installed on the system will be used to measure the parameter of the system’s environment and the data gathered will be sent to the server database.

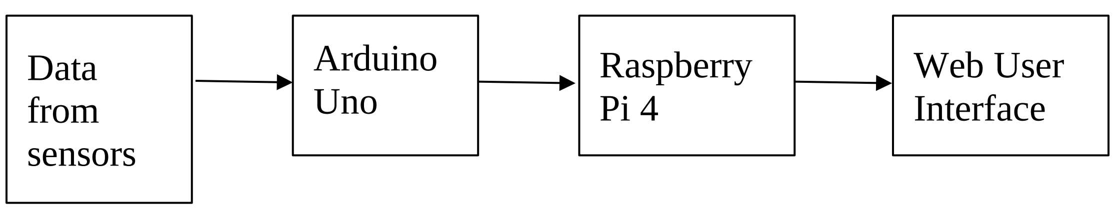


Figure 3.24 Block Diagram of Data Flow

Figure 3.24 shows the process of data from the sensors to the web user interface. The data gathered by the sensors connected to the Arduino Uno was sent to the Raspberry Pi 4 using USB Serial Connection. The data sent were displayed to the Web User Interface.

3.5 Generate a Predictive Analysis Model using a Bayesian Network Classifier that will Generate Output Decisions for Automating the Cultivation System suitable for Strawberry Growth

The study employs a Bayesian Network (BN) to verify the information acquired by the sensors to make the aeroponic system autonomous for quick actions. The algorithm uses an input-based process to create a probability distribution and infer an appropriate decision. Based on the information collected by the sensors, the algorithm constantly improves. The accuracy of the BN prediction will increase with the amount of data studied. After the algorithm has processed the data, the decision will be sent to the microcontroller to operate the actuators.

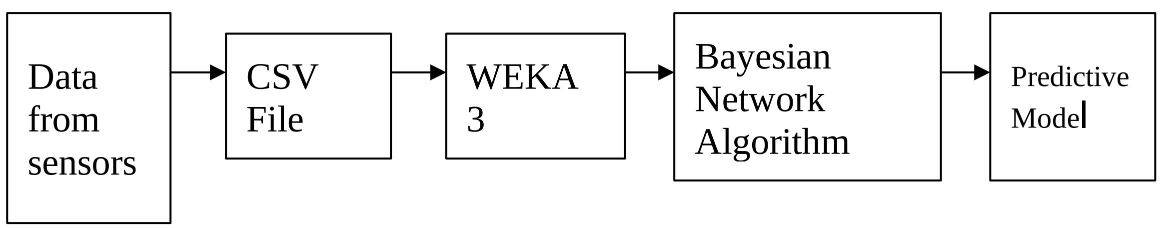


Figure 3.25 Generation of Predictive Model

Figure 3.25 shows the process of generating the predictive model. The data from the sensors will be outputted to a csv file and will be processed by the software WEKA 3 which in turn uses Bayesian Network Algorithm to create the desired predictive model.

3.5.1 Data Preprocessing

The sensor data sent to the server's database will be outputted to a CSV file for easier data sampling and processing. From (Alipio et al., 2017) study, they utilized 6,881 datasets to generate Bayesian Network. More dataset is recommended to achieve better accuracy.

3.5.2 Data Classification

The sampled and processed data will be used in a Bayesian Network Classifier. Bayesian classification is a probabilistic approach to learning and inference based on a different view of what it means to learn from data, in which probability is used to represent uncertainty about the relationship being learned.

3.5.3 Generate a Predictive Model and Bayesian Network Tree

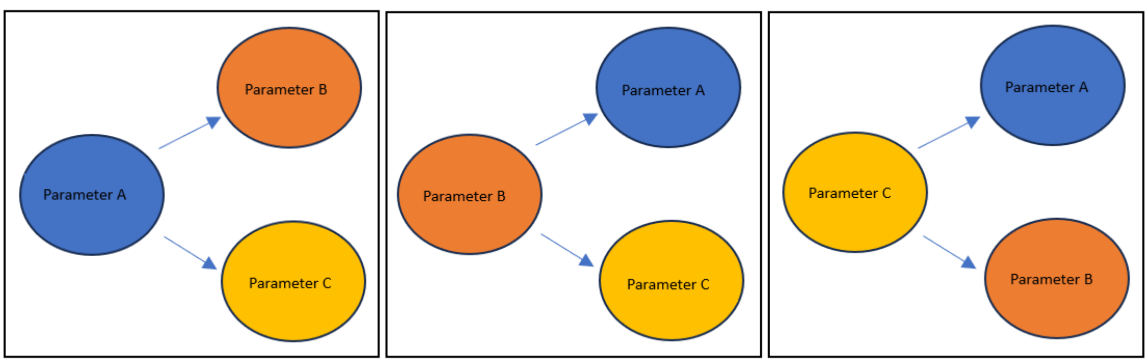


Figure 3.26 Sample Bayesian Network Classification Tree

Figure 3.26 is the sample Bayesian Network Classification tree that will be used for the smart vertical aeroponic farming system. This classification tree employs the dependency of one parameter to influence the probability or provide information to other parameters.

3.5.4 Evaluate the Predictive Model on the Supplied Sensor Data

The predictive model will then be re-evaluated using the current sensor readings. The output of the evaluation will be used to predict new sensor values, which will be used to automate the aeroponic system. In the automation of the aeroponic system, the Bayesian Network algorithm will be executed and control the states of the actuators based on the predicted sensor values. The algorithm will continuously monitor and compare the predicted and current values of the sensor. If neither of these values is equal, the actuation is kept going using the prediction algorithm.

3.6 Develop a Web User Interface that will Serve as a Graphical User Interface for Monitoring and Control of the Aeroponic System

In this project, a web user interface will be developed for easy data monitoring of different variables that must be maintained for the growth of the strawberries. The implementation will involve utilizing the Mycodo software to create a graphical user interface (GUI) for the aeroponic system.

3.6.1 Develop the GUI of the system

Mycodo software will be used to develop the GUI of the aeroponic system. Mycodo is an open-source software designed to run on the Raspberry Pi and other single-board computers. Mycodo consists of two parts, a daemon and a web server. The daemon performs tasks such as acquiring measurements from sensors and devices connected to the Raspberry Pi. The web server hosts a web interface that enables viewing and managing inputs and control actions from any browser-enabled devices. A dashboard will be created in the web interface that can be used for viewing and monitoring the sensor data.

3.6.2 Plot a Time Series Chart

A time series chart will be created in the dashboard interface to monitor the trend of the present and the past data from the sensor.

3.7 Compare the Harvested Strawberries from the Smart Aeroponic System to the Traditional Farming Method using a Welch's T-Test

This study will use a Welch's t-test to compare the means of two groups. A Welch's t-test is used when there are unequal variances between the means of two independent groups. The researchers will compare harvested strawberries from the vertical smart indoor aeroponic system with conventional farming.

3.7.1 Comparison of the Strawberry's Parameters via Conventional Farming and Aeroponics

In hypothesis testing, a statistical test called the Welch's T-Test is often employed to determine whether the population of interest differs from another group. In this study, the researchers will compare the outcome of a conventionally grown strawberry to a strawberry grown in an indoor aeroponics setup. This will determine the more successful and efficient way of farming.

Table 3.2 Sample Data Comparison of Strawberry's Parameters via Conventional Faming and Aeroponics

Parameters	Conventional Strawberry	Aeroponics Strawberry
Strawberry Yield		
Plant Height		
Leaf Count		

Table 3.2 suggests a sample data template for using the Welch T-Test.

3.7.2 Days Spent in Growing the Strawberries

The researchers will compare the number of days growing strawberries in an indoor aeroponics system to conventional farming. This will determine which way of farming is better for producing greater yields.

3.7.3 Comparison of Energy and Water Consumption between Conventional Farming and Aeroponics

The researchers will compare energy consumption (in watts) and the amount of water (in liters) of an indoor aeroponics setup to conventional farming. This will determine if the indoor aeroponics system will more efficiently handle the energy and water usages than the conventional method.

3.7.4 Comparison of Coverage of the Area used on the Two Methods

The researchers will compare the data between the indoor aeroponics system that utilizes no soil and conventional farming that utilizes soil. The coverage of the area (in square meters) used in the two methods will be measured. Thus, determining which way of farming consumes less space.

3.7.5 Assessment of the Statistical Test

The assessment of the outcome of the study will be determined by observing any notable differences from the harvested aeroponically-grown strawberry's yield, leaf count and plant height to the strawberry grown conventionally. The formula for Welch's t-test is as follows:

$$t = \frac{\underline{x_1} - \underline{x_2}}{\sqrt{\frac{s_1}{n_1} + \frac{s_2}{n_2}}}$$

Where:

- t = test statistic
- X1 & X2 = means of the two groups being compared
- s1 & s2 = standard deviations of two groups being compared
- n1 & n2 = sample sizes of the two groups being compare

3.8 Project Workplan

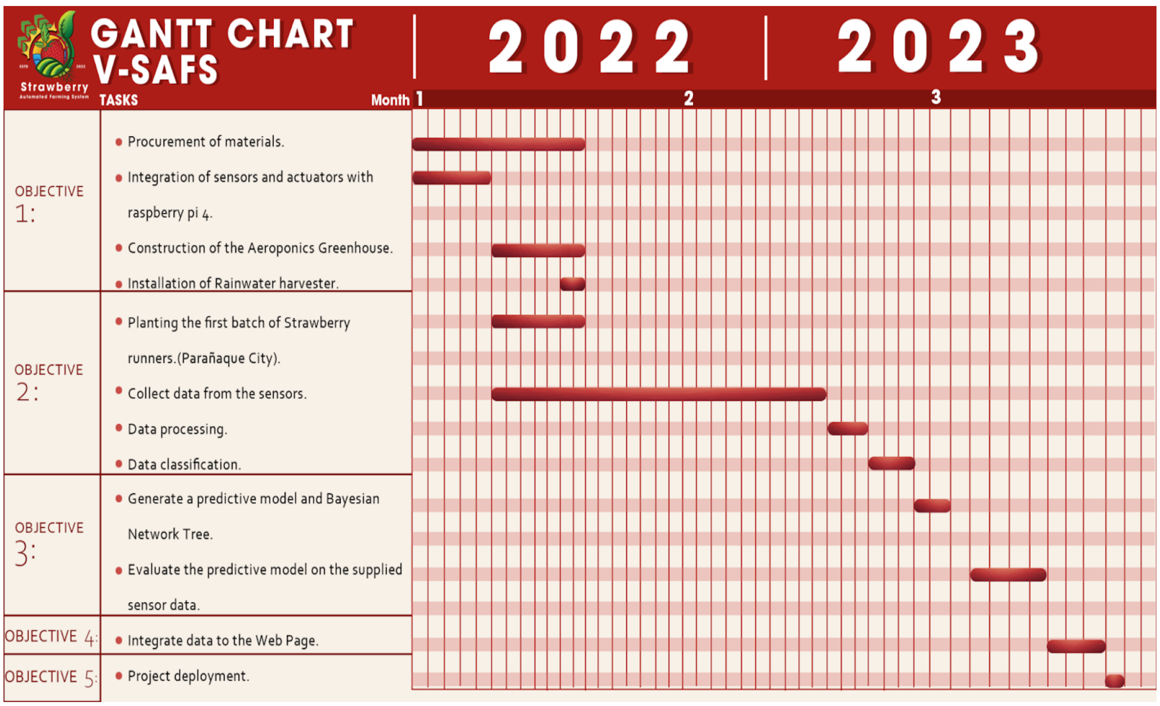


Figure 3.27 Project Workplan

Figure 3.27 displays a comprehensive timeframe in the form of a Gantt Chart for the project's execution in relation its predicted progress.

Chapter 4

RESULTS AND DISCUSSION

4.1 Project Technical Description

4.1.1 The Greenhouse

The greenhouse has dimensions of 12.5 ft x 9.2 ft x 7, and 9 feet. The roof's sloped form makes it simple to incorporate a rainwater harvester. Bamboo, a 200-micron UV sheet, and a 60% shade net are the main components of the greenhouse. As a result, strawberries will develop in an ideal environment and be protected from adverse weather.

Figure 4.1 Actual Greenhouse

Figure 4.1 shows the actual greenhouse situated in Mendez Crossing Tagaytay. A rainwater collection system was installed on the greenhouse's roof and connected to the water tank. Consequently, a misting system was installed to control and maintain the desired temperature inside the greenhouse.

4.1.2 The Aeroponics Set-up

The vertical Aeroponic tower is made of PVC pipe and measures 6 feet tall, 4.3 feet long, and 1.48 feet wide. This whole system is situated inside the greenhouse. The system used hydroton as a growing medium and a plastic container (1.64 ft x 1.15 ft x 1.15 ft) for the reservoir. This altogether is connected to a 220V AC main power source. There is also an available backup source in any case of failure or outage in the primary source. This backup is a 50-watt solar panel with a 40-Ah battery and an ATS or automatic transfer switch, which will automatically transfer the power supply from its primary source to a backup source when it detects outage.

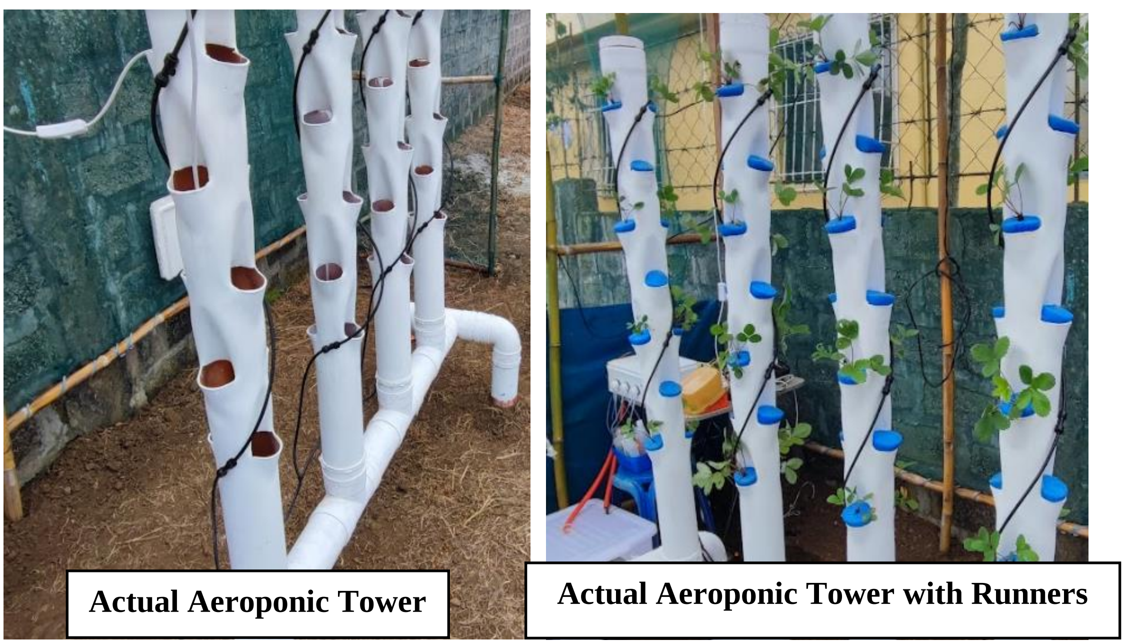
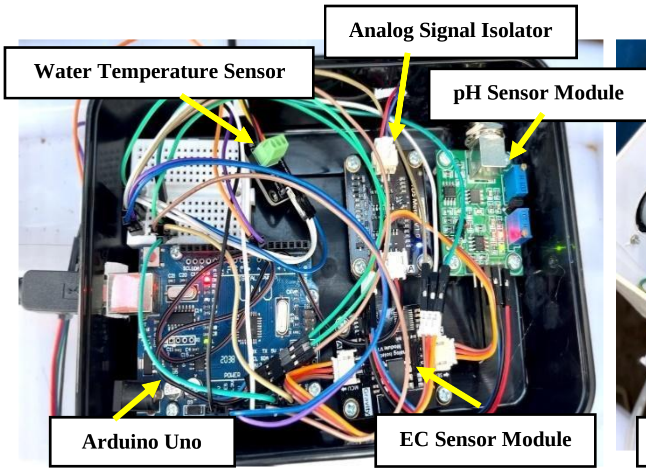


Figure 4.2 Vertical Aeroponic Tower Representation

Figure 4.2 shows the actual set-up of the smart vertical aeroponic system. The Raspberry Pi 4 has six embedded sensors for measuring the temperature, humidity, pH and EC of water, water level, and light exposure in the strawberry-growing environment. The system uses a mist to provide an enriched nutrient solution to the strawberry while keeping the pH and TDS levels within the acceptable range. When the sunlight is insufficient, it will also utilize a LED grow light to provide additional light exposure. When the outside temperature rises above a certain threshold, the temperature sensor located on top of the chassis senses the increase and activates the misting system of the greenhouse. The researchers also used a Web User Interface for continuous data monitoring and analysis.



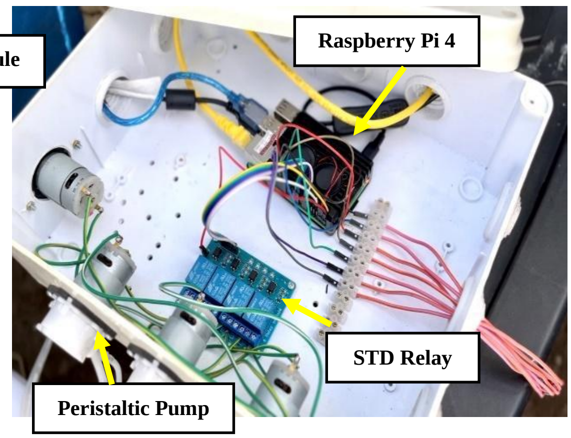


Figure 4.3 Chassis containing Raspberry Pi 4, Arduino Uno, Relay System and Main Circuit Connections

Figure 4.3 shows the chassis containing Raspberry Pi 4, Arduino Uno, Relay System and Main Circuit Connections. ABS IP68 weatherproof enclosure was used since the system is located inside the greenhouse. pH sensor board, TDS sensor board and four peristaltic pumps were also placed inside the chassis. The water pump and solutions pump are connected in the relay system to automatically correct the pH and EC level required for the strawberry cultivation.

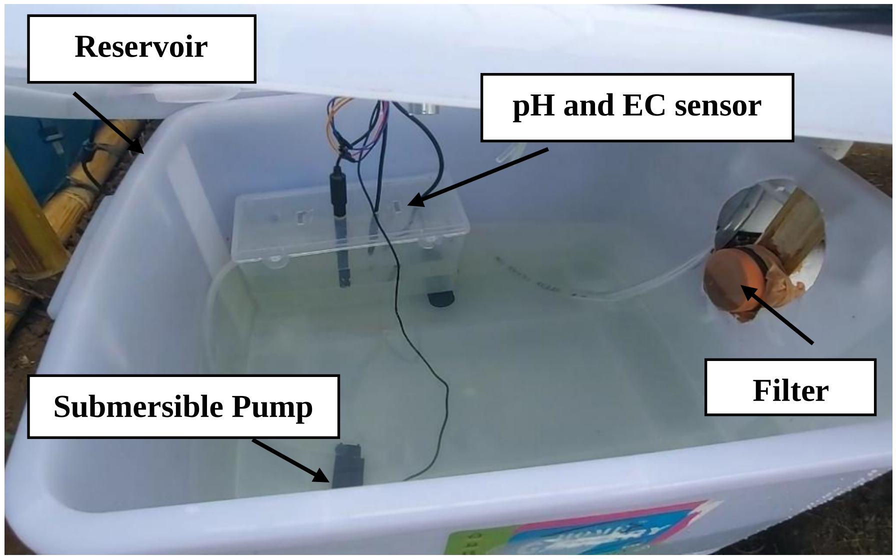


Figure 4.4 Water Reservoir

Figure 4.4 shows the water reservoir. Inside the water reservoir is a sample reservoir, it was constructed to divert a small volume of water from the main reservoir for the water sensors (temperature, pH, TDS probes) to measure. This is done to sub-sample the main water reservoir, which will buffer the sensors from the immediate effects of large pH and TDS swing that can occur in the main reservoir when the peristaltic pumps are dosing solutions.

4.2 Project Structural Organization

4.2.1 Sensor Readings

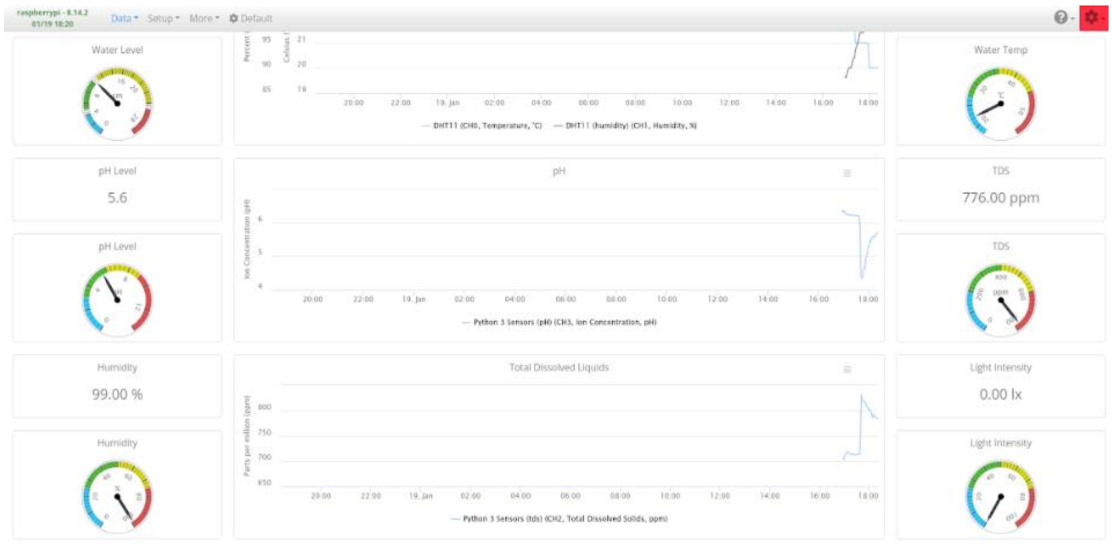


Figure 4.5 Real-time Sensor Measurements

Figure 4.5 shows the real-time measurement of parameters gathered from the sensors in the web user interface of the system. The researchers also use time series chart to plot and visualize the data coming from the sensors. This data will be utilized for the system's Bayesian Network predictive model to accurately control the parameters suitable for strawberry plant growth.

