Faculty of Electronic and Computer Technology and Engineering

DEVELOPMENT OF A ROBUST AUTOMATED HYDROPONIC SYSTEM BASED ON MESH NETWORK AND ARTIFICIAL INTELLIGENCE

NAVIN RAJ A/L SARAVANAN

Bachelor of Electronics Engineering Technology (Telecommunications) with Honours

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DEVELOPMENT OF A ROBUST AUTOMATED HYDROPONIC SYSTEM BASED ON MESH NETWORK AND ARTIFICIAL INTELLIGENCE

NAVIN RAJ A/L SARAVANAN

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Supervisor Name	:	Dr Adam Wong Yoon Khang
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ABSTRACT

In today's globalized landscape, technological strides have revolutionized agriculture, prompting a shift from traditional methods to innovative solutions In response to overcome the challenges of achieving optimal growth conditions, resolving inconsistent crop tracking in hydroponics, and ensuring resilient hydroponic system node redundancy, this project establishes a comprehensive framework. The primary objectives include the implementation of Artificial Intelligence for tracking and analyzing crop growth rates through sensor parameters, enhancing communication efficiency within the mesh network, and implementing a remote control system for precise and adaptive watering in the hydroponic system. The method involves ESP32 nodes connecting to the mesh network and subsequently to the Raspberry Pi 4 via Wi-Fi, enabling wireless communication. Utilizing MQTT protocol, the nodes transmit water level and crop height data, ensuring redundancy in case of node failure. The Raspberry Pi 4 monitors water levels and triggers alerts through the Blynk application, activating the water pump to maintain optimal conditions. Data is stored in a CSV file, compiled using Python, and imported into MATLAB to generate a predictive model using Neural Network algorithms. Results from the prediction model, including RMSE: 0.51387, R-squared: 0.35, MSE: 0.26407, and MAE: 0.34951, indicate improved predictive accuracy. The Blynk application provides real-time monitoring, offering users insights into the hydroponic system's status. This comprehensive approach bridges the gap between identified problems and innovative solutions, contributing to the advancement of efficient and resilient hydroponic systems.

ABSTRAK

Dalam landskap global hari ini, kemajuan teknologi telah merevolusikan pertanian, mendorong peralihan daripada kaedah tradisional kepada penyelesaian inovatif Sebagai tindak balas untuk mengatasi cabaran untuk mencapai keadaan pertumbuhan optimum, menyelesaikan penjejakan tanaman yang tidak konsisten dalam hidroponik, dan memastikan lebihan nod sistem hidroponik yang berdaya tahan, projek ini mewujudkan rangka kerja yang komprehensif. Objektif utama termasuk pelaksanaan Kepintaran Buatan untuk menjejak dan menganalisis kadar pertumbuhan tanaman melalui parameter sensor, meningkatkan kecekapan komunikasi dalam rangkaian mesh, dan melaksanakan sistem kawalan jauh untuk penyiraman yang tepat dan adaptif dalam sistem hidroponik. Kaedah ini melibatkan nod ESP32 yang menyambung ke rangkaian mesh dan seterusnya ke Raspberry Pi 4 melalui Wi-Fi, membolehkan komunikasi tanpa wayar. Menggunakan protokol MQTT, nod menghantar data paras air dan ketinggian tanaman, memastikan lebihan sekiranya berlaku kegagalan nod. Raspberry Pi 4 memantau paras air dan mencetuskan amaran melalui aplikasi Blynk, mengaktifkan pam air untuk mengekalkan keadaan optimum. Data disimpan dalam fail CSV, disusun menggunakan Python, dan diimport ke MATLAB untuk menjana model ramalan menggunakan algoritma Rangkaian Neural. Keputusan daripada model ramalan, termasuk RMSE: 0.51387, R-kuadrat: 0.35, MSE: 0.26407, dan MAE: 0.34951, menunjukkan ketepatan ramalan yang lebih baik. Aplikasi Blynk menyediakan pemantauan masa nyata, menawarkan pandangan pengguna tentang status sistem hidroponik. Pendekatan komprehensif ini merapatkan jurang antara masalah yang dikenal pasti dan penyelesaian inovatif, menyumbang kepada kemajuan sistem hidroponik yang cekap dan berdaya tahan.

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CHAPTER 1

INTRODUCTION

1.1 Background

The great majority of the world's food supply is produced through agriculture, which is the practice of farming which includes the cultivation of soil to yield crops and foods. It has only been largely accepted for 7000 years, but it has been performed irregularly over the past thousands of years. In this brief existence, agriculture has completely altered human society and sustained the ever-expanding global population that has increased exponentially in recent years [1]. However, in the past 50 years of Malaysia's agriculture has increased dramatically at the expense of the environment and sustainable development due to the many challenges that have emerged in the recent years. The current agricultural model can no longer fulfill the demands of ensuring food security and the sustainability of the agriculture development. Challenges such as worsening soil quality, climate changes and the usage of harmful substances such as herbicides and pesticides have positioned the agriculture sector against the threatening situation that it is facing now. According to the United Nations, approximately 9 percent of the global population faces hunger and an estimated around 840 million will experience food security by the year 2030 [2].

The hydroponic system is the best solution to counter this issue of food security and safety. Hydroponic system is the cultivation of crops without the need for soil as a medium. In organic farming and conventional farming, when a crop grows in a soil, the roots are always searching for adequate nutrition and water source to support the growth of the crops. If the plant's root system has direct exposure to the water source and nutrition, the crops does not have to use up any of its energy in finding its necessity and concentrate that energy in sustaining itself. This system promises the acceleration of growth among the crops, produces stronger yields of excellent quality crops. Moreover, the crops do not need soil to undergo the process of photosynthesis, thus eliminating soil from the equation of farming does not affect the growth of crop. However, before implementing the hydroponic system, a few procedures should be carried out to prepare a hydroponic system which would ensure the crops grow at the best rate and with good quality.

1.2 Global and Societal Issues

This project can address some societal and global issues that the world has been facing in recent years. Firstly, this project offers the perfect combat strategy for the uprising climate changes that we are experiencing in our daily life in recent years. Human activities such as burning of fossil fuels, deforestation and smoke and fumes from vehicles and factories increase the greenhouse effect and simultaneously raise the surface temperature of Earth. This affects the crops grown in the traditional farming to wilt due to the high temperatures that burns the leaves and the cellular system of the plant [3]. The hot temperatures also result in the water under the surface of Earth drying up at a faster rate than usual. This results in the roots of the plants to find and receive less water and if last long, the plants would wilt and die. Since the plants are grown in a closed and controlled environment, they are exposed to a perfect environment that enables them to grow and produce high quality vegetations which is nutritious and healthy to consume.

Next, this project also addresses societal and global issues in the aspect of natural resources by reducing environmental damage and the extinction of species and habitats. To increase the yield of plants and vegetations, more acres of land are required for them to be planted and grown. The life force, many forests which are habitats to many species of animals and the life of the creatures are lost due to over-exploitation of lands and intensive farming [4]. However, for this project, there is no soil or land required to grow the plants, but they only require the water source for them. In addition, the consumption of water in this project is much lesser than that of conventional farming since the water is recirculated and recycled.

Finally, this project can also address the social and global issues of consumers health by enhancing food safety. This is because of the establishment of this project is in a closed space, the seedlings are not exposed to pests and wildlife creatures which would bring in the need of using pesticides and herbicides which will affect the quality and nutritious level of the plants [5]. Adding these pesticides and herbicides can prevent the pest infestations from occurring but at the same time, they put consumer's health and safety at risk if they were to be consumed. Thus, this project ensures the yield and production of excellent vegetations which inhibits good taste, nutritious and healthy.

1.3 Problem Statement

In a hydroponic system, crops grow at a much faster rate and produce yields with excellent quality when compared to the traditional farming method using soil. However, the crops in the system must be exposed to the suitable parameters of the sensor to ensure that the crops will grow and yield excellent quality crops [6]. The progress and the growth of the crops in the hydroponic was monitored manually, but it was not the most effective method since the farmers would not be able to monitor the crops 24/7. Therefore, Artificial Intelligence is roped into the hydroponic system to observe and analyze the growth of the crops throughout their growth cycle on a regular basis.