4.2.2 Generate Predictive Model and Bayesian Network Tree

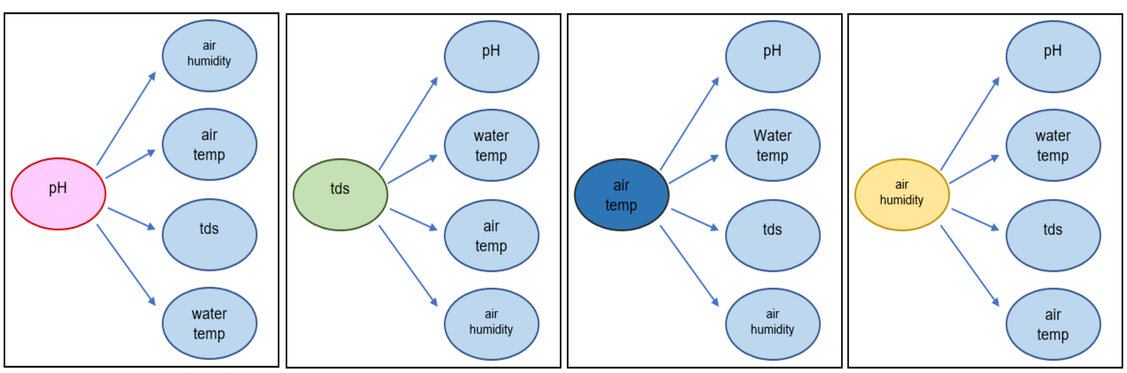


Figure 4.6 Generated Bayesian Network Tree (simplified) for Smart Vertical Aeroponic Farming System

The probabilistic distribution created by the Naive Bayes Classifier as shown in figure 4.6 will then be used to generate a predictive model and the Bayesian Network trees. Naive Bayes is a classification algorithm based on Bayes' theorem, which assumes that the presence or absence of a particular feature in a class is unrelated to the presence or absence of other features. It is called "naive" because it makes the simplifying assumption of independence between features. The sensor data from the other four parameters were fed into a specific BN tree of a chosen parameter, where the data was analyzed, and decisions were produced. Each BN tree's output was reliant on the other four controlling parameters being fed to its appropriate tree. By predicting each sensor value, a probabilistic relationship between the values will be established.

4.2.3 Evaluate the Predictive Model on the Supplied Sensor Data

The predictive model was re-evaluated using the current sensor readings. The output of the evaluation will be used to predict new sensor values, which will be used to automate the aeroponic system. In the automation of the aeroponic system, the Naive Bayes algorithm will be used to predict sensor values and control the states of the actuators based on the predicted sensor values. To assess the accuracy of the predictive model the accuracy percentage and mean root error is calculated. The Mean Absolute Error (MAE) is a commonly used metric to evaluate the accuracy of regression models. It measures the average absolute difference between the predicted and actual values. The acceptable Mean Absolute Error (MAE) can vary depending on the specific problem domain and context. Generally, a lower MAE indicates better predictive accuracy.

The algorithm will continuously monitor and compare the predicted and current values of the sensor. If neither of these values is equal, the actuation is kept going using the prediction algorithm.

```
=== Summary ===

Correctly Classified Instances        9499               61.075  %
Incorrectly Classified Instances      6054               38.925  %
Kappa statistic                          0.217
Mean absolute error                      0.0929
Root mean squared error                  0.2231
Relative absolute error                 86.5544 %
Root relative squared error             96.3152 %
Total Number of Instances            15553
```

Figure 4.7 Evaluated Model for Predicting pH using Naive Bayes

The summary of predictions in Weka, as shown in Figure 4.7 shows the evaluation of the accuracy of the model in determining the pH levels based on the given dataset. The summary shows the correct and incorrect pH predictions, enabling insights into the model's effectiveness in classifying instances accurately. A mean absolute error of 0.0929 was calculated between the pH prediction of the Naive Bayes and the actual pH, it also shows 61.08% accuracy in terms of correctly predicted pH values.

inst#	actual	predicted	error	prediction
1	5:5.7	5:5.7		0.951
2	5:5.7	6:5.8	+	0.571
3	5:5.7	6:5.8	+	0.724
4	5:5.7	6:5.8	+	0.679
5	5:5.7	5:5.7		0.965
6	5:5.7	6:5.8	+	0.727
7	5:5.7	5:5.7		0.903
8	5:5.7	6:5.8	+	0.672
9	5:5.7	6:5.8	+	0.804
10	5:5.7	6:5.8	+	0.84
11	5:5.7	6:5.8	+	0.655
12	5:5.7	6:5.8	+	0.776
13	5:5.7	5:5.7		0.885
14	5:5.7	5:5.7		0.807
15	5:5.7	5:5.7		0.807
16	5:5.7	6:5.8	+	0.76
17	5:5.7	6:5.8	+	0.643
18	5:5.7	6:5.8	+	0.77
19	5:5.7	5:5.7		0.893
20	5:5.7	5:5.7		0.879

Figure 4.8 Naive Bayes predicted pH values compared to actual pH values

In Figure 4.8, the "inst" column shows the individual instances from the dataset of pH values. The "actual" column displays the known values of the pH for each instance. The "predicted" column shows the values generated by the predictive model for the pH.

```
=== Summary ===

Correctly Classified Instances        4532              29.1391 %
Incorrectly Classified Instances     11021              70.8609 %
Kappa statistic                          0.0488
Mean absolute error                      0.086
Root mean squared error                  0.2124
Relative absolute error                 95.721  %
Root relative squared error            100.2109 %
Total Number of Instances            15553
```

Figure 4.9 Evaluated Model for Predicting Total Dissolved Liquids using Naive Bayes

The summary of predictions in Weka, as shown in Figure 4.9 shows the evaluation of the accuracy of the model in determining the TDS levels based on the given dataset. The summary shows the correct and incorrect TDS predictions, enabling insights into the model's effectiveness in classifying instances accurately. A mean absolute error of 0.086 was calculated between the TDS prediction of the Naive Bayes and the actual TDS values, it also shows 29.14% accuracy in terms of correctly predicted TDS values.

inst#	actual	predicted	error	prediction
1	9:758	11:764	+	0.247
2	9:758	7:753	+	0.288
3	9:758	7:753	+	0.372
4	9:758	5:747	+	0.427
5	9:758	6:750	+	0.415
6	9:758	6:750	+	0.351
7	9:758	5:747	+	0.35
8	9:758	5:747	+	0.307
9	9:758	8:756	+	0.301
10	9:758	7:753	+	0.414
11	9:758	7:753	+	0.323
12	9:758	6:750	+	0.398
13	9:758	8:756	+	0.268
14	9:758	5:747	+	0.446
15	9:758	6:750	+	0.356
16	9:758	8:756	+	0.471
17	9:758	6:750	+	0.403
18	9:758	5:747	+	0.424
19	9:758	7:753	+	0.249
20	9:758	8:756	+	0.334

Figure 4.10 Naive Bayes predicted TDS values compared to Actual TDS values

In Figure 4.10, the "inst" column shows the individual instances from the dataset of TDS. The "actual" column displays the known values of the TDS for each instance. The "predicted" column shows the values generated by the predictive model for the TDS.

```
=== Summary ===

Correctly Classified Instances       14902               95.8143 %
Incorrectly Classified Instances       651                4.1857 %
Kappa statistic                          0.3892
Mean absolute error                      0.0002
Root mean squared error                  0.0102
Relative absolute error                 39.8507 %
Root relative squared error             71.6964 %
Total Number of Instances            15553
```

Figure 4.11 Evaluated Model for Predicting Air Temperature using Naive Bayes

The summary of predictions in Weka, as shown in Figure 4.11 shows the evaluation of the accuracy of the model in determining the air temperature levels based on the given dataset. The summary shows the correct and incorrect air temperature predictions, enabling insights into the model's effectiveness in classifying instances accurately. A mean absolute error of 0.002 was calculated between the air temperature prediction of the Naive Bayes and the actual air temperature values, it also shows 95.81% accuracy in terms of correctly predicted air temperature values.

inst#	actual	predicted	error	prediction
1510	225:22.53	201:22.208211	+	0.158
1511	231:22.59	201:22.208211	+	0.063
1512	103:19.89	211:22.34	+	0.03
1513	407:29.51	71:19.23	+	0.035
1514	147:21.32	17:18.34	+	0.017
1515	319:24.26	211:22.34	+	0.046
1516	318:24.21	201:22.208211	+	0.211
1517	160:21.56	201:22.208211	+	0.186
1518	381:27.63	235:22.65	+	0.022
1519	183:21.9	29:18.56	+	0.034
1520	268:23.12	29:18.56	+	0.037
1521	198:22.16	201:22.208211	+	0.215
1522	334:25.12	85:19.47	+	0.024
1523	234:22.64	71:19.23	+	0.035
1524	26:18.53	286:23.45	+	0.023
1525	312:23.95	211:22.34	+	0.039
1526	92:19.59	235:22.65	+	0.022
1527	405:29.23	201:22.208211	+	0.184
1528	75:19.32	237:22.67	+	0.028

Figure 4.12 Naive Bayes predicted Air Temperature compared to Actual Air Temperature

In Figure 4.12, the “inst” column shows the individual instances from the dataset of temperature. The “actual” column displays the known values of the temperature for each instance. The “predicted” column shows the values generated by the predictive model for the temperature.

=== Summary ===

Correctly Classified Instances	14923	95.9493 %
Incorrectly Classified Instances	630	4.0507 %
Kappa statistic	0.407	
Mean absolute error	0.0022	
Root mean squared error	0.034	
Relative absolute error	47.1446 %	
Root relative squared error	72.1515 %	
Total Number of Instances	15553	

Figure 4.13 Evaluated Model for Predicting Air Humidity using Naive Bayes

The summary of predictions in Weka, as shown in Figure 4.13 shows the evaluation of the accuracy of the model in determining the air humidity levels based on the given dataset. The summary shows the correct and incorrect air humidity predictions, enabling insights into the model's effectiveness in classifying instances accurately. A mean absolute error of 0.0022 was calculated between the air humidity prediction of the Naive Bayes and the actual air humidity values, it also shows 95.95% accuracy in terms of correctly predicted air humidity values.

inst#	actual	predicted	error	prediction
1494	16:78.55	16:78.55		0.162
1495	16:78.55	11:77	+	0.115
1496	16:78.55	20:79.6	+	0.189
1497	16:78.55	17:79.2	+	0.126
1498	16:78.55	21:80.4	+	0.179
1499	16:78.55	35:85.1	+	0.112
1500	21:80.4	16:78.55	+	0.172
1501	21:80.4	32:83.5	+	0.115
1502	21:80.4	35:85.1	+	0.168
1503	21:80.4	16:78.55	+	0.115
1504	18:79.4	37:85.5	+	0.263
1505	18:79.4	16:78.55	+	0.115
1506	18:79.4	16:78.55	+	0.207
1507	11:77	32:83.5	+	0.135
1508	11:77	33:84	+	0.13
1509	11:77	32:83.5	+	0.152
1510	11:77	12:77.3	+	0.209
1511	33:84	16:78.55	+	0.194
1512	33:84	35:85.1	+	0.148
1513	33:84	22:80.931651	+	0.436

Figure 4.14 Naive Bayes predicted Air Humidity compared to Actual Air Humidity Values

In Figure 4.14, the "inst" column shows the individual instances from the dataset of Humidity. The "actual" column displays the known values of the humidity for each instance. The "predicted" column shows the values generated by the predictive model for the humidity.

4.2.4 GUI of the System

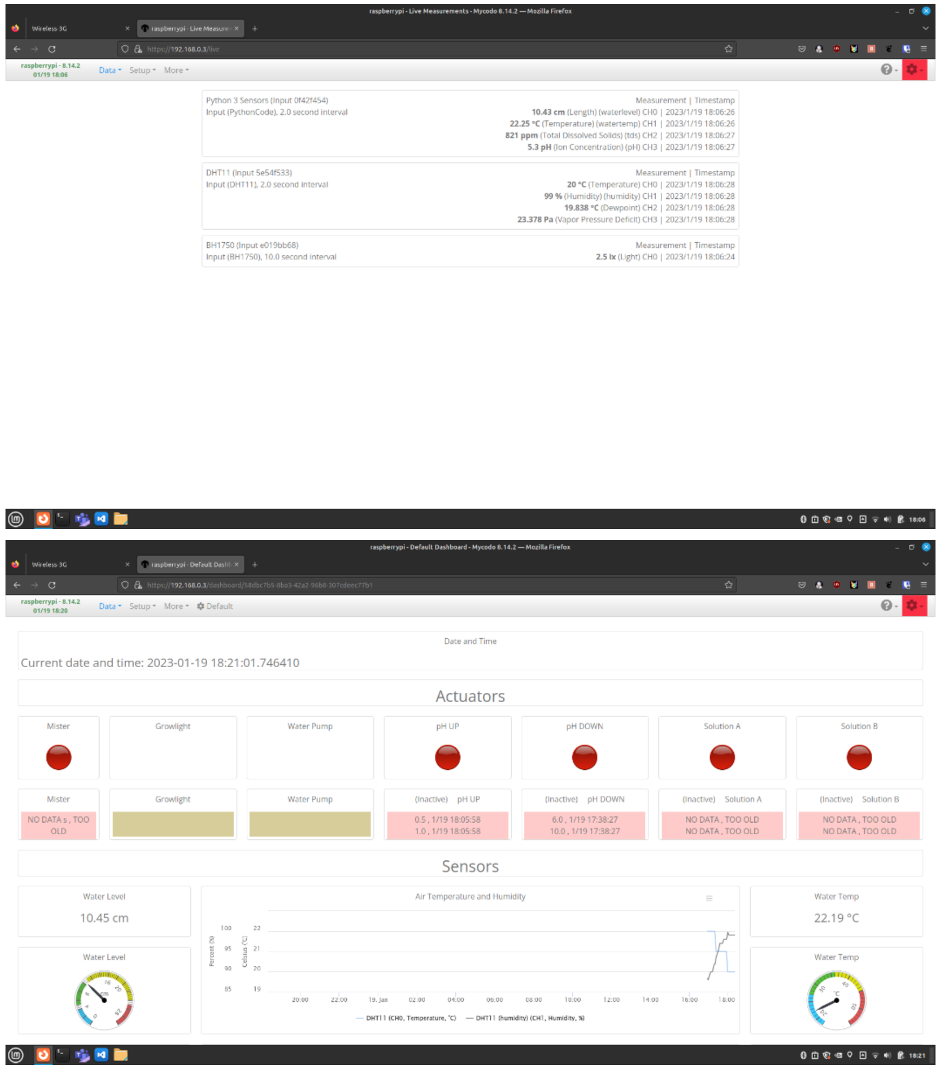


Figure 4.15 Web User Interface for Monitoring and Control of Aeroponic System

Figure 4.15 shows the created widgets and dashboard for the user interface to monitor the sensor values and the state of the actuators.

4.2.5 Time Series Chart

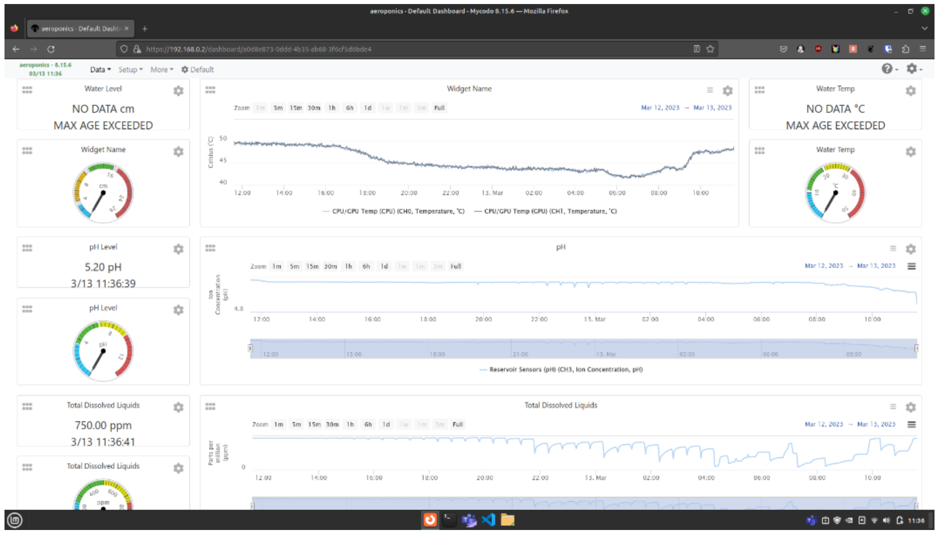


Figure 4.16 Time Series Chart in Dashboard

Figure 4.16 shows the time series plot created in the Dashboard to show the data that is collected and recorded over regular intervals of time.

4.3 Project Limitations and Capabilities

The project has the capability to monitor and control the temperature, humidity, water level, pH value, EC, and light intensity in a vertical setup greenhouse to meet the required parameters. Additionally, it will automate the control of pH and EC levels in the nutrient solution used for plant roots, ensuring the optimal conditions necessary for the growth of strawberry crops. The system will have solar panels for managing power supply and a backup battery to avoid interruptions in the event of a power loss.

The project was limited in comparing the strawberry plant growth parameters of the smart vertical aeroponics farming system from the conventional farming method. This comparison involves evaluating factors such as strawberry yield, leaf count, plant height, land usage and productivity, energy consumption, and water usage. This will assess the effectiveness and efficiency of the smart farming system in promoting plant growth and optimizing crop yields.

4.4 Project Evaluation

4.4.1 Comparison of pH Level between Aeroponics and Traditional Farming Method

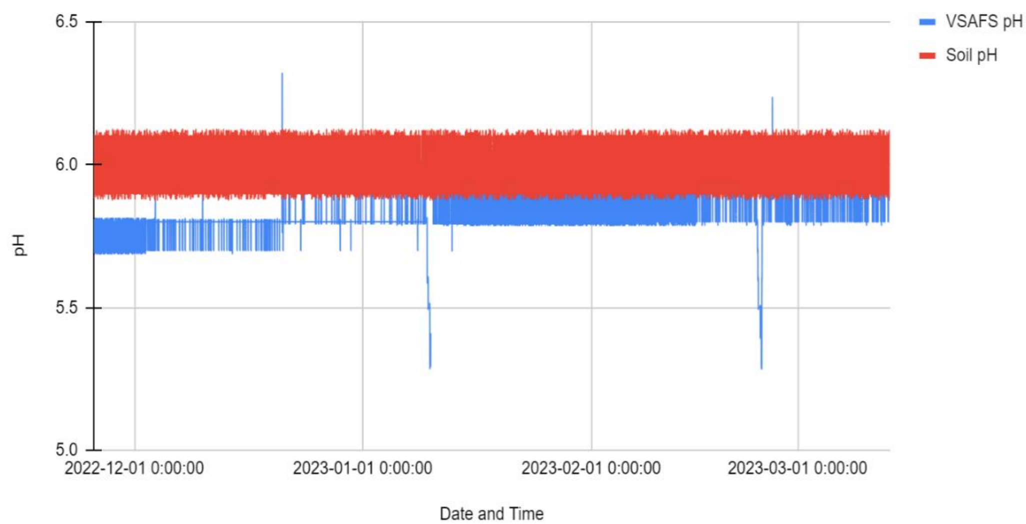


Figure 4.17 Comparison of gathered pH data between Aeroponics and Traditional Farming Method

Figure 4.17 illustrates a comparison between the pH levels of Aeroponics and Traditional Farming Methods. In conventional farming, the pH ranges from 6.1 (lowest) to 6.1 (highest), whereas Aeroponics maintains a pH range of 5.7 (lowest) to 5.9 (highest). These results demonstrate that the pH level of the water inside the reservoir is effectively maintained within the desired range of 5.5 to 6.0.

Occasionally, there may be a sudden increase or decrease in the pH level of the aeroponics system. The highest recorded pH spike is 6.3, while the lowest is

5.3. This fluctuation is typically caused by maintenance activities such as water changes and reservoir cleaning.

Table 4.1 pH data from Aeroponics and Traditional Farming Method compared using Welch's T-Test

	Average pH Level	Standard Deviation	Degrees of Freedom	t	p
Aeroponics	5.83	± 0.069	31104	30.901	0.0001
Traditional	6	± 0.07			

Table 4.1 presents a statistical comparison of pH data between two cultivation methods: aeroponics and traditional farming. Welch's t-test was used to analyze the data. The average pH level for the aeroponics method was found to be 5.83 pH, with a standard deviation of 0.069. On the other hand, the traditional farming method had an average pH level of 6, with a standard deviation of 0.07. The degrees of freedom were calculated as 31104.

The results of the t-test indicate a significant difference in pH levels between the two cultivation methods in strawberry cultivation. The t-value was calculated as 30.901, and the p-value was determined to be 0.0001. Based on these findings, we reject the null hypothesis, which states that there is no significant difference in pH levels between the two methods. Instead, we accept the alternative hypothesis, which suggests that there is indeed a significant difference in pH levels between aeroponics and traditional farming in strawberry cultivation.