Next, the construction and the configuration of the hydroponic system is important in the system operating effectively and efficiently. A robust hydroponic system shall be constructed and configured so that if one of the nodes is damaged, it will not ruin the whole hydroponic system [7]. Thus, a mesh configuration is implemented to improve the point-to-point communications between the IoT devices in the system. Mesh network allows the IoT devices to effectively communicate with one another to establish a reliable system that can adapt to the different changes in the environment and provides a better control system for the hydroponic system to operate well.

Finally, the challenge of farming and harvesting the crops consistently in the next cycles are difficult to track. It will be more difficult to analyze multi-farming hydroponic system which requires analyzing the growth rates of different crops which have different requirements [8]. Thus, the operation of the Artificial Intelligence powered hydroponic system relies heavily on the AI monitoring the growth of the crops and it involves collecting data, preprocessing the data, developing machine learning modules which is an application of Artificial Intelligence. These trained models can be used in monitoring the growth of crops in the next cycles to set a threshold if the growth of the crops is deviating from its previous cycle or if it continuously improves over time.

1.4 Project Objective

The objective of the project is to:

a) To implement Artificial Intelligence in tracking and analyzing the crop growth rates using the parameters of the sensors.

b) To enhance the efficiency and reliability of communication between devices within the mesh network.
c) To implement a remote controlling system for precise and adaptive watering delivery in the hydroponic system.

1.5 Scope of Project

The scope of research for the project is made to inform the features and components used in carrying out this project. Among the scope of this project is the utilization of Raspberry Pi 4 Model B microcontroller as the brain behind the computational tasks for the performance of the hydroponic system which is based on mesh configuration and Artificial Intelligence. Additionally, the hydroponic system is equipped with various sensors that will help to detect and track the various anomalies of many factors that will affect the yield and growth of the crops. The sensors that are used in this project are a water level sensor and ultrasonic sensor. The water level sensor is to detect the amount of water. The ultrasonic sensor is to detect and track the growth rate of the crop. The data and parameters from these sensors are linked together via Internet of Things (IoT) and are sent to the ESP32 microcontroller which will function as sensor nodes. Furthermore, Prediction Model is trained and generated which will be incorporated using the MATLAB Software and the IoT Connectivity is displayed via the Blynk application in real-time by connecting to the Wi-Fi. Furthermore, the Neural Network will play a key role in this project to extract sensor data using the prediction model to make. Finally, the aim of project is to give beneficial keys for the development of the agriculture sector.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Hydroponics is a method of growing crops without the need for soil as a medium, where the crops are instead immersed directly in a nutrient-rich water source. The application of hydroponics has been increasing in popularity in recent years, due to its many benefits, including higher crop yields, quicker growth rates and the capacity to grow crops in locations with poor soil conditions. Traditional hydroponic systems have limitations by their dependency on manual nutrient solutions monitoring and modifications, which can result in irregularities and inefficiencies in crops growth.

There is a rising interest in the creation of more reliable hydroponic systems that use mesh networks and Artificial Intelligence to get beyond these limitations. To maximize crops growth and minimize human errors, these systems can automatically monitor and modify environmental factors such as temperature, humidity, pH level, water level and nutrient levels. According to the research, mesh networks and AI can significantly increase crop yield, quality and resource efficiency when used in hydroponics.

As a result, the design of a more durable hydroponic system based on AI and mesh networks has the potential to revolutionize the agricultural industry and enhance food production in a way that is both efficient and sustainable [9].

2.2 Agriculture Field

Agriculture is the study and practice of raising crops for food, fiber, and other items made from plants. It is essential for sustaining life, boosting economic growth, and addressing issues with global food security. However, there are many challenges the agriculture sector faces that threaten the field itself.

Firstly, climate change is the biggest challenge of the agriculture field. Changing weather patterns and the increment in the frequency of extreme weather around the world and rising temperatures poses threats to agricultural productivity.