4.4.2 Comparison of Temperature between Aeroponics and Traditional Farming Method

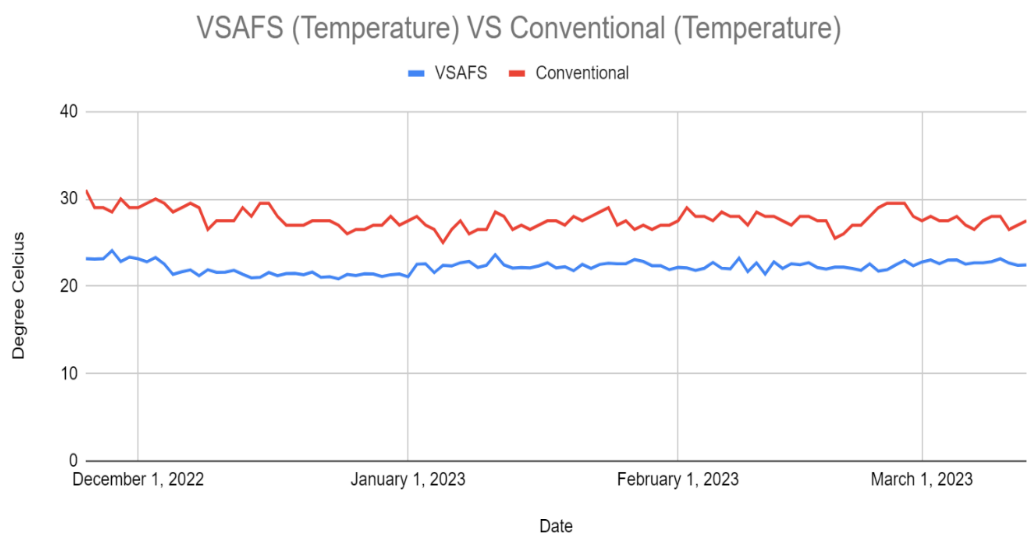


Figure 4.18 Comparison of Temperature between Aeroponics and Traditional Farming Method

According to the data presented in Figure 4.18, the aeroponics system achieved a temperature range of 20.85 degrees Celsius (lowest) to 24.08 degrees Celsius (highest). In contrast, the traditional farming system experienced temperatures ranging from 25 degrees Celsius (lowest) to 31 degrees Celsius (highest). The recorded temperatures of the aeroponics system fell within the favorable range of 18 to 25 degrees Celsius, which is optimal for the growth of strawberries.

These findings indicate that the mister system within the greenhouse of the aeroponics setup is functioning effectively. As a result, it maintains a slightly lower minimum temperature compared to the traditional farming method.

Table 4.2 Temperature data from Aeroponics and Traditional Farming Method compared using Welch's T-Test

	Average Temperature	Standard Deviation	Degrees of Freedom	t	P
Aeroponics	22.21	± 0.66	216	46.13	0.0001
Traditional	27.71	± 1.06			

Table 4.2 displays a statistical comparison of temperature data between two cultivation methods: aeroponics and traditional farming. The average temperature recorded for the aeroponics method was 22.21, while the traditional farming method had an average temperature of 27.71. These findings suggest that aeroponics exhibits better temperature control capabilities, maintaining lower temperatures that are ideal for the growth of strawberry plants. This observation also highlights the effectiveness of automatic misting techniques in maintaining optimal temperature levels.

Additionally, the standard deviation for temperature in the aeroponics method was found to be 0.66, whereas for the traditional farming method, it was 1.06. The degrees of freedom were calculated as 216.

To assess the statistical difference between the two cultivation methods, Welch's t-test was employed. The calculated t-value was determined to be 46.13, with a corresponding p-value of 0.0001. These results indicate a significant difference in temperature between the two methods. Therefore, we reject the null hypothesis, which assumes no significant difference, and accept the alternative hypothesis, suggesting a substantial disparity in temperature between aeroponics and traditional farming methods.

4.4.3 Comparison of Humidity between Aeroponics and Traditional Farming Method

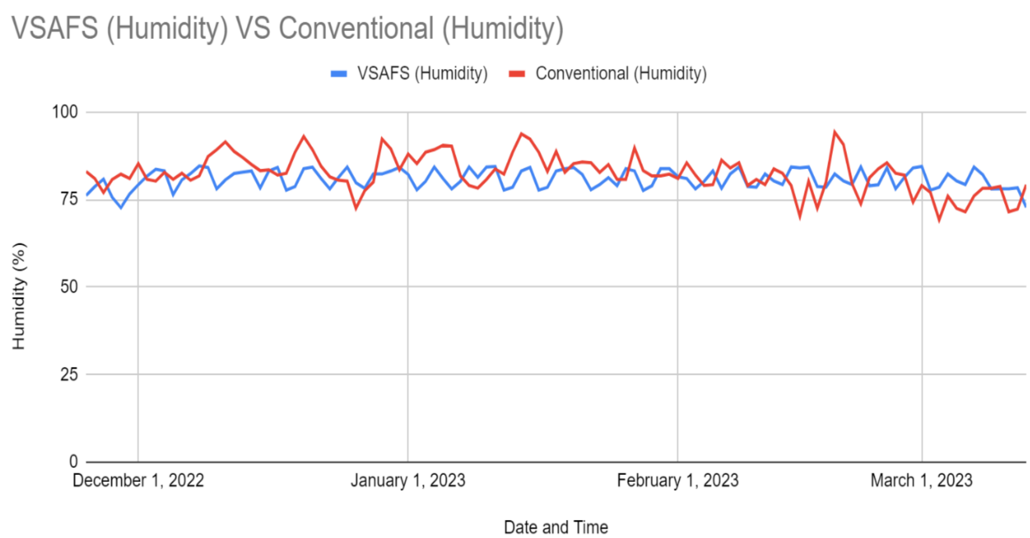


Figure 4.19 Line Graph Comparison of Humidity Between Aeroponics and Traditional Farming Method

Figure 4.19 shows the comparison between the humidity level of aeroponics and traditional farming method. In aeroponics, the humidity level ranges from 72.67 to 84.6 percent. On the other hand, the humidity level of traditional farming ranges from 69.25 to 94.25 percent. It indicates that both farming methods spike out the threshold value of 60 to 75 percent, ideal for strawberry growth.

Table 4.3 Humidity data from Aeroponics and Traditional Farming Method compared using Welch's T-Test

	Average Humidity	Standard Deviation	Degrees of Freedom	t	P
Aeroponics	82.46	± 5.28	216	2.845	0.0049
Traditional	80.84	± 2.76			

According to the data presented in Table 4.3, the average humidity level in aeroponics is 82.46, while in traditional farming, it is 80.84. This indicates that there is a slight difference in average humidity between aeroponics and traditional farming methods, with aeroponics tending to maintain a slightly higher average humidity. This variation in average humidity can be attributed to the controlled environment and misting techniques utilized in aeroponic systems, which are designed to maintain optimal moisture levels.

Additionally, the standard deviation values provide insights into the variability of humidity within each cultivation method. Aeroponics shows a higher standard deviation of 5.28, indicating a greater variation in humidity levels compared to traditional farming, which has a standard deviation of 2.76. This variability might be due to the continuous and precise misting process employed in aeroponics, leading to localized fluctuations in humidity levels.

To assess the statistical significance of the observed differences, a t-test was performed, resulting in a t-value of 2.845 and a p-value of 0.0049. With 216 degrees of freedom, the low p-value suggests that there is a statistically significant difference in average humidity between aeroponics and traditional farming. Therefore, we reject the null hypothesis, which assumes no significant difference, and accept the alternative hypothesis, indicating that there is indeed a significant difference in average humidity between the two methods. This finding reinforces the argument that aeroponics, with its controlled environment and misting techniques, promotes higher humidity levels compared to traditional farming methods.

4.4.4 EC Level of Smart Vertical Aeroponics Farming System

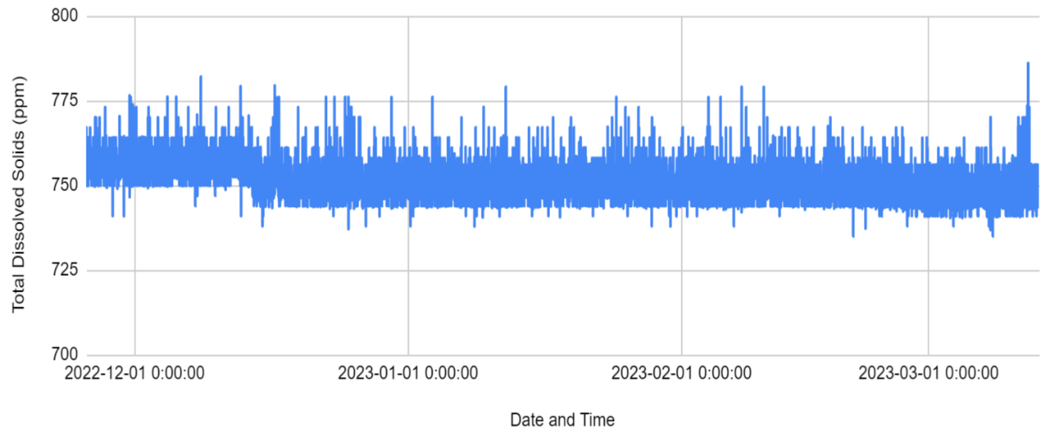


Figure 4.20 Gathered TDS data of Smart Vertical Aeroponics Farming System

Figure 4.20 shows a representation of data regarding the level of TDS (Total Dissolved Solids) that were collected. The data shows a range of TDS levels from 735 to 786 TDS. This range is significant as it indicates that the collected TDS levels fall within the predetermined range of 500 to 800 TDS.

4.4.5 Light Intensity Level of Smart Vertical Aeroponics Farming System

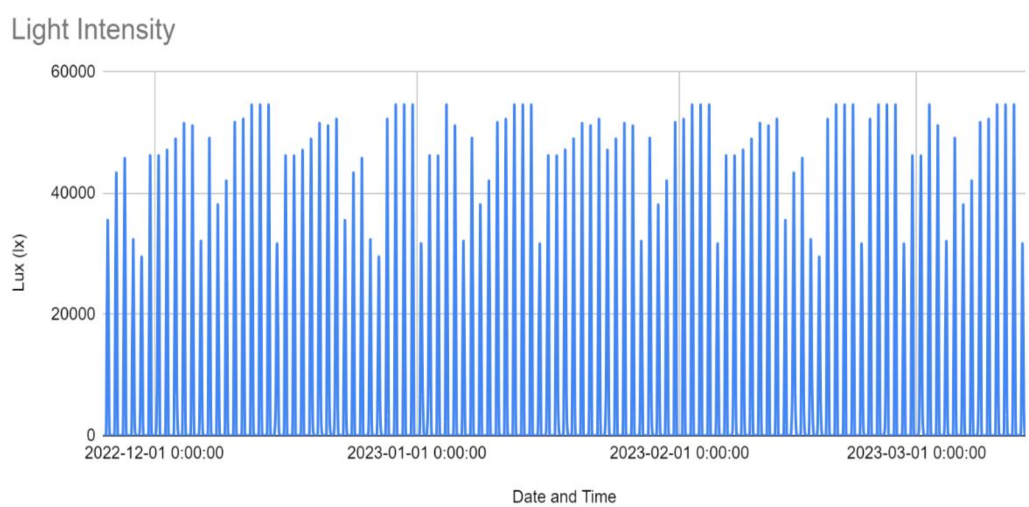


Figure 4.21 Gathered Light Intensity data of Smart Vertical Aeroponics Farming System

As shown in Figure 4.21 the smart vertical aeroponics farming system maintains a light intensity of approximately 10 lux (lowest) to 5500 lux (highest). This is low compared to the 6000-lux minimum requirement for the strawberry plant growth.

4.4.6 Growth Cycle

The comparison of plant growth cycle between Aeroponics and Conventional Farming system is outlined in Table 4.4. Starting from vegetative growth stage up to harvesting stage of the VSAFS and traditional were compared to assess which method will achieve strawberry production faster during the growth cycle. In VSAFS, the vegetative growth stage lasted approximately 2 to 3 months, starting on December 30, 2022, and ending on February 25, 2023. Following this stage, the flowering stage occurred for 1 to 2 weeks around Feb 25, 2023, leading to fruiting/ripening stage, which had a variable duration and began on Mar 17, 2023. While in conventional farming, the vegetative growth stage had a longer duration of 4 to 5 months spanning from December 1, 2022, to May 1, 2023. Similar to VSAFS, the flowering stage occurred for 1-2 weeks around May 1, 2023, followed by the fruiting/ripening stage, which began on May 17, 2023, and had a variable duration.

Table 4.4 Comparison of Plant Growth Cycle between Aeroponics and Traditional Farming Method

	Smart Vertical Aeroponic Farming System		Traditional Farming Method	
Growth Stage	Start Date	Duration	Start Date	Duration
*Planting (*Runners*) / Acclimation	Nov 25, 2022	2 weeks	-	-
*Root Development	Dec 9, 2022	2-3 weeks	-	-
**Planting / Germination	-	-	Oct 16, 2022	1-3 weeks
**Seedling	-	-	Nov 3, 2022	3-4 weeks
Vegetative Growth	Dec 30, 2022	2-3 months	Dec 1, 2022	4-5 months
Flowering	Feb 25, 2023	1-2 weeks	May 1, 2023	1-2 weeks
Fruiting /Ripening/Harvest	Mar 17, 2023	Variable	May 17,2023	Variable

4.4.7 Leaf Count

Table 4.5 Comparison of Leaf Count between Aeroponics and Traditional Farming Method

	Average Leaf Count	Standard Deviation	Degrees of Freedom	t	p
Aeroponics	17.53	± 3.43	60	1.141	0.2584
Traditional	16.62	± 2.9			

According to Table 4.5, the average leaf count in the aeroponics group was 17.53, while in the traditional farming group, it was 16.62. The t-value obtained for this comparison was 1.141, with degrees of freedom (df) calculated as 60 and a p-value of 0.2584. Based on these results, we fail to reject the null hypothesis, which states that there is no significant difference in leaf count between the two groups. Therefore, there is no statistically significant evidence to suggest a difference in leaf count between aeroponics and traditional farming methods.

Additionally, it is noteworthy that the standard deviation for leaf count was similar in both groups, with the aeroponics group exhibiting a standard deviation of 3.43 and the traditional farming group showing a standard deviation of 2.9. This similarity in standard deviations indicates comparable variability in leaf count within each group.

4.4.8 Plant Height

Table 4.6 Comparison of Plant Height between Aeroponics and Traditional Farming Method

	Average Plant Height (in cm)	Standard Deviation	Degrees of Freedom	t	p
Aeroponics	13.21	± 0.98	60	2.637	0.0106
Traditional	12.56	± 0.95			

According to Table 4.6, the average plant height in the aeroponics group was 13.21 cm, while in the traditional farming group, it was 12.56 cm. The obtained t-value for this comparison was 2.637, with degrees of freedom (df) calculated as 60 and a p-value of 0.0106. Based on these results, we reject the null hypothesis, which suggests no significant difference in plant height between the two groups. Therefore, there is statistically significant evidence to support the alternate hypothesis, indicating a significant disparity in plant height between the aeroponics and traditional farming methods.

However, it is important to note that although there was a significant difference in average plant height, the standard deviations for both methods were relatively low. The aeroponics group exhibited a standard deviation of 0.98 cm, while the traditional farming group showed a standard deviation of 0.95 cm. This suggests that the variability in plant height within each group is relatively small.

4.4.9 Strawberry Yield

Table 4.7 Comparison of Strawberry Yield between Aeroponics and Traditional Farming Method

	Total Yield Count	Mean (count) ± SD	Degrees of Freedom	t	P
Aeroponics	33	0.971 ± 1.114	55	2.123	0.0382
Traditional	14	0.483 ± 0.688			

According to Table 4.7, in the VSAFS group, a total of 34 plants were cultivated, resulting in a total yield count of 33. The average mean yield was calculated as 0.971, with a standard deviation of 1.114. On the other hand, in the traditional farming group, 29 plants were grown, yielding a total count of 14. The average mean yield for traditional farming was 0.483, with a standard deviation of 0.688.

To determine the statistical significance of the observed differences in yield between the two groups, Welch's t-test was performed with 55 degrees of freedom. The calculated t-value was 2.123, and the corresponding p-value was found to be 0.0382. Based on these results, we reject the null hypothesis, which assumes no significant difference in yield between the VSAFS and traditional farming methods. Thus, we accept the alternate hypothesis, suggesting a significant disparity in yield between the two cultivation methods.

In summary, the statistical analysis demonstrates a significant difference in yield between the VSAFS and traditional farming groups. The VSAFS group exhibited higher mean yields compared to traditional farming, as indicated by the t-value and p-value. These findings support the argument that the VSAFS method has a positive impact on yield compared to traditional farming methods.

4.4.10 Land Usage and Productivity

Table 4.8 Land Usage and Productivity

Land Usage	Smart Vertical Aeroponic Farming System	Traditional Farming
Length	4.3 ft (1.31 m)	112 cm (1.12 m)
Width	1.48 ft (0.45 m)	80 cm (0.8 m)
Land Area	0.59 sq.m (~0.6 sq.m)	0.896 sq.m
Average productivity per unit area	4.636	1.2

Table 4.8 shows that VSAFS requires a smaller footprint compared to traditional farming. The length and width of the aeroponics system were measured at 1.31 meters and 0.45 meters, respectively, resulting in a land area of 0.59 square meters. In contrast, traditional farming exhibited larger dimensions, with a length of 1.65 meters and a width of 0.96 meters, resulting in a land area of 1.58 square meters. It also shows substantial difference between the two methods in terms of land productivity per land area. VSAFS showed a significantly higher average productivity per unit area, with a recorded value of 4.636, compared to traditional farming, which yielded a productivity value of 1.2.

4.4.11 Water Usage

Table 4.9 Water Usage between Aeroponics and Traditional Farming System

Aspect	Smart Vertical Aeroponic Farming System (L per month)	Traditional Farming (L per month)
Water Usage	~ 32 liters	~ 480 liters
Irrigation Method	Fine mist or spray	Soil-Based Irrigation
Water Efficiency	High (up to 96% reduction)	Lower
Water Loss	Minimal (Evaporation)	Runoff and soil absorption
Recycling	Recycled	No recycling

In Table 4.9 VSAFS demonstrates a notable reduction, utilizing only 32 liters of water per month. This reduced water consumption is achieved through the implementation of a closed-loop system, where water is efficiently recycled and continuously supplied to the plant roots as mist. In contrast, traditional farming methods consume a considerably higher amount of water, totaling approximately 480 liters per month.

4.4.12 Energy Consumption

Table 4.10 Energy Consumption between Aeroponics and Traditional Farming System

Power Consumption (*in watts per day*)		
Smart Vertical Aeroponic Farming System		Traditional Farming Method
Raspberry Pi 4	3 watts	-
Arduino	0.03 watts	-
5V Sensors	0.5 watts	-
Peristaltic Pumps	24 watts	-
Diaphragm Pump	120 watts	-
LED Grow lights	100 watts	-
5V Submersible Pumps	4 watts	-
Total	251.53 watts	0 to none

Table 4.10 shows a comparison of power consumption between aeroponics and traditional farming system. In terms of energy consumption, VSAFS requires a modest amount of approximately 251.13 watts per month. This energy expenditure is attributed to the operation of various components such as pumps, lighting systems, sensors, and microcontrollers used in VSAFS. On the other hand, traditional farming methods consume almost zero to none watts of energy as they predominantly rely on natural processes and manual labor.

CHAPTER 5

SUMMARY OF FINDINGS, CONCLUSION AND RECOMMENDATION

5.1 Summary of Findings

In this study, an automated vertical aeroponics system composed of greenhouse, vertical tower, sensors, grow lights, water reservoir, rainwater harvester, solar panel, and actuators were constructed to cultivate strawberries.

Further, 15,554 datasets were gathered from the sensors from the growth stage to the harvesting stage of strawberry.

The results have shown the utilization of the gathered data which then generated a predictive model using a Bayesian network algorithm. It also displayed the evaluation of the predictive model to assess the accuracy. The predictive model in pH achieved 61.08% accuracy and 0.0929 mean absolute error, 29.14% accuracy and 0.086 mean absolute error for TDS level, 95.81% accuracy and 0.002 mean absolute error for air temperature, and 95.95% accuracy and 0.0022 mean absolute error for humidity.

Moreover, a web user interface was created to monitor and control the aeroponic system. The web user interface features different graphs and widgets such as time series plots to display sensor data.

Finally, the comparison between the harvested strawberries from the aeroponic system to the strawberries grown in traditional farming have shown the calculated t- value was 46.13 and p-value was 0.0001 that indicates that there is a significant difference in terms of temperature between the two methods. Additionally, there is a significant difference in terms of pH level for both methods in strawberry cultivation as it results with a t-value of 30.901 and o-value of 0.0001. The statistical significance of the observed differences in average humidity results in a t-value of 2.845 and a p-value of 0.0049, low p-value suggests that the difference in average humidity between aeroponics and traditional farming is statistically significant.

These findings support the advantages of aeroponic farming, such as faster growth, taller plants, higher crop yields, smaller land footprint, reduced water consumption, and potential water scarcity mitigation. This research will yield insights that can inform agricultural practices, policymaking, and initiatives for sustainable food production.

5.2 Conclusions

This study's objectives have been accomplished, resulting in the development of an efficient and sustainable indoor smart vertical aeroponic system for strawberry cultivation. By incorporating a range of sensors to monitor crucial factors such as humidity, temperature, water level, light intensity, pH, and EC level, the system guarantees ideal conditions for the strawberries' growth. Furthermore, the utilization of a Raspberry Pi 4 allows for centralized control and automation of the entire system.

The IoT interface collected sensor readings for further analysis in order to acquire data. This study also effectively demonstrated how a Bayesian Network Classifier was implemented in order to generate predictive analysis models, enabling the system to make informed decisions and automate strawberry-specific cultivation processes. It enhanced plant growth and yield, enabled remote monitoring and control, and facilitated data analysis for more informed decision making.

The algorithm that was used, which is the Bayesian Network, has presented results that provided accurate and sufficient predictions for the strawberries' parameters such as pH level, TDS level, air temperature, and air humidity.

For the purpose of facilitating user interaction, a web-based graphical user interface was created, allowing for simple monitoring and control of the aeroponic system. The IoT interface gathered sensor readings efficiently, providing insights into environmental conditions and nutrient levels for real-time surveillance and precise adjustments and the web-based user interface improved accessibility and usability, thereby facilitating monitoring and control process.

Lastly a comparison was made between strawberries grown using the smart vertical aeroponic system and traditional cultivation techniques, revealing that strawberries having a slightly acidic pH, and cooler temperature and higher humidity produces significantly higher yield and faster growth cycle compared to the strawberries grown in traditional farming systems. Utilizing statistical analysis, specifically a T-test, the yield and the quality of the strawberries was evaluated. This comparison functions as an objective evaluation of the system's efficacy and offers valuable insight for future enhancements.

In conclusion, the researchers found out that the indoor smart vertical aeroponic system designed for strawberry cultivation with the integration of various sensors and controlled using Raspberry Pi 4 is a highly effective and efficient farming method. It enables precise monitoring and control of environmental parameters, ensuring optimal conditions for strawberry growth.

Overall, the study highlighted the advantages of the smart vertical aeroponic system over conventional farming techniques through showing the observations that were observed within the timeframe of the strawberry planting, highlighting its potential for efficient and sustainable strawberry production.

5.3 Recommendations

The proponents of the study recommend fully using UV sheets instead of the net shade and adding additional mist nozzles to make all plant roots get the nutrient from the reservoir.

The proponents of the study recommend using wireless connection such as Message Queuing Telemetry Transport instead of USB serial connection to improve the system's overall scalability, as new devices can be added without altering the underlying system.

The proponents of the study recommend gathering larger data in order to effectively improve the accuracy of the predictive model.

The proponents of the study recommend creating a more customizable web user interface for easier monitoring and controllable user experience. Also, the proponents recommend making the web interface accessible to the internet.

The proponents of the study recommend to more strawberry harvesting cycle to know more about the effectiveness of the system

REFERENCES:

Aeroponics Nutrient Solution Recipe - Grower Today. (2021, August 18). https://www.growertoday.com/aeroponics-nutrient-solution recipe/#:~:text=The%20nutrient%20supplied%20in%20aeroponic%20plants%20is%20organic

Esmaeilizadeh, M., Malekzadeh Shamsabad, M. R., Roosta, H. R., Dąbrowski, P., Rapacz, M., Zieliński, A., Wróbel, J., & Kalaji, H. M. (2021). Manipulation of light spectrum can improve the performance of photosynthetic apparatus of strawberry plants growing under salt and alkalinity stress. PLOS ONE, 16(12), e0261585. https://doi.org/10.1371/journal.pone.0261585

Fitrianto Rahmad, L. Tanti, R. Puspasari, E. Ekadiansyah, and V. Agung Fragastia, "Automatic Monitoring and Control System in Aeroponic Plant Agriculture," 2020.

F. Rahman, I. J. Ritun, M. R. Ahmed Biplob, N. Farhin, and J. Uddin, "Automated aeroponics system for indoor farming using arduino," 2019. doi: 10.1109/ICIEV.2018.8641026.

G. Hagargund, "Bayesian inference and Internet of Things based plant health care," Eur. J. Mol. Clin. Med., vol. 08, no. 03, pp. 293–302, 2021, [Online]. Available: https://ejmcm.com/article_8405.html

Hancock, R. (2017). Water and Energy Conservation Grow System: Aquaponics and Aeroponics with a Cycle Timer By. August, 38. http://digitalcommons.calpoly.edu/cgi/viewcontent.cgi?article=1192&context=eesp

H. Farizan, A. G. Putrada, and R. R. Pahlevi, “Analysis of Support Vector Regression Performance in Prediction of Lettuce Growth for Aeroponic IoT Systems,” *2021 Int. Conf. Adv. Data Sci. E-Learning Inf. Syst. ICADEIS 2021*, no. October, 2021

Imran, S., Saxena, D., Kazimi, R., & Pratap, S. (2022). Effects of various growing media, as well as jeevamrit, on the growth and production of strawberry: A review. ~ 405 ~ the Pharma Innovation Journal, 11(4), 405–410. https://www.thepharmajournal.com/archives/2022/vol11issue4/PartF/11-3-279-378.pdf

Jurga, A. Pacak, D. Pandelidis, and B. Kaźmierczak, “A long-term analysis of the possibility of water recovery for hydroponic lettuce irrigation in an indoor vertical farm. Part 2: Rainwater harvesting,” Appl. Sci., vol. 11, no. 1, pp. 1–14, 2021, doi: 10.3390/app11010310.

K. Benke and B. Tomkins, “Future food-production systems: Vertical farming and controlled-environment agriculture,” *Sustain. Sci. Pract. Policy*, vol. 13, no. 1, pp. 13–26, 2017, doi: 10.1080/15487733.2017.1394054.

K. Janarthanan and K. Theviyanthan, “Cyberponics – A Fully Automated Greenhouse System,” no. December, p. 39, 2017, doi: 10.13140/RG.2.2.18524.28808.

M. I. Alipio, A. E. M. Dela Cruz, J. D. A. Doria, and R. M. S. Fruto, “A smart hydroponics farming system using exact inference in Bayesian network,” 2017 IEEE 6th Glob. Conf. Consum. Electron. GCCE 2017, vol. 2

017-Janua, no. Gcce, pp. 1–5, 2017,

M. Kanechi, Y. Hikosaka, C. Fukuda, and Y. Uno, “Ever-bearing strawberry culture using a new aeroponic system with dry-fog spray fertigation during the summer,” Acta Hortic., vol. 1176, 2017

M. R. Akon, S. Ahsan, J. Howlader, M. Hassan, M. Mahi, and M. M. I. Mollah, “EFFECT OF ELECTRICAL CONDUCTIVITY ON GROWTH AND YIELD OF STRAWBERRY CULTIVATED IN AEROPONIC SYSTEM,” vol. 9, pp. 239–250, 2018.

M. R. Akon, “The influence of nutrient solution pH on growth and yield of strawberry plants grown in aeroponic system,” vol. 16, pp. 23–28, 2019.

M. Salim Mir *et al.*, “Vertical farming: The future of agriculture: A review,” ~ *1175* ~ *Pharma Innov. J.*, no. 2, pp. 1175–1195, 2022, [Online]. Available: http://www.thepharmajournal.com

M. Tunio *et al.*, “Potato production in aeroponics: An emerging food growing system in sustainable agriculture for food security,” *Chil. J. Agric. Res.*, vol. 80, pp. 118–132, 2020

N. K. Kumar and T. S. Prasaath, “Field Monitoring and Rain Water Harvesting Automation Using Internet of Things,” Int. Res. J. Mod. Eng. Technol. Sci. @International Res. J. Mod. Eng., no. 04, pp. 2582–5208, 2277, [Online]. Available: www.irjmets.com Prisca, M., Maarten, V., Jan, V. D., Bart, N., Wouter, S., Timo, H., Barbara, D. C., & Bram, V. de P. (2022). Blue and far-red light control flowering time of woodland strawberry (Fragaria vesca) distinctively via CONSTANS (CO) and FLOWERING LOCUS T1 (FT1) in the background of sunlight mimicking radiation. Environmental and Experimental Botany, 198, 104866.

Propagation of strawberries by runners and seeds (Best methods?). (2021, June 22). https://www.technicalagri.com/propagation-of-strawberries-by-runners-and-seeds/

Ramalingannanavar, N., Nemichandrappa, M., Srinivasa Reddy, G. V., Dandekar, A. T., Kamble, J. B., & Dhanoji, M. M. (2020). Design, Development and Evaluation of Solar Powered Aeroponic system – A Case Study. International Journal of Current Microbiology and Applied Sciences, 9(3), 3102–3112.

R. C. Richey, "Developmental Research: The Definition and Scope," 1994 Natl. Conv. teh Assoc. fr Educ. Commun. Technol., pp. 714–720, 1994, [Online]. Available: http://files.eric.ed.gov/fulltext/ED373753.pdf

S. C. Kerns and J.-L. Lee, "Automated Aeroponics System Using IoT for Smart Farming," Eur. Sci. J., 2017

"Sensor Fusion." https://en.wikipedia.org/wiki/Sensor_fusion (accessed Nov. 06, 2022).

S. Karuniawati, A. Gautama Putrada, and A. Rakhmatsyah, "Optimization of grow lights control in IoT-based aeroponic systems with sensor fusion and random forest classification," *Proceeding - 2021 Int. Symp. Electron. Smart Devices Intell. Syst. Present Futur. Challenges, ISESD 2021*, no. January, 2021

S. Liu, J. McGree, Z. Ge, and Y. Xie, "Classification methods," Comput. Stat. Methods Anal. Big Data with Appli., pp. 7–28, 2016

S. Zhang, J. Zhang, T. Yue, and X. Jing, "Impacts of climate change on urban rainwater harvesting systems," Sci. Total Environ., vol. 665, pp. 262–274, 2019, doi: 10.1016/j.scitotenv.2019.02.135.

Security, F., & Mechanisms, C. (n.d.). in Selected Areas in the Philippines ACKNOWLEDGEMENT

Tunio, M. H., Gao, J., Shaikh, S. A., Lakhiar, I. A., Qureshi, W. A., Solangi, K. A., & Chandio, F. A. (2020). Potato production in aeroponics: An emerging food growing system in sustainable agriculture for food security. Chilean Journal of Agricultural Research, 80(1), 118–132.

United Nations. (2021). Assessing the Impact of COVID-19 on Food Systems and Adaptive Measures Practiced in Metro Manila, (August), 1–21. Retrieved from https://philippines.un.org/sites/default/files/2021-08/Urban Food Systems and the Pandemic.pdf

Y. Hikosaka, M. Kanechi, M. Sato, and Y. Uno, “Dry-fog aeroponics affects the root growth of leaf lettuce (Lactuca sativa L. cv. Greenspan) by changing the flow rate of spray fertigation,” *Environ. Control Biol.*, vol. 53, no. 4, pp. 181–187, 2015

ANNEX I

Data

Aeroponics and Conventional Plant Height Data		
Plant Number	Aeroponics Plant Height (cm)	Conventional Plant Height (cm)
1	14.2	11.2
2	12.1	11.9
3	11.5	11.3
4	14	11.8
5	13.9	12.2
6	12.4	13.2
7	12.4	12.6
8	13.6	11.7
9	11.9	14.7
10	13.5	12.4
11	12.9	12.8
12	13.3	13.5
13	12.3	12.9
14	13.8	12.5
15	13.9	13.2
16	12.2	12
17	12.6	12.6
18	14.8	13.3
19	13.7	14.8
20	14.3	12.3
21	13	14.3
22	13.1	12.1
23	14.7	12.2
24	14.7	12.8
25	12.1	12.6
26	12.8	11.6
27	14.1	13.1
28	13.6	11.4
29	14.1	11.3
30	13	-
31	11.5	-
32	14.6	-
33	11.6	-
34	12.8	-
Avgerage	*13.20588235*	*12.56206897*
Standard Deviation	*0.98317395*	*0.9510947801*

Aeroponics and Conventional Leaf Count Data		
Plant Number	Aeroponics Leaf Count	Conventional Leaf Count
1	19	18
2	20	19
3	21	20
4	18	17
5	19	11
6	11	19
7	21	20
8	18	15
9	19	18
10	20	19
11	21	10
12	18	17
13	19	18
14	10	19
15	21	15
16	18	17
17	19	18
18	20	11
19	21	20
20	11	16
21	22	21
22	12	19
23	20	16
24	17	17
25	21	13
26	11	15
27	20	15
28	17	16
29	15	13
30	16	-
31	17	-
32	13	-
33	15	-
34	16	-
Average	*17.52941176*	*16.62068966*
Standard Deviation	*3.431010931*	*2.895979887*

Aeroponics and Conventional Yield Count Data		
Plant Number	Aeroponics Yield Count	Conventional Yield Count
1	2	0
2	1	2
3	2	2
4	2	0
5	1	0
6	1	1
7	5	1
8	2	2
9	1	1
10	2	0
11	1	0
12	2	0
13	1	1
14	0	0
15	1	0
16	0	0
17	0	1
18	0	0
19	2	0
20	0	1
21	2	0
22	0	0
23	0	0
24	0	1
25	2	0
26	1	1
27	0	0
28	2	0
29	0	0
30	0	-
31	0	-
32	0	-
33	0	-
34	0	-
Average	0.9705882353	0.4827586207
Standard Deviation	*1.114240987*	*0.6876819061*

ANNEX II

Source Code

Sensor Arduino Code

```
//Libraries

#include <EEPROM.h>

#include "GravityTDS.h"

#include <Adafruit_Sensor.h>

#include <DHT.h>

#include <DHT_U.h>

#include <Wire.h>

#include <BH1750.h>

#include <OneWire.h>

#include <DallasTemperature.h>


//Set Up

// Water Temp

#define ONE_WIRE_BUS 4

OneWire oneWire(ONE_WIRE_BUS);

DallasTemperature sensors(&oneWire);


//For EC Sensor

#define TdsSensorPin A1

GravityTDS gravityTds;

tdsValue = 0;


//For Water Level

const int trigPin = 9;

const int echoPin = 10;
```

```
long duration;
int distance;

//For DHT 22 Sensor
#define DHTPIN 2
#define DHTTYPE   DHT22

DHT_Unified dht(DHTPIN, DHTTYPE);
uint32_t delayMS;

//For Light
BH1750 GY30;

//For pH Sensor
#define SensorPin A0
unsigned long int avgValue;  //Store the average value of the sensor feedback
float b;
int buf[10],temp;

//For Light Intensity Sensor
int light = 8;

//For millis() every sensor
unsigned long prevTime_EC = millis();
unsigned long prevTime_DHT = millis();
unsigned long prevTime_WATERLEVEL = millis();
```

```
unsigned long prevTime_pH = millis();

unsigned long prevTime_LIGHT = millis();

long interval_SENSOR = 1000;


void setup()

{

   Serial.begin(115200);

   Serial.println("Ready");


   //For EC Sensor

   gravityTds.setPin(TdsSensorPin);

   gravityTds.setAref(5.0);  //reference voltage on ADC, default 5.0V on Arduino UNO

   gravityTds.setAdcRange(1024);  //1024 for 10bit ADC;4096 for 12bit ADC

   gravityTds.begin();  //initialization


   //For Water Level

   pinMode(trigPin, OUTPUT); // Sets the trigPin as an Output

   pinMode(echoPin, INPUT); // Sets the echoPin as an Input


   //For DHT 22 Sensor

   dht.begin();

   sensor_t sensor;

   dht.temperature().getSensor(&sensor); //get temperature value

   dht.humidity().getSensor(&sensor); //get humidity level value

   delayMS = sensor.min_delay / 1000;
```

```
  //For Light Intensity Sensor
  Wire.begin(); // Initialize the I2C bus for use by the BH1750 library
  GY30.begin(); // Initialize the sensor object
}

void loop()
{
  unsigned long currentTime = millis();

  //For EC Sensor and Water Temp
  if (currentTime - prevTime_EC > interval_SENSOR)
  {
    float temperature = sensor.requestTemperature();
    gravityTds.setTemperature(temperature);  // set the temperature and execute
temperature compensation
    gravityTds.update();  //sample and calculate
    tdsValue = gravityTds.getTdsValue();  // get and print the ec value
    Serial.print(temperature);
    Serial.print(",");
    Serial.print(tdsValue,0);



    prevTime_EC = currentTime;
  }

  //For DHT 22 Sensor
```

```
if (currentTime - prevTime_DHT > interval_SENSOR)
{
 delay(delayMS); // Delay between measurements.
 sensors_event_t event;
 dht.temperature().getEvent(&event); // Get temperature and print its value.
 Serial.print(",");
 Serial.print(event.temperature);
 dht.humidity().getEvent(&event); // Get humidity level and print its value.
 Serial.print(",");
 Serial.print(event.relative_humidity);

 prevTime_DHT = currentTime;
}

//For Waterlevel Sensor
if (currentTime - prevTime_WATERLEVEL > interval_SENSOR)
{
   // Clears the trigPin
 digitalWrite(trigPin, LOW);
 delayMicroseconds(2);
 // Sets the trigPin on HIGH state for 10 micro seconds
 digitalWrite(trigPin, HIGH);
 delayMicroseconds(10);
 digitalWrite(trigPin, LOW);
 // Reads the echoPin, returns the sound wave travel time in microseconds
 duration = pulseIn(echoPin, HIGH);
```

```
  // Calculating the distance

  distance = duration * 0.034 / 2;

  float waterlevel = 25.6 - distance

  Serial.print(",");

  Serial.print(waterlevel);


  prevTime_WATERLEVEL = currentTime;

}


//For pH Sensor

if (currentTime - prevTime_pH > interval_SENSOR)

{

  for(int i=0;i<10;i++)       //Get 10 sample value from the sensor for smooth the value

  {

    buf[i]=analogRead(SensorPin);

    delay(10);

  }

  for(int i=0;i<9;i++)        //sort the analog from small to large

  {

    for(int j=i+1;j<10;j++)

    {

      if(buf[i]>buf[j])

      {

        temp=buf[i];

        buf[i]=buf[j];

        buf[j]=temp;
```

```
        }
      }
    }
    avgValue=0;
    for(int i=2;i<8;i++)                    //take the average value of 6 center sample
    avgValue+=buf[i];
    float phValue=(float)avgValue*5.0/1024/6; //convert the analog into millivolt
    phValue=3.5*phValue;                    //convert the millivolt into pH value
    Serial.print(",");
    Serial.print(phValue,2);

    prevTime_pH = currentTime;
  }

  //For Light Intensity Sensor
  if (currentTime - prevTime_LIGHT > interval_SENSOR)
  {
    float lux = GY30.readLightLevel(); // read the light level from the sensor and store it
in a variable
    Serial.print(",");
    Serial.println(lux);

    prevTime_LIGHT = currentTime;
  }
}
```

Bayesian Inference Python Code

WekaPred.py

```
from weka.core.converters import Loader
from weka.classifiers import Classifier
from weka.classifiers import Evaluation
from weka.classifiers import PredictionOutput
from wekaClassAttrib import ph,wt,tds
import wekaexamples.helper as helper
import csv

def main():
    global predVal_ph, predVal_tds, predVal_wt, predVal_at, predVal_ah
    # Load Data DIR
    data_dir1 = "/home/cfirme/Documents/bayesianwekathesis/pythonScripts/"
    test_dir = "/home/cfirme/Documents/bayesianwekathesis/pythonScripts/"

    loader = Loader(classname="weka.core.converters.ArffLoader")

    # Train Data
    data_tds = loader.load_file(data_dir1 + "traindata.arff", class_index="third")
    data_ph = loader.load_file(data_dir1 + "traindata.arff", class_index="first")

    # Test Data
    test_tds = loader.load_file(test_dir + "testdata.arff", class_index="third")
```

```
test_ph = loader.load_file(test_dir + "testdata.arff", class_index="first")

# Build Classifier
cls_tds = Classifier(classname="weka.classifiers.bayes.NaiveBayes")
cls_ph = Classifier(classname="weka.classifiers.bayes.NaiveBayes")
cls_tds.build_classifier(data_tds)
cls_ph.build_classifier(data_ph)

# Data Evaluation
helper.print_title("Evaluating BayesNet classifier on pH, TDS, watertemp,
airtemp, airhumid")
pred_outputph =
PredictionOutput(classname="weka.classifiers.evaluation.output.prediction.PlainText")
pred_outputtds =
PredictionOutput(classname="weka.classifiers.evaluation.output.prediction.PlainText")
evaluation_ph = Evaluation(data_ph)
evaluation_tds = Evaluation(data_tds)
evl_ph = evaluation_ph.test_model(cls_ph, test_ph, output=pred_outputph)
evl_tds = evaluation_tds.test_model(cls_tds, test_tds, output=pred_outputtds)
print("prediction output:\n" + str(pred_outputph))
print("prediction output:\n" + str(pred_outputtds))

lst_ph = int(evl_ph)
predVal_ph = ph[lst_ph]
lst_tds = int(evl_tds)
predVal_tds = tds[lst_tds]
```

```
def predval_values():
    with open('/home/cfirme/Documents/bayesianwekathesis/aeroponics_pred.csv',
'w') as header:
    writer = csv.writer(header)
    writer.writerow([predVal_ph, predVal_tds])
    print("Predicted Values: {0},{1}\n".format(predVal_ph, predVal_tds))
```

ANNEX III

Bill of Materials

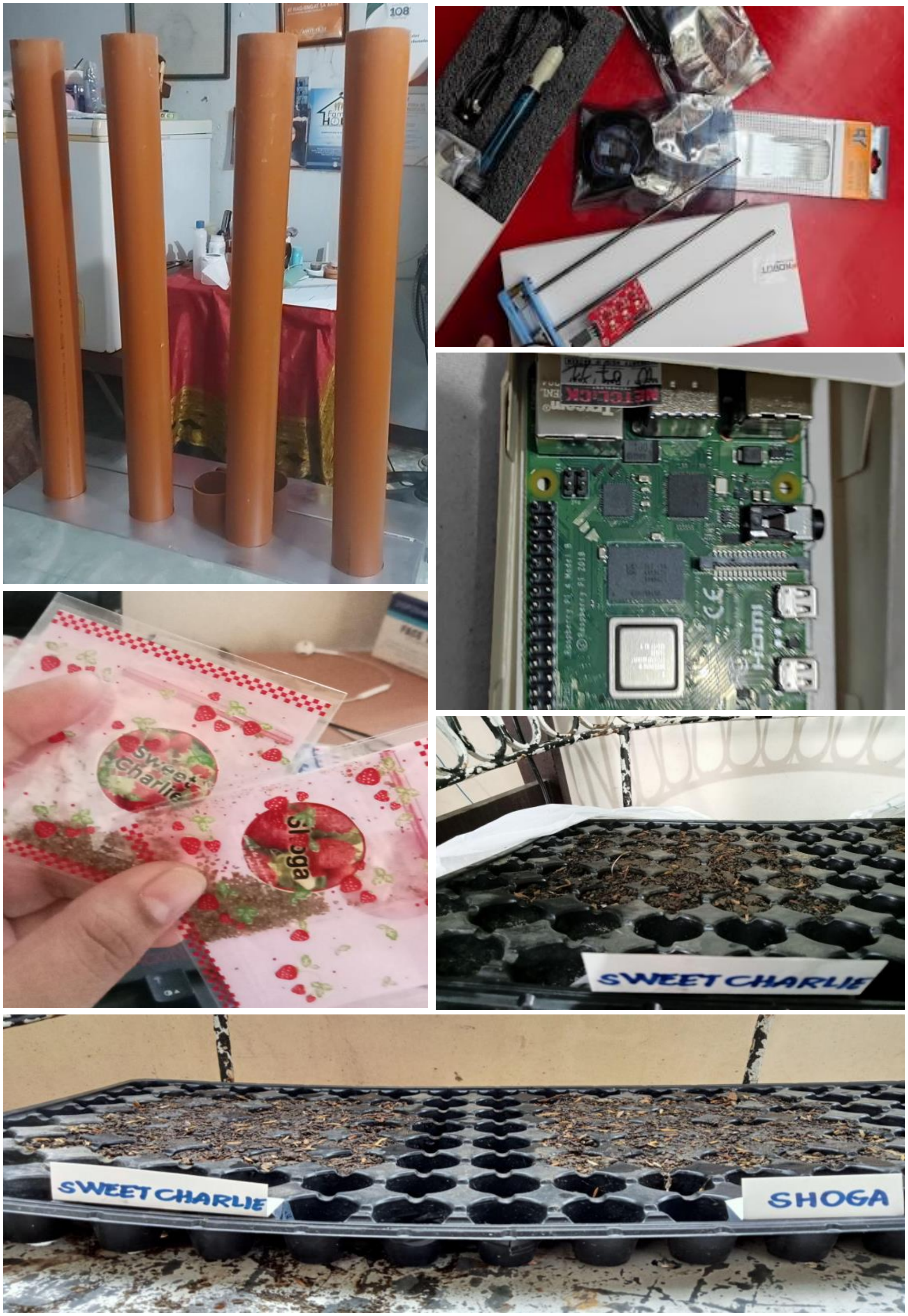
Item #	Unit	Item Description	Qty.	Unit Cost	Total Cost
1	pc	pH Sensor Meter for Arduino (Df Robot)	1	1,400.00	1,400.00
2	pc	Dht22 Temp and Humidity Sensor	1	180.00	180.00
3	pc	Analog Tds Sensor Meter (Df Robot)	1	845.00	845.00
4	pc	Full Size Breadboard	1	65.00	65.00
5	pc	Water Level Sensor	1	290.00	290.00
6	pc	Arduino Uno	1	650.00	650.00
7	pc	Raspberry Pi 4	1	6,500.00	6,500.00
8	pc	Rainwater Level Sensor	1	40.00	40.00
9	pc	Rpi4 Aluminum Heat Sink Case W/ Dual Fan	1	450.00	450.00
10	pc	Unsoldered Gy-30 Bh1750fv1	1	80.00	80.00
11	pc	Boysen Flat Latex White Paint	1	175.00	175.00
12	pc	Grow Lights	3	500.00	1,500.00
13	pc	Extension Wire	1	219.00	219.00