Next, limited access to resources is also one of the main challenges faced by the agriculture field and its farmers. They often have limited access to essential resources like land, water, money, and technology which blocks and hinders the productivity of agriculture to fluctuate. The lack of access to these resources can affect the sustainability and the productivity of agriculture.

Then, the list continues with food security and hunger as one of the challenges the world is facing in recent times. Ensuring global food security of the crops cultivated from the agriculture field remains to be a difficult challenge to overcome. The agriculture sector is essential in producing enough nutrient-rich crops to sustain a growing global population.

Finally, a lack of sustainable farming practices poses challenges to the growth of the agriculture field. Environmental damage, soil erosion, water pollution, and the loss of natural resources can all be reduced by promoting and practicing sustainable agriculture practices. Long-term sustainability can be increased by encouraging techniques like organic farming, precision farming, and conservation agriculture [10].

2.3 Hydroponic System

Hydroponic systems are a method of growing crops in a soilless medium where the roots are submerged in a nutrient-rich solution. The system is made to give crops access to all nutrients, water, and oxygen they require for healthy growth. Crops are cultivated in trays or containers that are filled with a growing medium like perlite, coconut coir or rockwool in a hydroponic system. To give the crops the nutrients and water they require, the plants are submerged in a nutrient-rich solution that is pumped through the growing medium. The solution is recirculated to reduce waste and preserve the ideal pH and nutrition levels.

In comparison to conventional soil-based agriculture, the use of hydroponic systems has many benefits, including higher crop yields, faster rates of growth, and the capacity to cultivate crops in locations with poor soil conditions. For instance, based on a study titled, Evaluation of Hydroponic Systems for the Cultivation of Lettuce (Lactuca Sativa L., Var. Longifolia) and Comparison with Protected Soil-based Cultivation, 2020), the study states that hydroponic systems use less water and fertilizers, making them more environmentally friendly and sustainable than conventional agriculture. Hydroponic systems have been effectively utilized to grow several crops, such as lettuce, tomatoes, and strawberries [11].

The DWC systems' setup and design comprises several crucial elements. First, a container for the crops and fertilizers solution is chosen. This container needs to be big enough to hold the crops and leave room for root development. It is frequently enclosed with plastic and is not exposed to direct light source to stop algae growth.

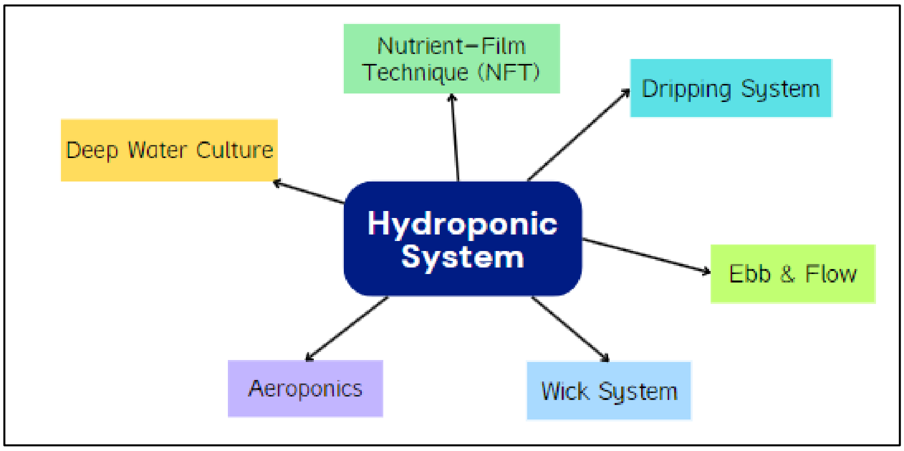

Figure 2.1 Techniques of Hydroponic Systems

In the DWC technique, net pots are essential because they support the crops and permit the roots to freely dangle into the nutrient solution. These containers, which are frequently made of mesh or plastic, offer support, and permit the movement of oxygen around the roots. The net pots are positioned inside the container so that the roots are completely immersed in the nutrient solution.

The DWC setup also includes an aeration system to guarantee optimum oxygenation to the roots. Typically, this system comprises of a tubing, an air pump, and air stones. The roots are kept oxygenated and anaerobic conditions are avoided by the air stones, which the air pump uses to add oxygen to the nutritional solution [12].

A crucial component of the DWC approach is managing the nutrient solution. The correct concentrations of vital nutrients necessary for crop growth are measured and mixed carefully to create the nutritional solution. These nutrients usually include micronutrients (such as iron, zinc, and copper) and macronutrients (such as nitrogen, phosphorus, and potassium) required for a variety of physiological activities. For the crops to absorb nutrients as efficiently as possible, the pH level of the nutrient solution must be kept constant. The pH is frequently modified using pH adjusters or controllers to ensure that it falls within the range for the crops being cultivated. The pH level should be regularly checked and adjusted to help avoid toxicities or nutrient deficiencies [13].

Overall, hydroponic systems are a modern and promising type of farming that have several advantages over conventional soil-based techniques. As a result, they have attracted more attention recently as a method of efficient and sustainable food production.

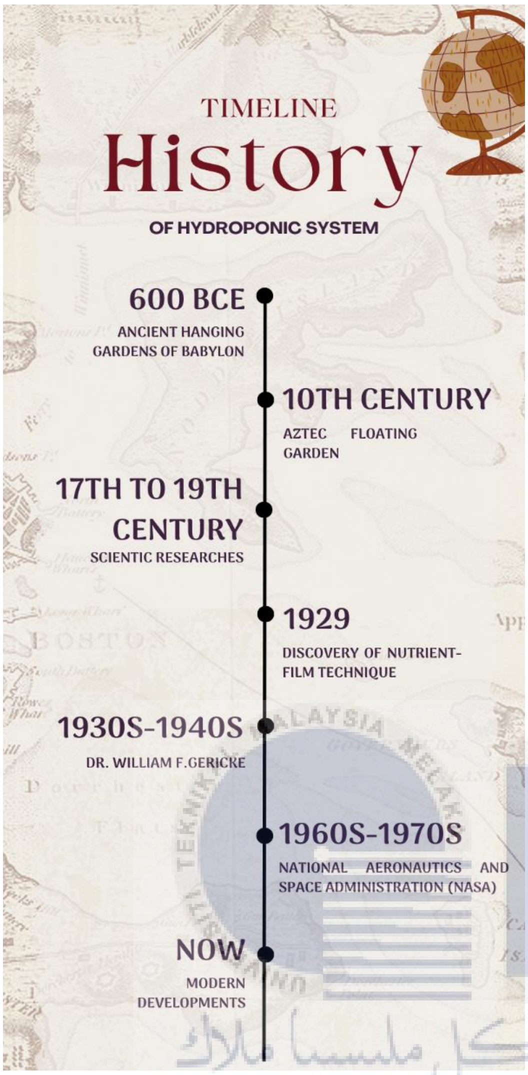

Figure 2.1 shows the history of hydroponics is said to began from 600 BCE itself at Babylon known as the Ancient Hanging Gardens of Babylon. The garden has said to employed an advanced irrigation system to grow crops without soil. Next, in the 10th century, the Aztecs in Mesoamerica developed a system known as "chinampas" which is a floating island used from agriculture and they utilized nutrient-rich water from Lake Texcoco allowing crops to grow hydroponically. Then, in the 17th to 19th century, two researches had been conducted one by a Belgian botanist Jan van Helmont who discovered that plants derive nutrients from water and by German botanist Julius von Sachs and Wilhelm Knop who identified essential mineral

Figure 2.2 History of Hydroponic Systems

nutrients for crop growth. Furthermore, in1929, the Nutrient-Film technique (NFT) was discovered by Dr. Allen Cooper of the University of California, Berkeley. Then, in the 1930s to 1940s, Dr. William F.Gericke who is a professor at the University of California, popularized the term hydroponics and conducted extensive researches. Next, in the 1960s to 1970s, National Aeronautics and Space Administration (NASA) developed the Hydroponic wick system which led to advancements in closed-loop systems and controlled environment agriculture [14]. Finally, modern advancements in technology have infused with the application of the hydroponic system. Technologies like automation, sensor integration and precise climate control have advanced hydroponic systems with new emerging techniques such as Deep-Water Culture (DWC), aeroponics and vertical farming [15].