14	pc	PVC Fittings	4	270.00	1,080.00
15	pc	Orocan Box (Reservoir)	1	1,000.00	1,000.00
16	pc	Solar Panel	1	1,400.00	1,400.00
17	pc	Solar Controller	1	560.00	560.00
18	m	Speaker Wire	5	26.00	130.00
19	pc	Inverter (500w)	1	907.00	907.00
20	pc	Solar Battery (40AH)	1	2,183.00	2,183.00
21	pc	ATS	1	1,000.00	1,000.00
22	pc	pH UP and DOWN solution	2	250.00	500.00
23	pc	Nutrient Solution	1	330.00	330.00
24	pc	Clone Collar Foam	70	2.50	175.00
25	pc	Jumper Wires	80	1.50	120.00
26	pc	Storage Box	1	245.00	245.00
27	pc	PVC Pipe 4’	1	875.00	875.00
28	pc	PVC CO 4 Orange	3	65.00	195.00

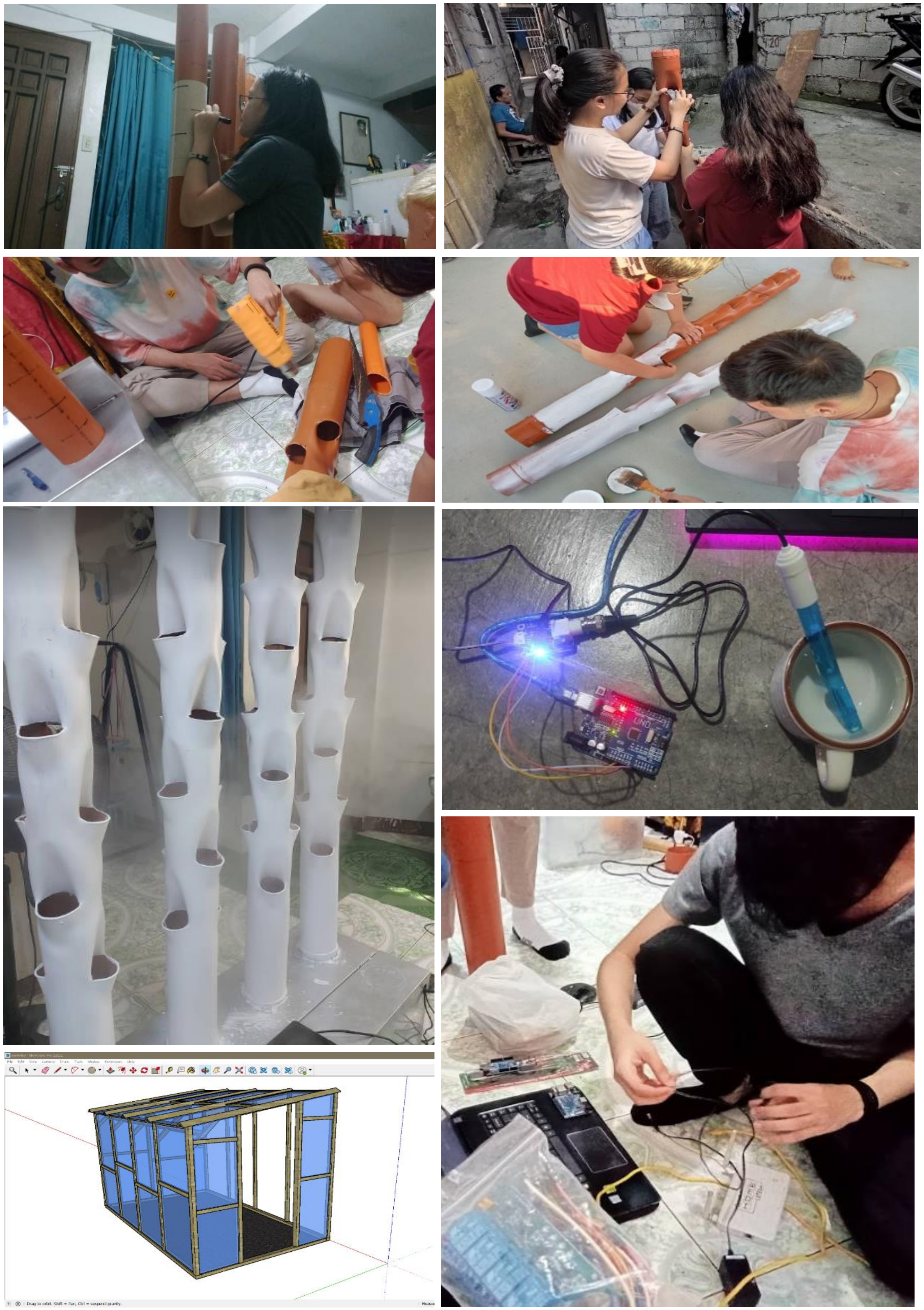
29	pc	Sealant	1	235.00	235.00
30	pc	2V 5W Peristaltic Liquid Pump ID:3mm OD:5mm 19~100 mL/min	3	350.00	1,050.00
31	m	UV Sheet	1	660.00	660.00
32	m	Shade Net	1	2,250.00	2,250.00
33	pack	Strawberry Seeds	2	250.00	500.00
34	pc	Cement/Sand/Gravel	1	650.00	650.00
35	pc	Plywood	1	1,360.00	1,360.00
36	pc	Bamboo	1	3,000.00	3,000.00
37	pc	Gutter and Rivet	1	450.00	450.00
38	pc	PVC Solvent	1	120.00	120.00
TOTAL					**33,369.00**

ANNEX IV

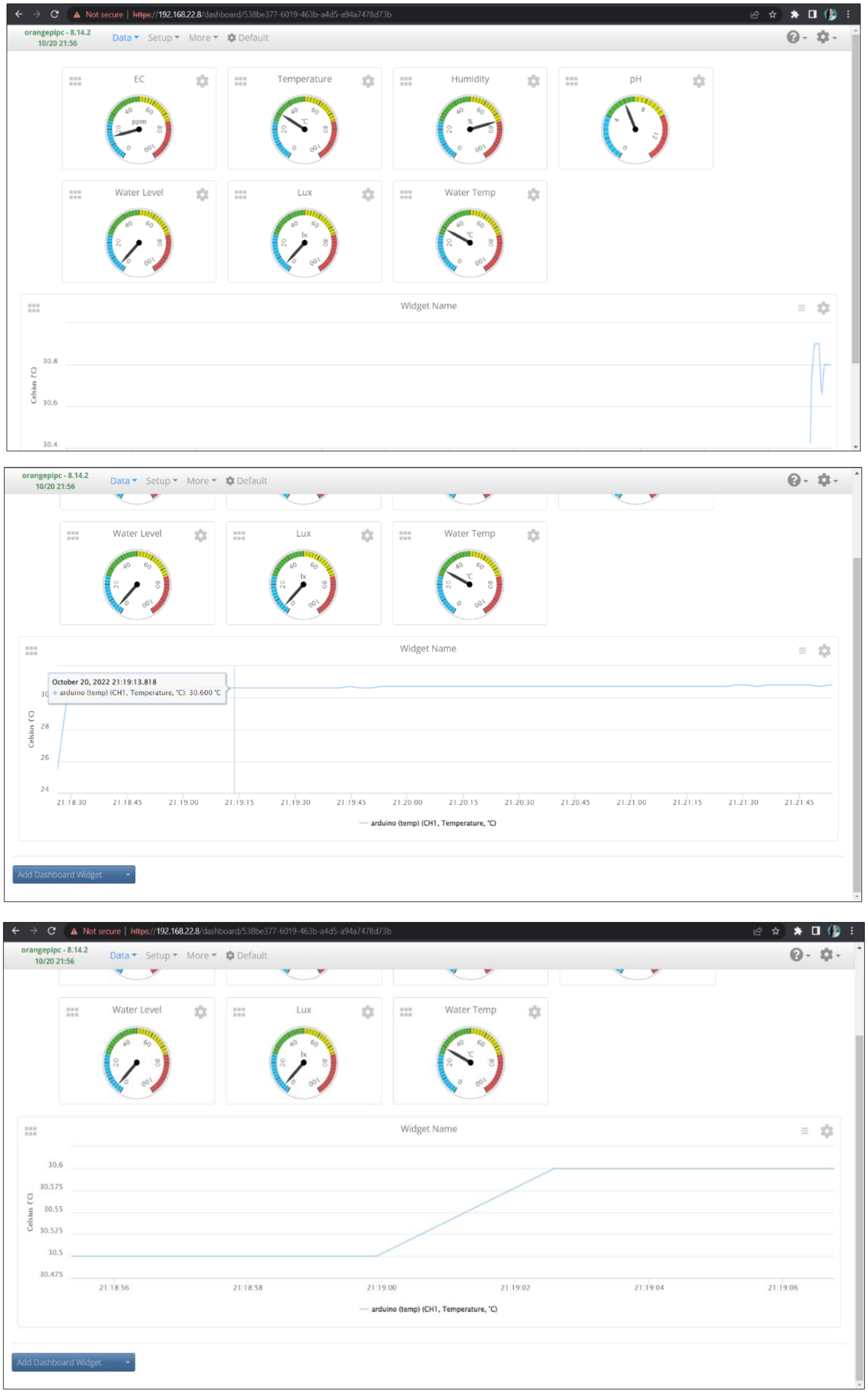
Project Documentation



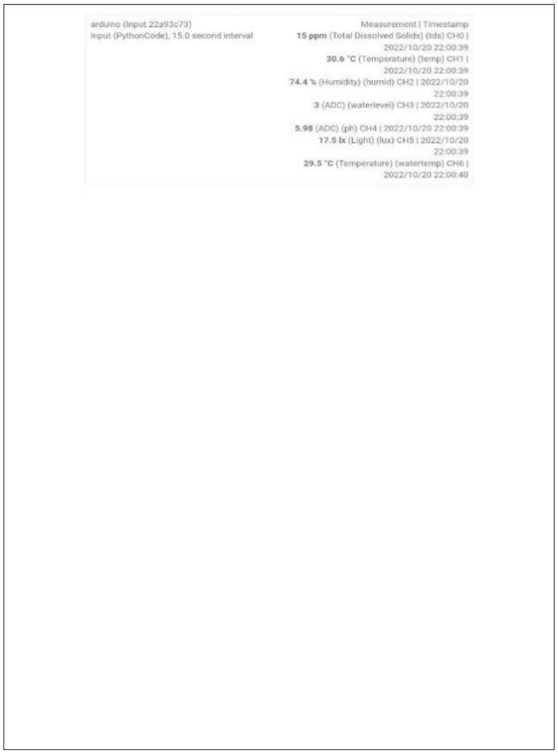
Procurement of Materials



Initial Building of Aeroponic Towers, Testing of Sensors,
3D Model of Planned Greenhouse



Initial GUI Website View




```
//Libraries
#include <EEPROM.h>
#include "GravityTDS.h"
#include <Adafruit_Sensor.h>
#include <DHT.h>
#include <Wire.h>
#include <BH1750.h>
#include <OneWire.h>
#include <DallasTemperature.h>

//Set Up
//Water Temp Sensor
#define ONE_WIRE_BUS 5
#define ONE_WIRE_BUS1 3

OneWire oneWire(ONE_WIRE_BUS);

DallasTemperature sensors(&oneWire);
float Celcius=0;

//For EC Sensor
#define TdsSensorPin A1
GravityTDS gravityTds;

float temperature = 25,tdsValue = 0;

//For DHT 22 Sensor
#define DHTPIN 2
#define DHTTYPE DHT22
DHT dht(DHTPIN, DHTTYPE);


DHT_Unified dht(DHTPIN, DHTTYPE);
uint32_t delayMS;

//For Waterlevel Sensor
BH1750 GY30;

//For pH Sensor
#define SensorPin A0
unsigned long int avgValue;  //Store the average value of the sensor feedback
float b;

int buf[10],temp;

//For Light Intensity Sensor
int light = 8;
```


```
//For Light Intensity Sensor
int light = 8;

//For millis() every sensor
unsigned long prevTime_WATERTEMP = millis();
unsigned long prevTime_EC = millis();
unsigned long prevTime_DHT = millis();
unsigned long prevTime_WATERLEVEL = millis();
unsigned long prevTime_pH = millis();
unsigned long prevTime_LIGHT = millis();
long interval_SENSOR = 2000;

void setup()
{
    Serial.begin(115200);
    //Serial.println("Ready");

    //For Water Temp
    sensors.begin();
    pinMode(ONE_WIRE_BUS1, INPUT_PULLUP);

    //For EC Sensor
    gravityTds.setPin(TdsSensorPin);
    gravityTds.setAref(5.0);  //reference voltage on ADC, default 5.0V on Arduino UNO
    gravityTds.setAdcRange(1024);  //1024 for 10bit ADC;4096 for 12bit ADC
    gravityTds.begin();  //initialization

    //For DHT 22 Sensor
    dht.begin();

    //For Light Intensity Sensor
    Wire.begin(); // Initialize the I2C bus for use by the BH1750 library
    GY30.begin(); // Initialize the sensor object
}

void loop()
{
    unsigned long currentTime = millis();

    //For Water Temp
    if ((unsigned long)(currentTime - prevTime_WATERTEMP) > interval_SENSOR)
    {
      sensors.requestTemperatures();
      Celcius=sensors.getTempCByIndex(0);
      Serial.print("<");
      Serial.print(Celcius);
```

Initial GUI Mobile View and Plot Time Series Chart

Building of the Aeroponic Setup and Construction of the Greenhouse in the Deployment Site

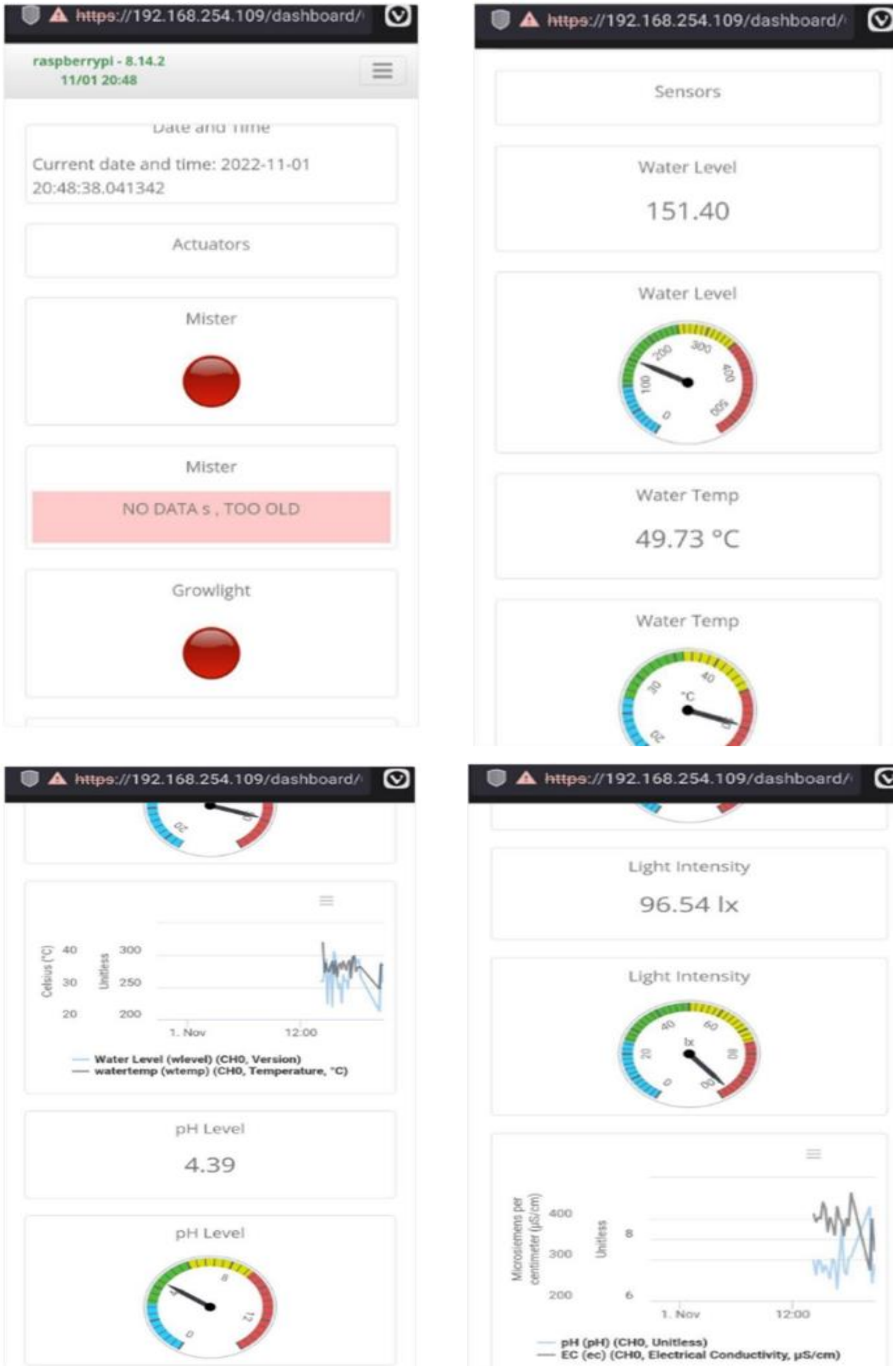
Actual Setup of the Greenhouse

Actual Aeroponics Setup with the Strawberry Runners

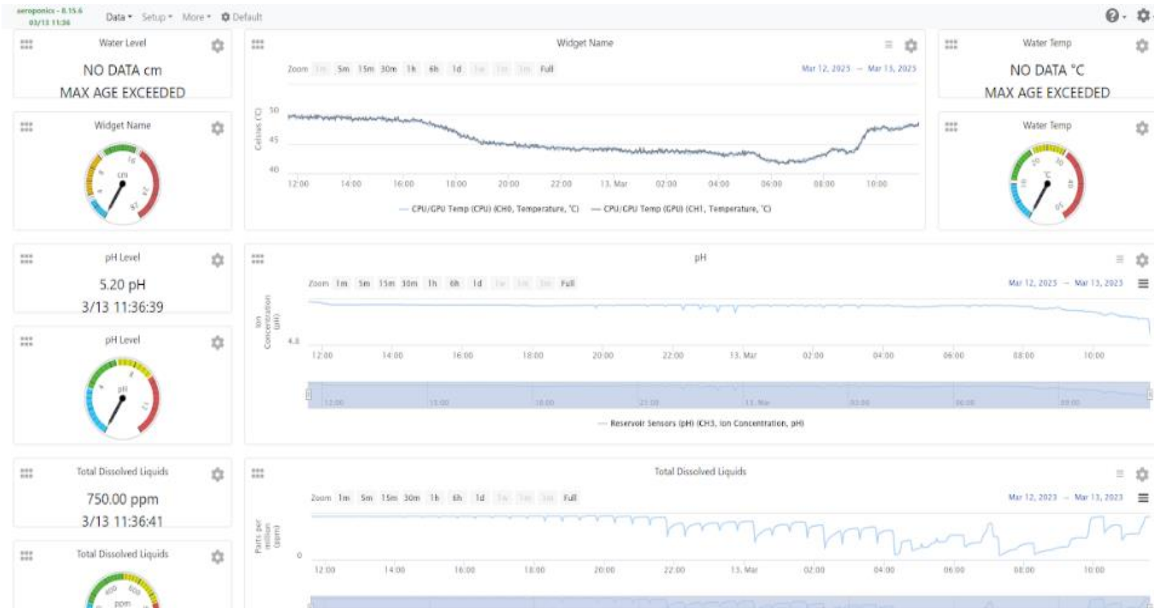
Traditional Farming of Strawberries

Progress of Strawberries on the Aeroponic System; Harvested Strawberries

Updated GUI Website



Updated GUI Website (Mobile View)