2.4 Advantages and Disadvantages of Hydroponic Systems

Hydroponic systems have many advantages when compared to conventional soil-based agriculture, however there are also some disadvantages to consider.

Firstly, the advantage that the hydroponic system has is increased crop yields. According to a study, hydroponic systems allow for more exact control of nutrient delivery, lighting, and temperature, which can aid the hydroponic system to increase its crop yields.[16].

Then, hydroponic systems are also more efficient resourcefully than conventional methods since they need less water and fertilizers. According to a study, lettuce cultivated hydroponically uses less water and fertilizers and produces fewer greenhouse gases than lettuce grown conventionally [17].

Next, hydroponic systems also allow crops to grow at faster rates with the provision of optimal growing necessities. According to a study, in comparison to the conventional soil-based agriculture, the hydroponic system offers faster growth rates to produce vegetables. This was attributed due to the capacity to precisely regulate the growing conditions that allow the crops to receive the optimal amount of nutrients.[18].

Moreover, using hydroponic systems provides better nutrition management since the systems enable precise nutrient supply control, which can enhance crop health and growth. According to a study, to maximize crop development and fruit quality, the hydroponic system was supplied with accurate and balanced nutrient supplies at all stages of their growth [19].

Finally, hydroponic systems are also pathways to reduced use of pesticides and herbicides. The hydroponic system requires fewer pesticides and herbicides because they are less vulnerable to diseases and pests. The crops grown hydroponically have excellent quality since pest and disease control benefit [20].

However, there are several disadvantages that we must consider in the application of hydroponic systems. Firstly, building a hydroponic system requires a high initial cost due to the requirement for specialized equipment like pumps, grow lights, and nutrient solutions. For small-scale farmers, the upfront cost of installing a hydroponic system can be an obstacle. According to a study, the price of installing a hydroponic system varies depending on the size, complexity, and amount of automation of the system. This expense is greater than that of conventional soil-based techniques, making it a less practical choice for some farmers [21].

Next, a fully functioning hydroponic system requires high energy consumption. Based on a report, hydroponic systems use a lot of energy since they require artificial lighting, heating, and cooling. If these requirements are not met in the system, the crops grown in the hydroponic systems would not be able to develop and grow healthily [22].

Finally, in developing a hydroponic system, technical expertise is necessary to run and maintain hydroponic systems. However, in some areas, this expertise may not be easily accessible. The adoption of hydroponic systems in some areas can be hindered by a lack of technical knowledge in operating and managing the system.

2.5 Artificial Intelligence in Hydroponic Systems

Artificial Intelligence (AI) is subsection of computer science that involves the study of algorithms and systems that carry out operations that ordinarily require human intelligence, such as speech recognition, decision-making and language translation.

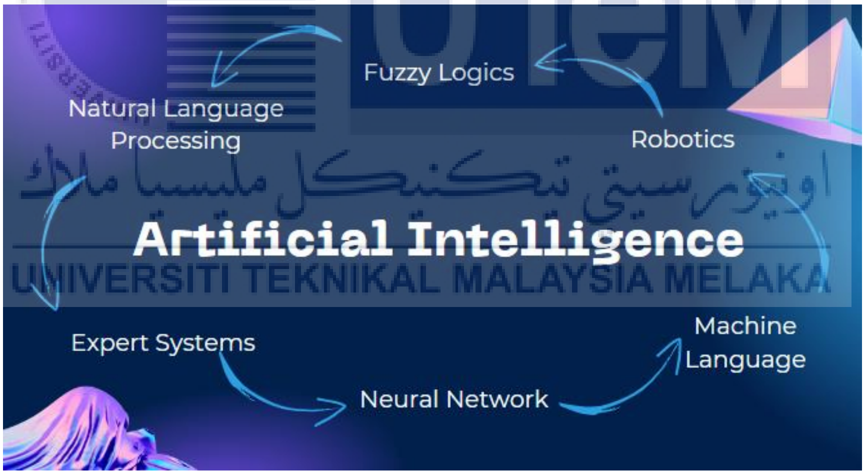

Figure 2.3 Branches of Artificial Intelligence

Figure 2.3 shows the branches of Artificial Intelligence in the current world application. Firstly, Machine Learning (ML) which develops algorithms and models that enable systems to learn from data and improve their performance over time. It can be trained on large datasets to recognize patterns, make predictions, or classify information.