Time Series Chart with Data Obtained from Sensors

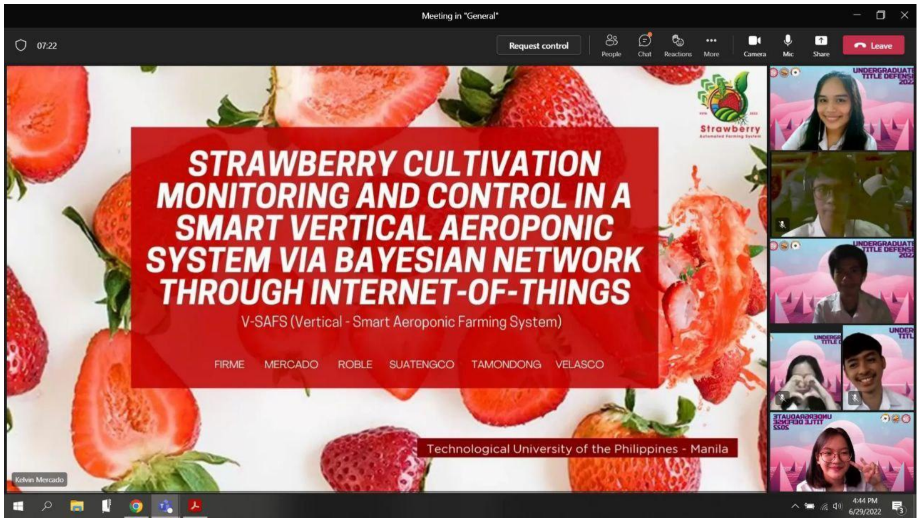
Controls of the sensors and actuators for the Aeroponic System

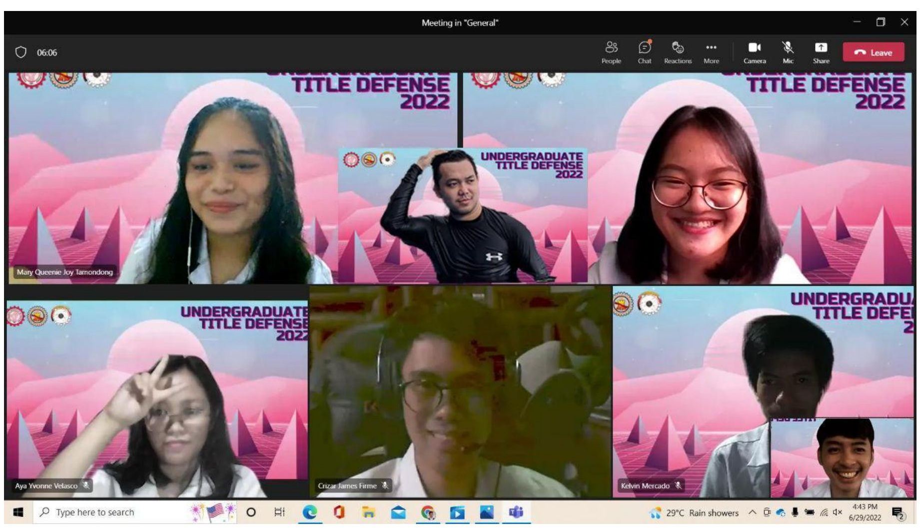
Site Visit with Engr. Glenn Virrey and Engr. Mark Melegrito

ANNEX V

Defense Documentation

Topic Defense





Title Defense

Progress Presentation

Pre-Final Defense

Final Defense

ANNEX VI

Researcher’s Profile

CAREER OBJECTIVE

To pursue and establish a career in Network Engineering where I can implement my academic skills in accomplishing the company's goal while improving my skills and knowledge

PERSONAL INFORMATION

Number	09693190028
Email	crizar03@gmail.com
Address	36 Sangley St.
	Greenheights Village
	Paranaque City 1700
Birthdate	2001 March 17
Nationality	Filipino
Civil Status	Single

I certify that the written information is true and correct.

CRIZAR JAMES FIRME

Applicant

CRIZAR JAMES B. FIRME

TECHNICAL SKILLS

- Proficient in Computer Systems and Configuration
- Proficient with Microsoft Word, Excel and PowerPoint
- Knowledgeable in Linux Operating System
- Knowledgeable in Computer Network and Server Administration
- Knowledgeable in Cisco router and switch configuration and operation
- Knowledgeable in Programming Language (Python & Bash)

SOFT SKILLS

- Stress Management
- Problem Solving and Analytical Skills
- Adaptability

EDUCATION

Bachelor of Science in Electronics Engineering
(2019 – 2023)
Technological University of the Philippines – Manila
Ayala Boulevard, Ermita, Manila

STEM Strand
(2017 – 2018)
Rogationist College
Silang, Cavite

CHARACTER REFERENCE

Lizbeth R. Alpapara
Administrative Officer VIII
City Government of Paranaque
Phone: (+63)9760192321
Email: bethcris_23@yahoo.com

KELVIN G. MERCADO

CAREER OBJECTIVE

Seeking a challenging position in Electronics and Communication Engineering, where I can apply my technical knowledge, problem-solving skills, and passion for innovation to contribute to developing and implementing cutting-edge technologies in the Telecommunication and Information and Communication Technology field.

PERSONAL INFORMATION

Number	09212591269
Email	kelvinmercado719@gmail.com
Address	BLK 2 Lot 16 Lote St. Brgy. Dulong Bayan, City of San Jose Del Monte, Bulacan
Birthdate	2000 December 20
Nationality	Filipino
Civil Status	Single

I certify that the written information is true and correct.

KELVIN G. MERCADO

Applicant

TECHNICAL SKILLS

- Network Design and Simulation (Cisco Packet Tracer)
- Electronics and Circuit Design (Multisim, Proteus, PSIM, FluidSIM)
- Software Programming Development (Python, Matlab, GNU Octave)
- Oriented in Microsoft Applications (Word, Excel, Powerpoint)
- Basic knowledge of Cybersecurity

SOFT SKILLS

- Fast Learned
- Time Management
- Decision Making
- Organized

EDUCATION

Bachelor of Science in Electronics Engineering (2019 – 2023)
Technological University of the Philippines – Manila
Ayala Boulevard, Ermita, Manila

STEM Strand
(2017 – 2019)
Sapang Palay National High
San Jose Del Monte, Bulacan

CHARACTER REFERENCE

Engr. Mark Rudolfh M. Manarang
Operations Specialist
Subic Thermal Power Station
Phone: 09351717689
Email: markrudolfhmanarang15@gmail.com

CAREER OBJECTIVE

To share a win-win situation where I can contribute my skills and abilities in the field of Electronics Engineering, fostering career growth, gaining valuable work experience, and actively contributing to the achievement of organizational goals.

PERSONAL INFORMATION

Number	09651792269
Email	roblericajoy@gmail.com
Address	544 Tulip St. Zapote I, Bacoor City, Cavite
Birthdate	2000 August 17
Nationality	Filipino
Civil Status	Single

I certify that the written information is true and correct.

RICA JOY B. ROBLE
Applicant

RICA JOY B. ROBLE

TECHNICAL SKILLS

- Proficient in Computer Configuration
- Advance knowledge in Microsoft Office
- Fundamental understanding of CISCO routing and subnetting
- Basic Electronics and Communication, Troubleshooting and Soldering

SOFT SKILLS

- Passionate and driven
- Results and goal oriented
- Adaptive in multi-tasked and fast-paced working environment

EDUCATION

Bachelor of Science in Electronics Engineering (2019 – 2023)
Technological University of the Philippines – Manila
Ayala Boulevard, Ermita, Manila

STEM Strand (2017 – 2019)
STI Academic Center Las Piñas City
Alabang – Zapote Road, Las Piñas City

CHARACTER REFERENCE

Nikka Joy S. Cunanan
Automotive Icon Incorporated
Head Office Finance and Accounting Assistant Associate
09458974006

CAREER OBJECTIVE

To utilize Electronics Engineering foundation to assist the company in designing, developing, and implementing solutions, to work in a dynamic and diverse team environment, collaborating with professionals in the industry to achieve the organization's goals by sharing my knowledge and enhancing my expertise and to grow as a person and in the field/organization I am associated with, by utilizing my foundation of industry best practices.

PERSONAL INFORMATION

Number	09351310945
Email	suatengcoralphemerson@gmail.com
Address	0667 Bangkal St. Bulihan Dulo, Plaridel, Bulacan
Birthdate	2001 January 21
Nationality	Filipino
Civil Status	Single

I certify that the written information is true and correct.

RALPH EMERSON R. SUATENGCO
Applicant

RALPH EMERSON R. SUATENGCO

TECHNICAL SKILLS

- Project Management: Experience in managing electronics projects, including planning, scheduling, and coordinating resources
- Computer-Aided Design (CAD) Tools: Proficiency in using CAD software like AutoCAD or SolidWorks for designing mechanical aspects of electronic systems
- Microsoft Office Expertise
- Adobe Softwares knowledge especially Adobe Photoshop

SOFT SKILLS

- Communicates well
- Works effectively in diverse teams
- Ability to learn and adapt
- Has leadership skills
- Dedication to learn continuously

EDUCATION

Bachelor of Science in Electronics Engineering (2019 – 2023)
Technological University of the Philippines – Manila
Ayala Boulevard, Ermita, Manila

STEM Strand (2017 – 2019)
La Consolacion University of the Philippines – Malolos (LCUP)
Catmon Road, Malolos, Bulacan

CHARACTER REFERENCE

Engr. Glenn C. Virrey
College Professor
University of Sto. Thomas – Manila
09178707167

MARY QUEENIE JOY R. TAMONDONG

CAREER OBJECTIVE

A highly organized and hard-working individual. Seeking to contribute to strengthening the company's manpower with the skills and knowledge obtained in Electronics Engineering while at the same time to also obtain additional skills and personal growth through experiences

PERSONAL INFORMATION

Number	09978318356
Email	maryqueeniejoy@gmail.com
Address	10022 Phase 6 Package 4 Brgy 178 Camarin, Caloocan City
Birthdate	2001 September 21
Nationality	Filipino
Civil Status	Single

I certify that the written information is true and correct.

MARY QUEENIE JOY R. TAMONDONG
Applicant

TECHNICAL SKILLS

- Knowledgeable in Microsoft Applications (Word, Excel, Powerpoint)
- Basic Electronics Troubleshooting
- Technical Support Expertise
- Proficient in using MATLAB for simulation and analysis of electronic circuits

SOFT SKILLS

- Keen to detail
- Can work under pressure
- Great organizational skills
- Has leadership skills
- Determined and dedicated

EDUCATION

Bachelor of Science in Electronics Engineering
(2019 – 2023)
Technological University of the Philippines – Manila
Ayala Boulevard, Ermita, Manila

STEM Strand
(2017 – 2019)
Our Lady of Fatima University – Quezon City
Hilltop Mansion Subdivision Lagro, Quezon City

CHARACTER REFERENCE

Engr. Glenn C. Virrey
College Professor
University of Sto. Thomas – Manila
09178707167

CAREER OBJECTIVE

To strengthen my time management abilities under strict working hours and to obtain office job experience. Whether I choose to work in an office or in the field in the future, these goals will undoubtedly be beneficial. I also anticipate improving my multitasking abilities through this experience.

PERSONAL INFORMATION

Number	09288149138
Email	ayayvonne.velasco@gmail.com
Address	481 Abbey Road 1, Brgy 73, Caloocan City
Birthdate	2001 March 23
Nationality	Filipino
Civil Status	Single

I certify that the written information is true and correct.

AYA YVONNE S. VELASCO
Applicant

AYA YVONNE S. VELASCO

TECHNICAL SKILLS

- Proficient in programming languages such as Python and R programming
- Circuit design and analysis
- Proficiency in cisco, IP addressing and subnetting
- Proficiency in using variety of statistical tests
- Octave and Matlab programming

SOFT SKILLS

- Good communication
- Teamwork
- Professionalism
- Continuous learning
- Problem-solving

EDUCATION

Bachelor of Science in Electronics Engineering
(2019 – 2023)
Technological University of the Philippines – Manila
Ayala Boulevard, Ermita, Manila

STEM Strand
(2017 – 2019)
University of the East – Caloocan
105 Samson Road, Caloocan City

CHARACTER REFERENCE

Rhio Castro
Virtual Asssistant
Private Client
Phone: 09437281923
E-mail: riricastro12@gmail.com

ANNEX VII

User’s Manual

ESTD 2022

STRAWBERRY
Automated Farming System

USER'S MANUAL

1. INTRODUCTION

Welcome to the user manual for the Vertical Strawberry Aeroponics Farming System! This comprehensive guide will provide you with all the necessary information to set up and maintain your aeroponic system specifically designed for growing strawberries. Whether you are a seasoned gardener or a beginner, this manual will walk you through the process, step by step.

Aeroponics is an innovative method of growing plants that involves suspending the plant roots in a misted nutrient solution, allowing them to absorb water, oxygen, and nutrients directly. This technique provides numerous benefits, such as faster growth, increased yield, and reduced water usage compared to traditional soil-based methods.

Once your system is up and running, we'll discuss the ideal environmental conditions for strawberry growth, including lighting, temperature, humidity, and nutrient requirements. We'll provide you with a detailed nutrient schedule to ensure your strawberries receive the optimal balance of minerals and vitamins for healthy development.

You will also learn about the essential maintenance tasks, such as monitoring pH levels, cleaning the system, and preventing or troubleshooting common issues that may arise during the growing process. Additionally, we'll guide you on pruning and harvesting techniques to help you maximize your strawberry yield.

By following this user manual closely and dedicating the necessary care and attention to your strawberry aeroponics system, you will soon be enjoying the satisfaction of growing your own delicious and healthy strawberries. So, let's get started and embark on this exciting journey of aeroponic strawberry cultivation!

2. SYSTEM OVERVIEW

This project is an automatic monitoring and control system for vertical strawberry aeroponics farming. This aeroponics system has a web application that monitors and regulates the parameters and actuators to generate real-time analysis. The system will also generate a predictive analysis model using a Bayesian network and a time series chart.

The ***VSAFS*** consists of four towers, an Arduino board with pH, TDS, water temperature, DHT22, HC-SR04, and light sensors, and a Raspberry Pi 4. The Arduino gathers data from the sensors and sends it to the Raspberry Pi 4, which uses the open-source project Mycodo to display and machine learning Bayesian inference to process the data and control the solution pumps, root mist system pumps, grow lights, and a humidifier.

With Mycodo configured, you can now view and analyze the data from the sensors. Access the Mycodo web interface and navigate to the data visualization section. Here, you can view real-time sensor readings, historical data, and graphical representations of the sensor data over time. Analyze the data to monitor the health and performance of your aeroponics system.

3. COMPONENTS

It's important to familiarize yourself with these components before proceeding with the installation process. Understanding their functions and how they work together will ensure a successful setup and operation of your strawberry aeroponics system.

1. VSAFS Hardware

- PVS Pipe
- Reservoir
- Mist

ilicon Tube

et Pots

- Peristaltic Pump

2. Arduino

- Arduino board (e.g., Arduino Uno)
- pH sensor
- TDS sensor
- Water temperature sensor (DS18B20)
- HC-SR04 Sonar Sensor
- DHT11 or DHT22 sensor (for humidity and temperature)
- Light sensor (BH1750)
- Wires and connectors for sensor connections (e.g, Jumper Wires, USB Serial)

3. Raspberry Pi 4

- Raspberry Pi 4 Model B (or newer)
- Power supply for Raspberry Pi 4 (5v, 3A)
- MicroSD card (16GB or larger) with Raspbian or Raspberry Pi OS installed
- HDMI cable and monitor (for initial setup)
- USB keyboard and mouse (for initial setup)
- Ethernet cable or Wi-Fi dongle (for internet connectivity)
- Wires and connectors (as required)

4. SETUP AND INSTALLATION

Before you begin, make sure you have all the components mentioned in the previous section of this manual. Take the time to organize your materials and tools to ensure a smooth installation process. It's also a good idea to read through the entire setup and installation manual (***duplication manual***) before you start, so you have a clear understanding of the tasks involved.

Throughout the installation process, safety is of utmost importance. Ensure that you follow any safety guidelines provided by the manufacturer and take necessary precautions when working with electrical components, water, and tools.

By carefully following the setup and installation instructions, you'll be well on your way to enjoying the benefits of growing your own delicious and healthy strawberries using the aeroponics method. Let's get started!

1. Connecting the hardware

- Connect the Arduino to the Raspberry Pi 4 using a USB cable.
- Connect the Arduino's sensors (pH, TDS, water temperature, DHT11, and light sensors) to the appropriate pins on the Arduino board.
- Connect the solution pumps, root mist system pumps, grow lights, and humidifier to the Raspberry Pi 4's GPIO pins or use appropriate relay modules for higher current devices.
- Double-check and ensure that all the wirings and connections are secured to avoid any electrical hazards.

2. Configuring Mycodo

- Install the latest version of Mycodo on your Raspberry Pi 4 by following the installation instructions provided by the Mycodo project.
- Once installed, access the Mycodo web interface by entering the Raspberry Pi's IP address into a web browser on a device connected to the same network.

- Follow the on-screen instructions to set up a new Mycodo instance, specifying the necessary settings such as the database and user credentials.
- Configure the data acquisition settings to receive data from the Arduino board. Specify the appropriate communication method (e.g., USB) and the corresponding port.
- Configure the sensors and assign them to their respective input channels in Mycodo.
- Set up appropriate data logging intervals, graphing options, and alerts as per the requirements.

5. AUTOMATION AND CONTROL

In the world of aeroponics, automation and control play a crucial role in maintaining optimal conditions for strawberry growth and maximizing the efficiency of your system. This section of the user manual will introduce you to the various automation and control features that can be implemented in your strawberry aeroponics setup.

Automating certain processes not only saves time and effort but also ensures consistent and precise control over environmental factors that directly impact plant growth. By utilizing automation and control systems, you can fine-tune parameters such as misting intervals, lighting schedules, nutrient delivery, and environmental monitoring.

1. Required Parameters

Parameters	Value
pH	**5.5 to 6**
TDS	**500 to 800 ppm**
Water Temperature	**18 to 25 degrees Celsius**
Greenhouse Temperature (inside the greenhouse environment)	**18 to 25 degrees Celsius**
Light level intensity	**>6000 lux**
Average level of humidity	**60 to 75 percent**

2. Remote Monitoring and Control

- Use Mycodo's control functions to trigger actions based on the sensor data. For example, you can configure Mycodo to activate the solution pumps when the pH level drops below a certain threshold.
- Utilize Bayesian inference to learn from the data and refine the control actions over time. The machine learning algorithm will adapt to the specific needs of your plants.

6. MAINTENANCE AND TROUBLESHOOTING

While aeroponic systems offer numerous advantages for growing strawberries, occasional issues or challenges may arise during the cultivation process. This section of the user manual will provide you with a troubleshooting guide to help you identify and resolve common problems that you may encounter with your strawberry aeroponics system.

By understanding the potential issues and their solutions, you'll be better equipped to maintain a healthy and thriving strawberry crop. Remember to approach troubleshooting systematically, starting with the simplest solutions and gradually progressing to more complex ones if necessary.

1. Troubleshooting

Here are some common issues you may encounter and steps to troubleshoot them:

1.1 Insufficient or Uneven Mist Coverage

- Ensure that the misting nozzles or sprayers are not clogged. Clean or replace them if necessary.
- Verify that the pump is functioning correctly and providing sufficient pressure to create a fine mist.
- Check the positioning of the misting nozzles or sprayers to ensure they are evenly distributed over the strawberry plants' root zone.

1.2 Nutrient Imbalances

- Monitor the pH levels regularly and adjust as needed using the provided pH adjusting kit.
- Check for potential sources of pH fluctuations, such as fluctuations in water quality or excessive nutrient accumulation.
- Review the nutrient schedule and ensure that you are providing the appropriate concentrations of nutrients for strawberries.
- Check the nutrient solution's temperature, as extreme temperatures can affect nutrient absorption.

1.3 Temperature and Humidity Issues

- Ensure proper ventilation and airflow within the growing area to maintain optimal temperature and humidity.

- Consider implementing cooling or heating systems to regulate temperature, especially in challenging climates.

1.4 Pest and Diseases

- Identify the pest or disease accurately and take appropriate measures, such as introducing biological controls or applying organic treatments.
- Practice good hygiene by regularly cleaning and disinfecting your aeroponic system and removing any affected plant material.

2. Maintenance and Safety

- Verify that the Arduino is properly communicating with the Raspberry Pi 4.
- Ensure that the sensors are correctly wired and connected to the Arduino.
- Verify the configuration settings in Mycodo, including the correct communication method and port.
- Check for any error messages or alerts in the Mycodo web interface.
- Regularly inspect and clean the sensors to maintain accurate readings.
- Regularly inspect and prune your strawberry plants to remove dead leaves, runners, or any diseased or damaged parts.
- Ensure that all electrical connections, including the pump and timers, are properly installed and grounded. Avoid exposing electrical components to water or moisture.

ANNEX VIII

Duplication Manual

ESTD 2022

STRAWBERRY
Automated Farming System

DUPLICATION MANUAL

V-SAFS

1. INTRODUCTION

Welcome to the Prototype Duplication Guide. This document serves as a comprehensive resource for individuals seeking to duplicate the Vertical Strawberry Aeroponics System (VSAFS) prototype successfully. This prototype is an automated system allowing us to monitor and control the important cultivation parameters for vertical strawberry aeroponics farming using sensors, actuators, microcontrollers, and a predictive analysis model using a Bayesian Network. Duplicating the prototype allows you to replicate an automatic environment suitable for your strawberry plant growth. Whether you are an inventor, engineer, entrepreneur, farmer, or student this guide will provide you with the essential steps and considerations to achieve accurate and reliable results.

Before we begin, it's essential to note that this manual assumes you have some basic knowledge of aeroponics systems and their components. Additionally, please ensure you have access to the necessary materials and tools before proceeding with the duplication process. Each section of this manual will guide you through the specific tasks required for duplicating the strawberry aeroponics system successfully. Take your time to read and understand each step before proceeding.

Remember, the success of your aeroponics system relies on proper implementation and maintenance. With careful attention to detail and regular upkeep, you'll be able to enjoy the fruits of your labor in no time!

2. OVERVIEW

2.1 Aeroponics System Flowchart

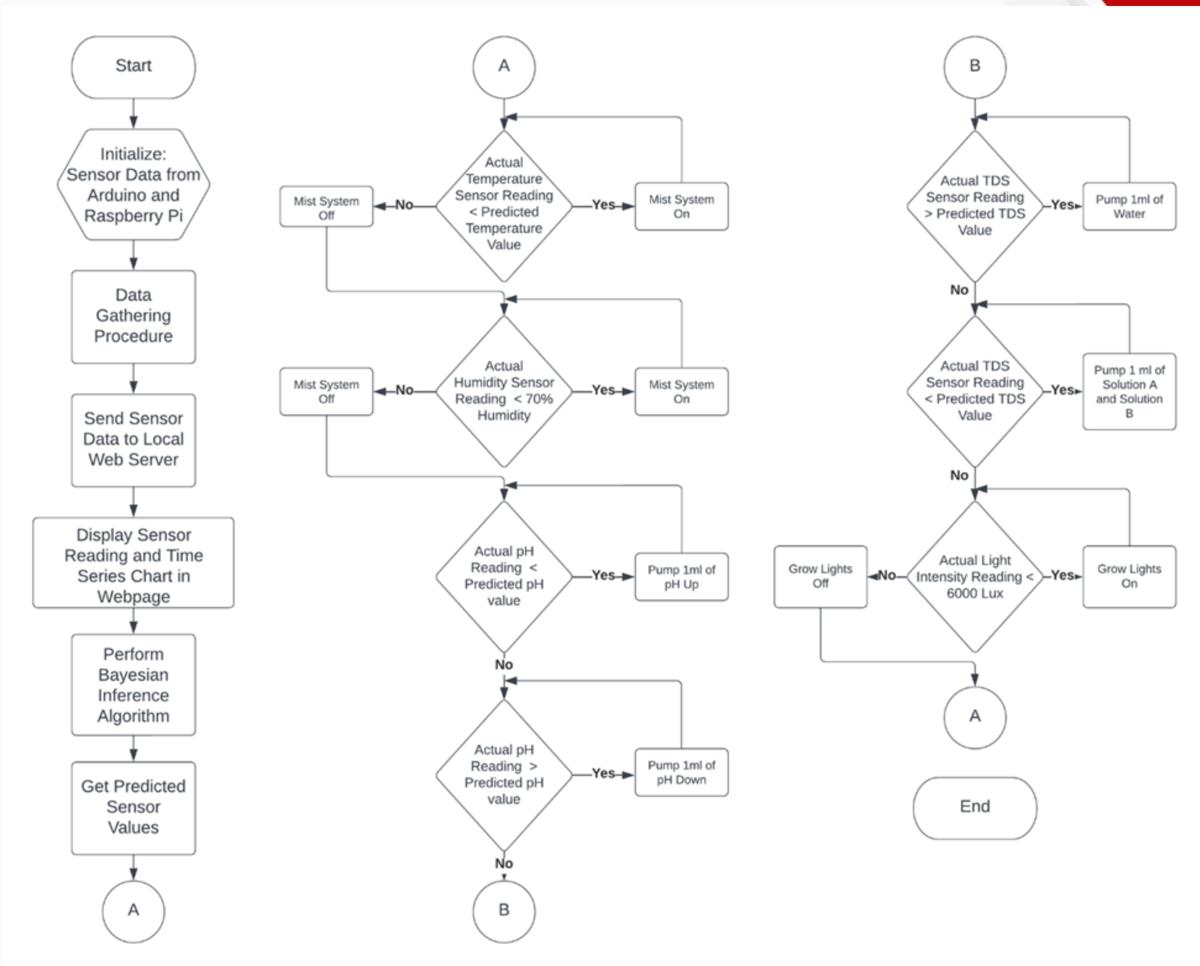


Figure 2.1 VSAFS Flowchart

This flowchart shows the overall functionality of VSAFS featuring the utilization and transmission of sensor data to the local web server. It also highlights the incorporation of the Bayesian algorithm in the system, facilitating decision-making by evaluating the gathered data and applying it to the VSAFS.

2.2 Aeroponics System Block Diagram

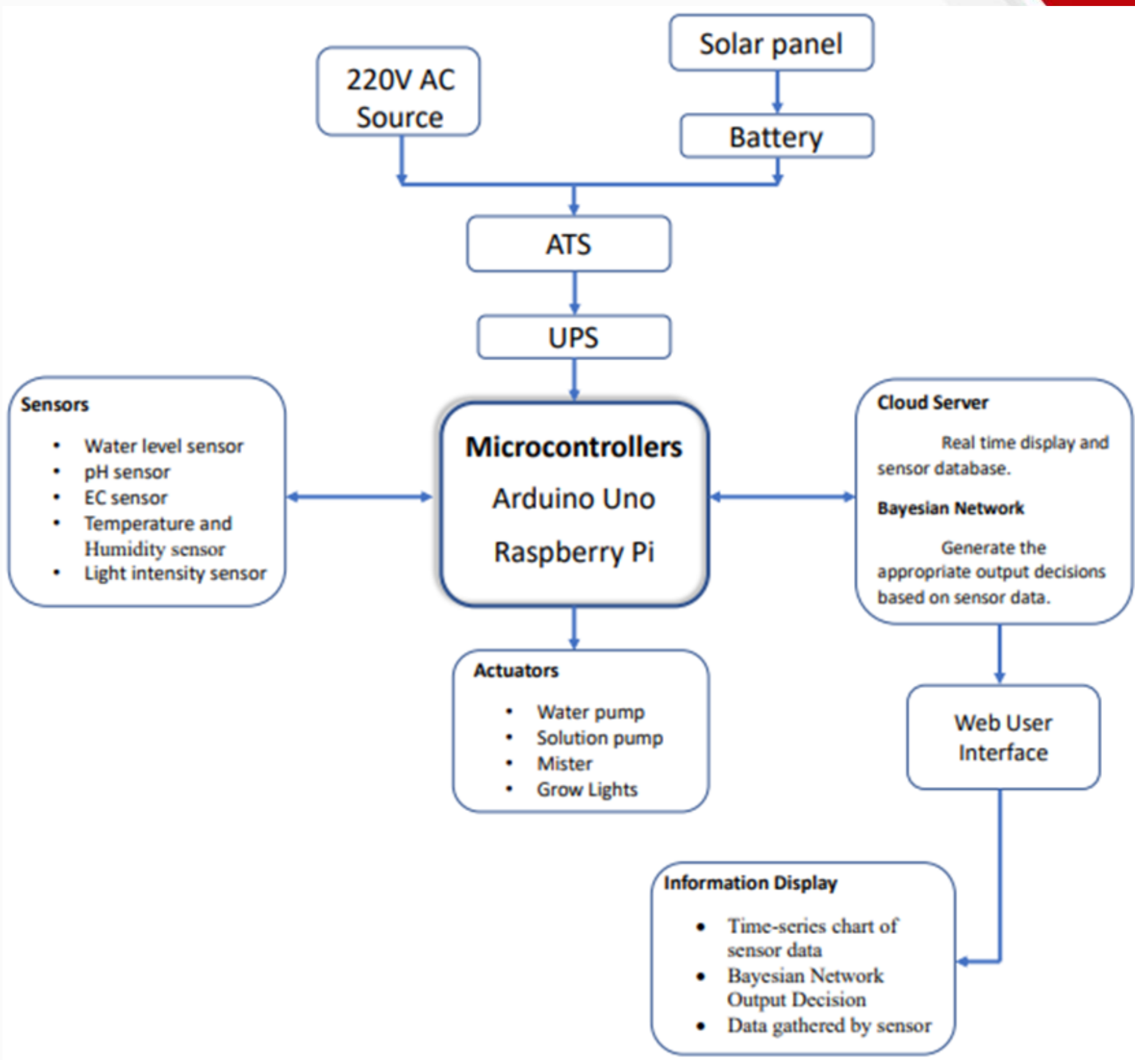


Figure 2.2 VSAFS Block Diagram

Figure 3 shows the overall connection of VSAFS through the use of Arduino Uno and Raspberry Pi 4 as the microcontrollers. These microcontrollers centralize the connection between the sensors, actuators, power supply, and web user interface for them to communicate to each other.

3. HARDWARE

3.1 List of Materials

Quantity	Material	Specification
Greenhouse		
50	Bamboo	2 in. x 10 ft
1	UV sheet	200-micron, 4m x 6m
4	Net	60% shade, 4 m x 6 m
Vertical Aeroponic Towers		
6	PVC pipes	4 in. x 8 ft.
1	Plastic container	1.64 ft x 1.15 ft x 1.15 ft
5	PVC elbow	4 in.
6	PVC Tee	4 in.
Power Supply (secondary source)		
1	Solar Panel	50 watts
1	Automatic Transfer Switch (ATS)	Any brand
1	Battery	40 Ah
1	Solar Controller	-
1	Inverter	500 W
System		
1	Raspberry Pi 4	4GB RAM
1	Arduino Uno	Version R3
2	SPDT Relay	4 SRD-05VDC-SL-C
1	Waterproof Enclosure Box	Plastic
1	pH sensor	pH 4502c

1	TDS sensor	Gravity: Analog TDS Sensor
1	Water temperature sensor	DS18B20
1	Temperature and humidity sensor	DHT22
1	Water level sensor	HCSR04
1	Water sprayer and submersible pump	12 VC 5 A
1	Light intensity sensor	BH1750
3	LED grow lights	Blue and red LED
4	Peristaltic pump	5 VDC 0.5 A
Miscellaneous		
30 30 30	Connecting wires	30cm male-to-male 30cm female-to-male 30cm female-to-female
1	Extension wires	5-10 meters
1	pH up solution	500 mL
1	pH down solution	500 mL
1	Strawberry growth solution A	500 mL
1	Strawberry growth solution B	500 mL
1	Peristaltic pump tube	10 meters
1	Personal Computer (for software)	Any OS

3.2 Greenhouse

Figure 3.1 VSAFS Greenhouse

Step-by-step instructions on how to construct the VSAFS Greenhouse:

- ***Step 1:*** Choose a suitable location where you can build your greenhouse.
- ***Step 2:*** Decide on the size and shape based on your preferences for your greenhouse. Consider factors like available space, your budget, and the types of plants you want to grow. Also, select the materials you want for your greenhouse. In the case of VSAFS, it uses Bamboo as the foundation and net and UV sheet as the cover. You can use any other material base also in your preferences.
- ***Step 3:*** Sketch out a plan of your greenhouse to guide you during construction.

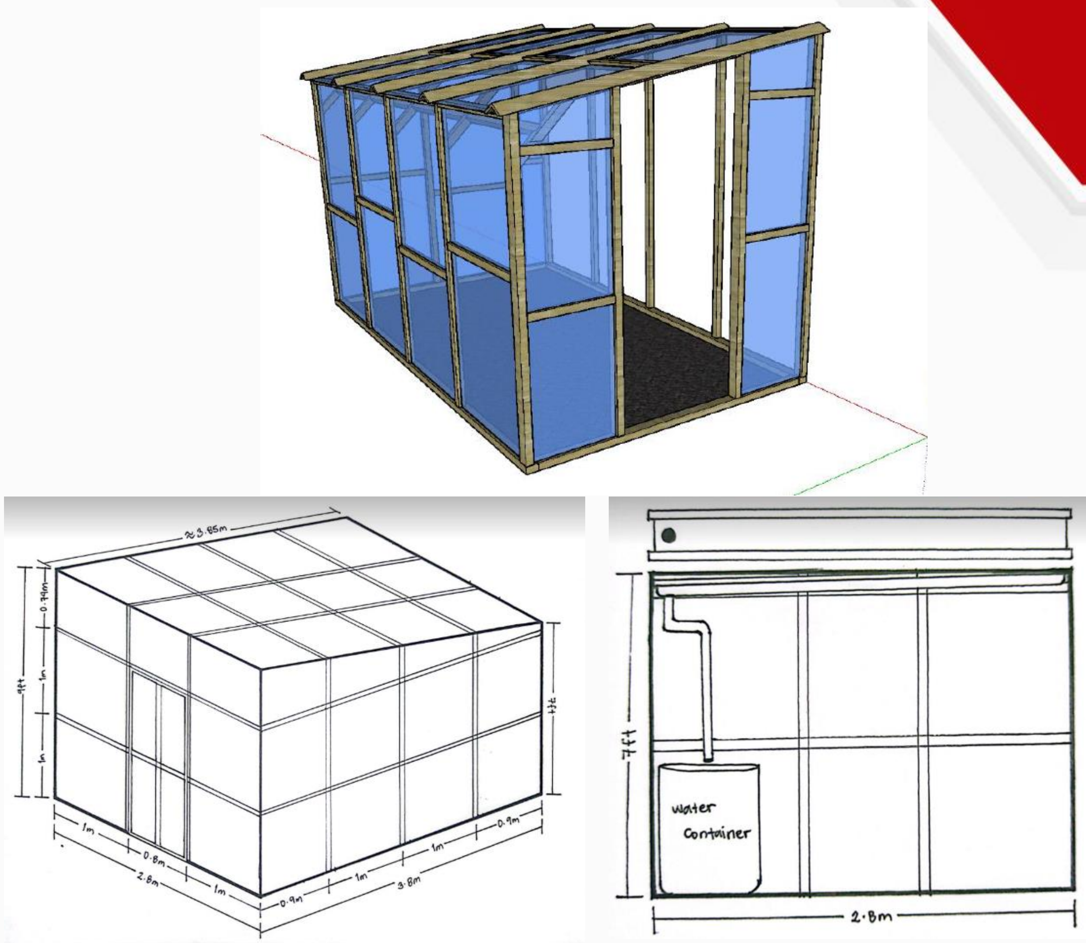


Figure 3.2 VSAFS Greenhouse Sketch

- ***Step 4:*** Prepare the foundation of your greenhouse. Choose the level of your foundation based on the height of your vertical tower. (If you want to use concrete blocks to make it stronger, do as you will)
- ***Step 5:*** Construct the frame of your greenhouse. VSAFS use bamboo and cut into pieces to match the desired lengths. Assemble them according to your design. Use nails or screws to secure the joints. (You can also use stronger materials for the frame of your greenhouse)

- *Step 6:* Install the walls and roofs of your greenhouse. VSAFS uses 60% shade net as the wall and 200 microns UV sheet as the roof of the greenhouse. Cut and securely staple your net and uv sheet based on the area of your walls and roof.
- *Step 7:* Add the door of your greenhouse. Also consider adding a ventilation system, use an exhaust fan and water sprayer to control the temperature and humidity inside your greenhouse.
- *Step 8:* If desired, build benches or shelves inside the greenhouse to provide space for plants and gardening tools. Ensure they are sturdy and capable of supporting the weight of your plants.
- *Step 9:* For the rainwater harvester, use a drain to harvest the rain. To store the rain harvested, use PVC pipe from the drain directed on your water storage. You can use a pale or drum as your water storage.
- *Step 10:* Finally, check for the possible damages during the construction of your greenhouse.

3.3 Vertical Aeroponic Towers

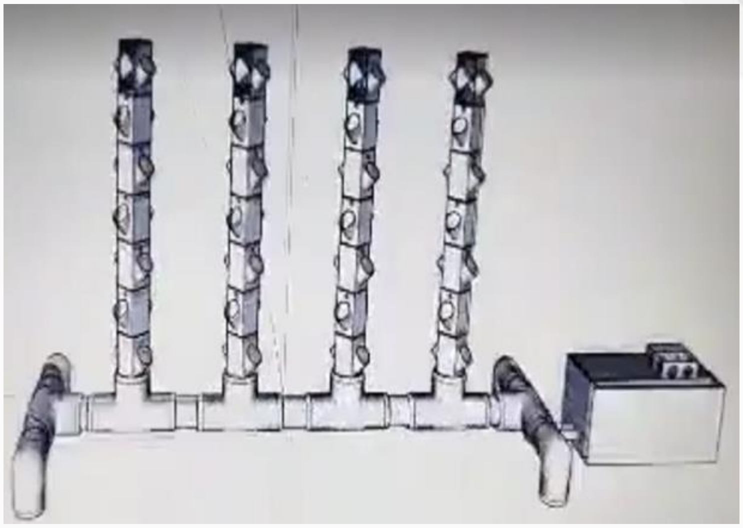


Figure 3.3 Vertical Aeroponic Towers

Step-by-step instructions on how to construct the VSAFS Vertical Aeroponic Towers:

- ***Step 1:*** Design your vertical aeroponic tower. Decide on the size and height of your tower based on the available space in your greenhouse and the plants you want to grow. Refer to Figure 5 to guide you during construction.
- ***Step 2:*** Measure and cut the PVC pipes to desired lengths for vertical sections of the tower. The height of the towers of VSAFS is 6 feet, but you can adjust it based on your preferences.
- ***Step 3:*** Use a saw and heat gun to create 2-inch diameter holes in the PVC pipes where you will insert the net pots. The 2 inches diameter has enough space for strawberry plant growth.
- ***Step 4:*** Assemble the vertical aeroponic tower. Join the PVC pipes using elbows and tees according to the design. Ensure the tower is stable and stands upright.
- ***Step 5:*** Install the water pump. Place a submersible water pump in the reservoir at the base of the tower. Connect the pump to the water sprayer and install it around the towers. The pump will deliver the nutrient solution to the plants through the

tower. The excess solution will be utilized as the tower uses a closed-loop system for it.

- ***Step 6:*** Insert plastic net pots or cups into the holes drilled in the PVC pipes. These will hold your plants and growing medium. Ensure the pots fit securely in the holes and are at a slight angle to allow for proper water flow.

3.4 VSAFS Main Circuit Connection

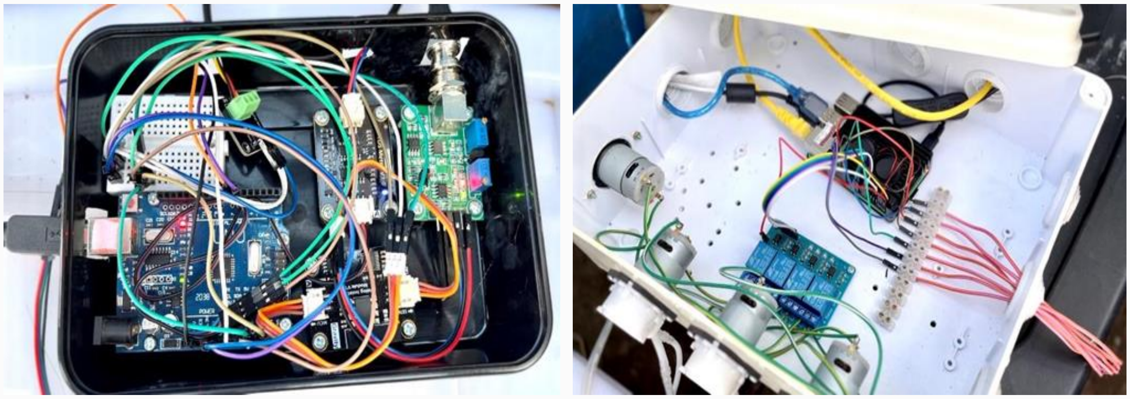


Figure 3.4 VSAFS Main Circuit Connections

Arduino Uno Pin Configuration:

- ***Step 1:*** Connect the VCC pin and ground pin of all sensors to the 5V source pin and ground pin of the Arduino respectively.

Water Level Sensor (HCSR04):

- ***Step 2:*** Connect the trigger pin to the D10 pin of Arduino Uno.
- ***Step 3:*** Connect the echo pin to the D9 pin of the Arduino Uno.

Water Temperature Sensor (DS18B20):

- ***Step 4:*** Connect the DO pin to the D4 pin of the Arduino Uno.

Temperature and Humidity Sensor (DHT22):

- ***Step 5:*** Connect the OUT pin to the D2 pin of the Arduino Uno.

Light Intensity Sensor (BH1750):

- ***Step 6:*** Connect the SDA pin to the A4 pin of the Arduino Uno.
- ***Step 7:*** Connect the SCL pin to the A5 pin of the Arduino Uno.

TDS Level Sensor (Gravity: Analog TDS Sensor):

- ***Step 8:*** Connect the A pin to the A1 pin of the Arduino Uno

pH Level Sensor (pH4502c):

- ***Step 9:*** Connect the PO pin to the A0 pin of the Arduino Uno.

Sensor Setup:

- ***Step 10:*** Place the probes of pH sensor, TDS sensor, and water temperature sensor slightly submerged in the nutrient solution. (Note: Don't set up the pH sensor beside the TDS sensor. TDS sensors generate electricity when acquiring the tds value of the nutrients solution that can cause the fluctuation of pH sensor reading.)
- ***Step 11:*** Place the water level sensor attached to the reservoir's lid facing the nutrient solution.
- ***Step 12:*** Place the light intensity sensor and DHT22 in a secure place to monitor the environmental parameters inside the greenhouse.

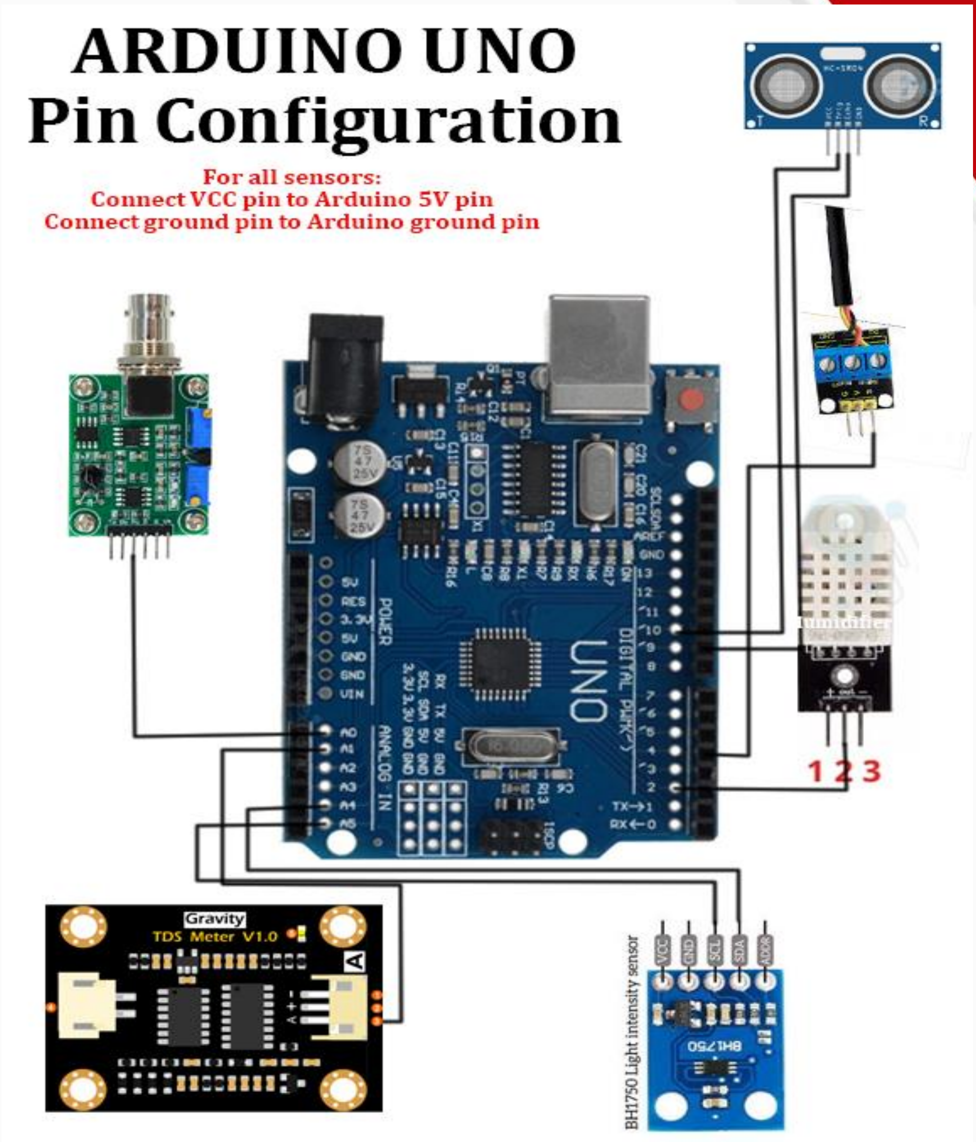


Figure 3.5 Arduino Uno Pin Configuration

Raspberry Pi (RPI) 4 Pin Configuration:

- ***Step 1:*** Connect a power source to the power supply USB port of the RPI 4.
- ***Step 2:*** Connect the VCC pin and COM pin of relays 1, 4, 6, and 7 to the 5V source pin RPI 4. For relays 3 and 5, connect the COM pin to an AC source. Relay 2 COM pin is connected to a 12V source.
- ***Step 3:*** Connect the ground pin of all relays to the ground pin of RPI 4.
- ***Step 4:*** Connect the IN pin of the relays to the following RPI 4 pin:

Relay 1 - pin 8

Relay 2 - pin 21

Relay 3 - pin 16

Relay 4 - pin 23

Relay 5 - pin 20

Relay 6 - pin 25

Relay 7 - pin 24

- ***Step 5:*** Connect the NO pin of the relay 1, 4, 6 and 7 to the positive pin of the respective pump of each relay.
- ***Step 6:*** Connect the ground pin of all pumps to the ground pin of RPI 4.
- ***Step 7:*** Connect the Inward tube of pumps to the following:

Pump 1 - Solution B

Pump 2 - pH up

Pump 3 - Solution A

Pump 4 - pH down

- ***Step 8:*** Connect the outward tube of pumps to the nutrient solution in the reservoir.
- ***Step 9:*** Connect the IN pin of the following relays to the respective actuators:

Relay 2 - Water sprayer

Relay 3 - Humidifier

Relay 5 - LED grow lights

- ***Step 10:*** Connect the other wire of the other actuators to the AC source to complete the circuit.

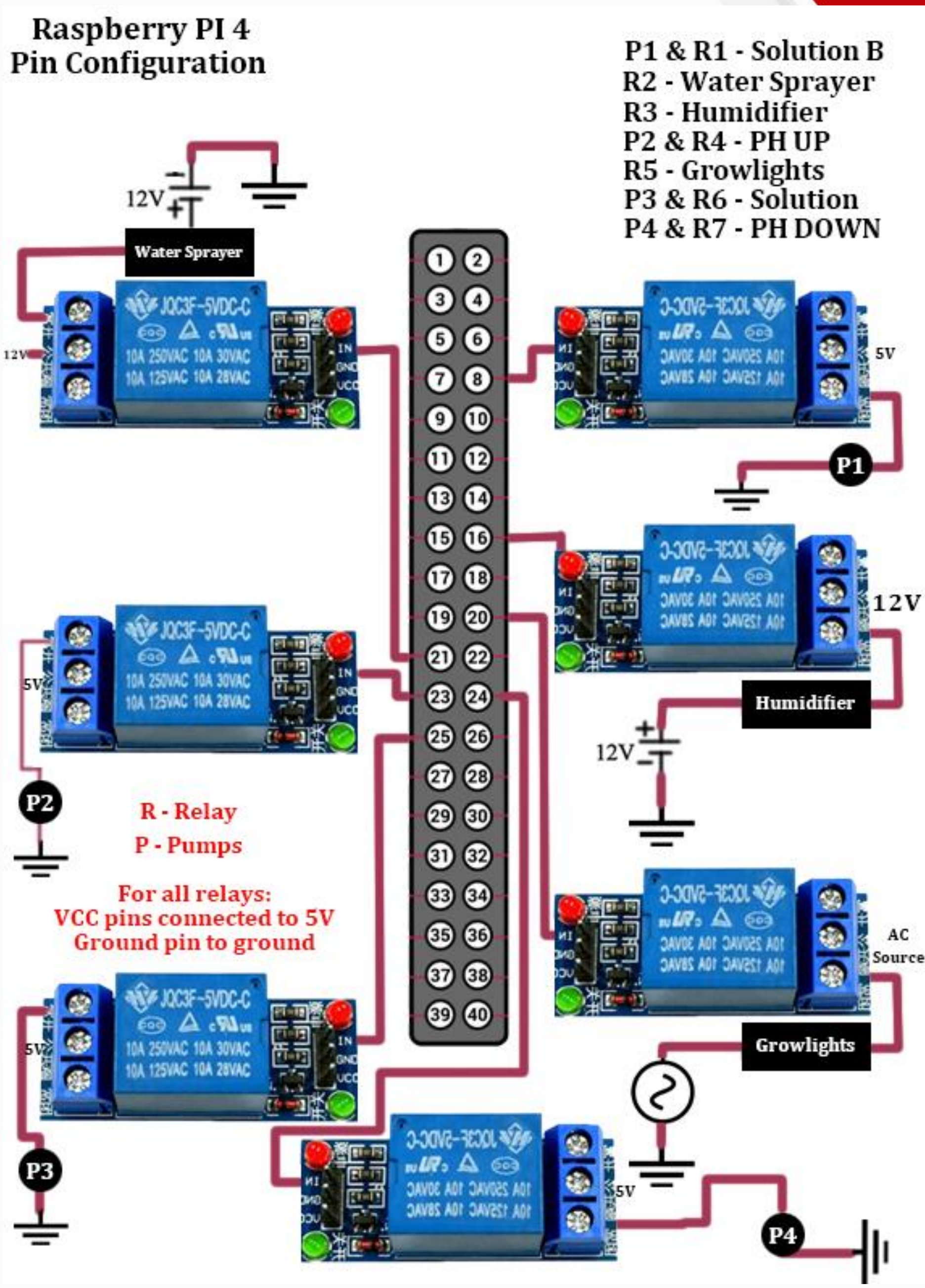


Figure 3.6 Raspberry Pi 4 Pin Configuration

4. SOFTWARE

4.1 System Software

Arduino Uno Sensor:

- ***Step 1:*** Using Arduino IDE, replicate the Arduino Uno Sensor Code in the source code section. If you haven't already, download and install the Arduino IDE from the official Arduino website (https://www.arduino.cc/en/software). Choose the appropriate version for your operating system.
- ***Step 2*****:** Connect your Arduino Uno board to your computer using a USB cable. Ensure that the board is properly recognized, and drivers are installed if required.
- ***Step 3:*** Click on the "Verify" button (checkmark icon) or go to "Sketch" -> "Verify/Compile" to compile your code. The IDE checks for syntax errors and ensures that the code is compatible with the Arduino board.
- ***Step 4:*** From the "Tools" menu, select the appropriate board and port. Choose "Arduino Uno" from the "Board" submenu. Then, select the correct port under the "Port" submenu. If you're unsure, check the port in the "Device Manager" (Windows) or "System Report" (Mac) when the Arduino Uno is connected.
- ***Step 5:*** Click on the "Upload" button (right arrow icon) or go to "Sketch" -> "Upload" to upload the code to the Arduino Uno board. The IDE will compile the code again and then transfer it to the board. You will see the upload progress in the bottom status bar.
- ***Step 6:*** After the code is uploaded successfully, you should see the message "Done uploading" in the status bar. This indicates that the code has been transferred to the Arduino Uno.

Bayesian Inference Script:

- ***Step 1:*** Git clone the repository https://gitlab.com/crizar03/bayesianwekathesis.git. Edit all the necessary data paths and information inside the Arffdata.py and WekaPred.py
- ***Step 2:*** Run the script aeroponics_bayes.py, this can be done using cron

  "crontab -e "

  The command is provided below"

  */5 * * * * python3 "/path/to/aeroponics_bayes.py"

  Then save the crontab by pressing "ESC" then ":wq"

4.2 Web User Interface

Mycodo Environmental Monitoring and Regulation System:

- ***Step 1:*** To create the Mycodo Environmental Monitoring and Regulation System, you need the following:
  - SBC (Raspberry Pi, any version: Zero, 1, 2, 3, or 4)
  - Debian-based operating system
  - An active internet connection
- ***Step 2:*** Once booted and logged in, run the following command to initiate the Mycodo install:

  "curl -L https://kizniche.github.io/Mycodo/install | bash"
- ***Step 3:*** After installation, open a web browser to the SBC's IP address and you will be prompted to create an Admin user and login

  https://127.0.0.1

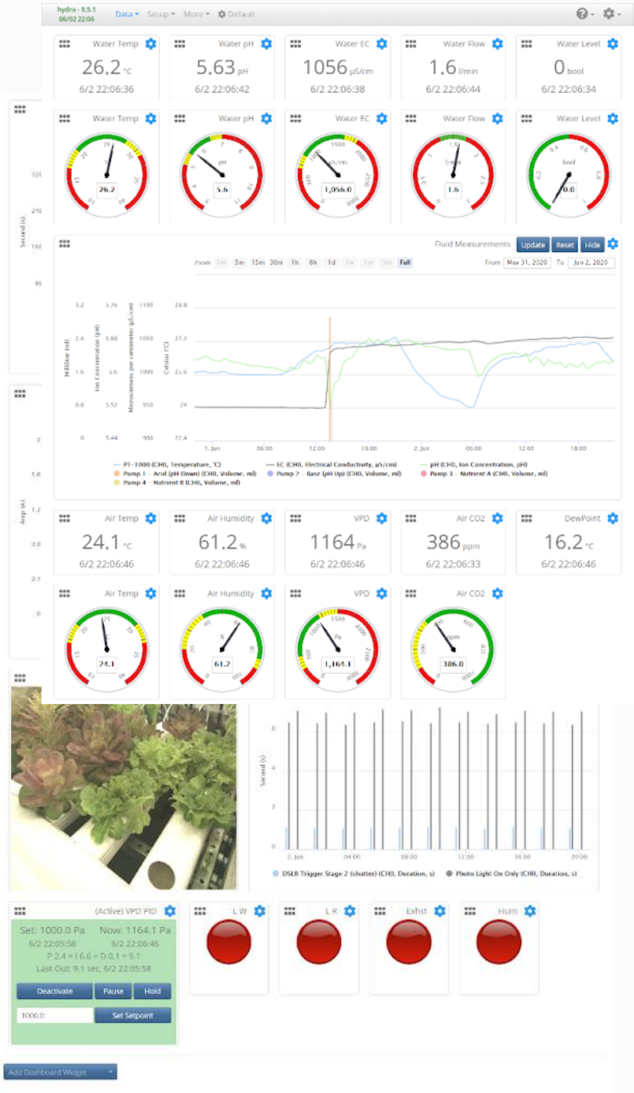
- *Step 4:* After creating an Admin user, add the widgets and graphs needed for your system. (Note:Visit the official Mycodo Documentation page for more information such as features, screenshots, and other information: https://kizniche.github.io/Mycodo/)

Configuring Mycodo:

- *Step 5:* Adding and Configuring Inputs. After logging in, ensure that the Arduino is connected to the Raspberry Pi via USB Serial.
- *Step 6*: Navigate to the Setup -> Data page and use the drop-down menu to search for the Python code and add them
- *Step 7:* Edit the Python code input to read the data from the Arduino (Check the sample Python code for reading data sent by the Arduino on the source code section)
- *Step 8:* Adding and Configuring Outputs. Navigate to the Setup -> Output page and add four "ON/OFF GPIO" and four "Generic Peristaltic Pump". Set the Pin (GPIO) for each On/Off Output and the Peristaltic Pump to the pins you connected in the pin configuration earlier.
- *Step 9:* Automation. Navigate to Setup -> Function and Add Conditional and Trigger Function per your needs. Visit the Mycodo Documentation for more information about the Conditional and Trigger Functions.
- *Step 10:* Adding and Configuring a Dashboard. On the Data -> Dashboard page, there are many types of widgets that can be added, organized by dragging and resized. The possible most useful widget is the Graph. Graphs allow you to select any number of Inputs, Outputs, PID controllers, and other measurements to be

displayed on a historical graph. Graphs are updated automatically with new data, so you always see the latest measurements. There are also a number of settings to tune the graph to your liking, including the x-axis duration, series colors, and range selector, among others. You can also create multiple dashboards to organize different views, or to prevent one dashboard from becoming too cluttered. I won't go into too much detail here, but suffice to say, configuring a dashboard and exploring the various widgets is one of the more fun experiences in Mycodo.

Below is the sample screenshot of the Dashboard,



5. SOURCECODE

5.1 Sensor Arduino Code

```
//Libraries
#include <EEPROM.h>
#include "GravityTDS.h"
#include <Adafruit_Sensor.h>
#include <DHT.h>
#include <DHT_U.h>
#include <Wire.h>
#include <BH1750.h>

//Set Up
//For EC Sensor
#define TdsSensorPin A1
GravityTDS gravityTds;

float temperature = 25,tdsValue = 0;

//For DHT 22 Sensor
#define DHTPIN 2
#define DHTTYPE   DHT22

DHT_Unified dht(DHTPIN, DHTTYPE);
uint32_t delayMS;

//For Light
BH1750 GY30;

//For pH Sensor
#define SensorPin A0
unsigned long int avgValue;  //Store the average value of the sensor feedback
float b;
int buf[10],temp;

//For Light Intensity Sensor
int light = 8;

//For millis() every sensor
unsigned long prevTime_EC = millis();
```

```
unsigned long prevTime_DHT = millis();
unsigned long prevTime_WATERLEVEL = millis();
unsigned long prevTime_pH = millis();
unsigned long prevTime_LIGHT = millis();
long interval_SENSOR = 1000;

void setup()
{
	Serial.begin(115200);
	Serial.println("Ready");

	//For EC Sensor
	gravityTds.setPin(TdsSensorPin);
	gravityTds.setAref(5.0);  //reference voltage on ADC, default 5.0V on Arduino UNO
	gravityTds.setAdcRange(1024);  //1024 for 10bit ADC;4096 for 12bit ADC
	gravityTds.begin();  //initialization

	//For DHT 22 Sensor
	dht.begin();
	sensor_t sensor;
	dht.temperature().getSensor(&sensor); //get temperature value
	dht.humidity().getSensor(&sensor); //get humidity level value
	delayMS = sensor.min_delay / 1000;

	//For Light Intensity Sensor
	Wire.begin(); // Initialize the I2C bus for use by the BH1750 library
	GY30.begin(); // Initialize the sensor object
}

void loop()
{
	unsigned long currentTime = millis();

	//For EC Sensor
	if (currentTime - prevTime_EC > interval_SENSOR)
	{
	gravityTds.setTemperature(temperature);  // set the temperature and execute temperature compensation
	gravityTds.update();  //sample and calculate
```

```
tdsValue = gravityTds.getTdsValue();  // get and print the ec value
Serial.print("EC Level: ");
Serial.print(tdsValue,0);
Serial.println(" ppm");

prevTime_EC = currentTime;
}

//For DHT 22 Sensor
if (currentTime - prevTime_DHT > interval_SENSOR)
{
delay(delayMS); // Delay between measurements.
sensors_event_t event;
dht.temperature().getEvent(&event); // Get temperature and print its value.
Serial.print(F("Temperature: "));
Serial.print(event.temperature);
Serial.println(F(" °C"));
dht.humidity().getEvent(&event); // Get humidity level and print its value.
Serial.print(F("Humidity: "));
Serial.print(event.relative_humidity);
Serial.println(F(" %"));

prevTime_DHT = currentTime;
}

//For Waterlevel Sensor
if (currentTime - prevTime_WATERLEVEL > interval_SENSOR)
{
int sensor=analogRead(A3);
Serial.print("Water Level: ");
Serial.println(sensor);

prevTime_WATERLEVEL = currentTime;
}

//For pH Sensor
if (currentTime - prevTime_pH > interval_SENSOR)
{
for(int i=0;i<10;i++)          //Get 10 sample value from the sensor for
smooth the value
```

```
{
buf[i]=analogRead(SensorPin);
delay(10);
}
for(int i=0;i<9;i++)     //sort the analog from small to large
{
for(int j=i+1;j<10;j++)
{
if(buf[i]>buf[j])
{
temp=buf[i];
buf[i]=buf[j];
buf[j]=temp;
}
}
}
avgValue=0;
for(int i=2;i<8;i++)                      //take the average value of 6 center sample
avgValue+=buf[i];
float phValue=(float)avgValue*5.0/1024/6; //convert the analog into millivolt
phValue=3.5*phValue;                      //convert the millivolt into pH value
Serial.print("pH: ");
Serial.print(phValue,2);
Serial.println(" ");

prevTime_pH = currentTime;
}

//For Light Intensity Sensor
if (currentTime - prevTime_LIGHT > interval_SENSOR)
{
float lux = GY30.readLightLevel(); // read the light level from the sensor and store it in a variable
Serial.print("Light Intensity Level: ");
Serial.print(lux);
Serial.println(" lx");

prevTime_LIGHT = currentTime;
```

```
	}
}
```

5.2 Bayesian Interface Python Code

```
WekaPred.py
from weka.core.converters import Loader
from weka.classifiers import Classifier
from weka.classifiers import Evaluation
from weka.classifiers import PredictionOutput
from wekaClassAttrib import ph,wt,tds
import wekaexamples.helper as helper
import csv

def main():
	global predVal_ph, predVal_tds, predVal_wt, predVal_at, predVal_ah
	# Load Data DIR
	data_dir1 = "/home/cfirme/Documents/bayesianwekathesis/pythonScripts/"
	test_dir = "/home/cfirme/Documents/bayesianwekathesis/pythonScripts/"

	loader = Loader(classname="weka.core.converters.ArffLoader")

	# Train Data
	data_tds = loader.load_file(data_dir1 + "traindata.arff", class_index="third")
	data_ph = loader.load_file(data_dir1 + "traindata.arff", class_index="first")

	# Test Data
	test_tds = loader.load_file(test_dir + "testdata.arff", class_index="third")
	test_ph = loader.load_file(test_dir + "testdata.arff", class_index="first")

	# Build Classifier
	cls_tds = Classifier(classname="weka.classifiers.bayes.NaiveBayes")
	cls_ph = Classifier(classname="weka.classifiers.bayes.NaiveBayes")
	cls_tds.build_classifier(data_tds)
	cls_ph.build_classifier(data_ph)

	# Data Evaluation
```

```
    helper.print_title("Evaluating BayesNet classifier on pH, TDS, watertemp, airtemp, airhumid")
    pred_outputph = PredictionOutput(classname="weka.classifiers.evaluation.output.prediction.PlainText")
    pred_outputtds = PredictionOutput(classname="weka.classifiers.evaluation.output.prediction.PlainText")
    evaluation_ph = Evaluation(data_ph)
    evaluation_tds = Evaluation(data_tds)
    evl_ph = evaluation_ph.test_model(cls_ph, test_ph, output=pred_outputph)
    evl_tds = evaluation_tds.test_model(cls_tds, test_tds, output=pred_outputtds)
    print("prediction output:\n" + str(pred_outputph))
    print("prediction output:\n" + str(pred_outputtds))

    lst_ph = int(evl_ph)
    predVal_ph = ph[lst_ph]
    lst_tds = int(evl_tds)
    predVal_tds = tds[lst_tds]

def predval_values():
    with open('/home/cfirme/Documents/bayesianwekathesis/aeroponics_pred.csv', 'w') as header:
    writer = csv.writer(header)
    writer.writerow([predVal_ph, predVal_tds])
    print("Predicted Values: {0},{1}\n".format(predVal_ph, predVal_tds))
```

5.3 Python Read Serial Code

```
import serial

# Configure the serial connection
arduino_port = '/dev/ttyUSB0'  # Replace with your Arduino port
baud_rate = 9600  # Replace with your Arduino baud rate

# Create a serial object
ser = serial.Serial(arduino_port, baud_rate)

while True:
```

```
    # Read the data from Arduino
    data = ser.readline().decode().strip()

    # Split the data into separate values
    values = data.split(',')

    # Check if all 6 values are received
    if len(values) == 6:
        # Process the values as needed
        value1 = float(values[0])
        value2 = float(values[1])
        value3 = float(values[2])
        value4 = float(values[3])
        value5 = float(values[4])
        value6 = float(values[5])

        # Print the values
        print(f"Value 1: {value1}")
        print(f"Value 2: {value2}")
        print(f"Value 3: {value3}")
        print(f"Value 4: {value4}")
        print(f"Value 5: {value5}")
        print(f"Value 6: {value6}")

# Close the serial connection
ser.close()
```