Next, Fuzzy Logic is a branch of AI that deals with reasoning and decision-making in the presence of uncertainty. Unlike traditional logic, which is based on binary true or false values, fuzzy logic allows for partial truths, where the truth value can range between completely true and false.

Then, Natural Language Processing (NLP) involves the interaction between computers and human language, enabling systems to understand, interpret and generate human language. It includes tasks such as speech recognition, language translation, and text generation.

Additionally, Expert systems aim to possess decision-making capabilities of humans. They mainly use a knowledge base, a set of rules and an inference engine to reason or solutions to complex problems.

Furthermore, another branch of AI is Robotics. It refers to the field of robotics that incorporates AI technologies and techniques to enable robots to perform tasks autonomously or with minimal human intervention. AI plays a crucial role in improving the capabilities of robots by enabling them to reason, learn and make decisions based on environment and tasks.

Finally, Neural Network is a branch of AI and is a model inspired by the structure and functionality of human brain neural networks. Neural networks consist of interconnected nodes or artificial neurons that process and transmit information [23].

In this hydroponic system, the Convolutional Neural Network (CNN) is implemented in the prediction model to process and analyze the sensor data and use it to decide or correct the parameters of the system to control any deviations or irregularities.

A study shows that CNN-based approaches detect crop illnesses in the smart hydroponic system with high accuracy. The technology offers real-time disease monitoring capabilities, enabling quick responses. Based on this study, CNN also could effectively analyze video data from cameras in the smart hydroponic system to find crop diseases. It emphasizes the potential for enhancing disease management and enhancing crop health in hydroponic systems by utilizing deep learning techniques [24].

2.6 Benefits of Hydroponic Systems Based on Artificial Intelligence

AI and Machine Learning algorithms are used in real-time by AI-based hydroponic systems to monitor and control the growth environment leading to several benefits.

Firstly, AI-based hydroponic systems can increase crop yields. AI-based hydroponic systems use machine learning and AI algorithms to continuously track and control the growth environment. This enables the system to produce the perfect environment for crop growth by optimizing parameters such as light, temperature, humidity, and nutrient levels. According to a study, the system can control the light intensity they receive based on their growth stage and the time of the day to ensure that crops receive the right quantity of light for photosynthesis. AI-based hydroponic systems can increase crop yields by giving crops the perfect growing circumstances [25].

Next, AI-based hydroponic systems can reduce the consumption of resources. Hydroponic systems are constructed to give crops the water and nutrients they need while using the least amount of electricity, water, and fertilizers. AI and ML are used in AI-based hydroponic systems to track and control growing conditions in real-time, which can reduce the use of resources. According to a study, the system can control the concentration of nutrient solution to deliver the ideal ratio of nutrients to each crop, hence lowering the demand for fertilizers [26].

Then, AI-based hydroponic systems can also enhance sustainability. Meeting the current needs without sacrificing the ability of future generations to meet their own needs is what sustainability is all about. We can grow food in a way that is more environmentally, socially, and economically sustainable by adopting AI-based hydroponic systems. Minimizing resource utilization is one way this system can improve sustainability. Hydroponic systems are a more sustainable way to grow food since they require less water, fertilizer, and electricity. This can help save natural resources and reduce greenhouse gas emissions. Additionally, AI-based hydroponic systems can reduce the use of toxic chemicals like pesticides and herbicides. These systems can help diagnose and prevent crop diseases and pests without the use of harmful pesticides by closely monitoring crop growth and reacting to changes in real-time. According to a study, AI enhances sustainability across the agriculture sector since its capabilities include optimization, prediction, and better decision-making for a more sustainable future. [27]

Finally, AI-based hydroponic systems can also carve a path to increased crop diversity. This is since hydroponic systems allow growers from the constraints of preparing and managing the optimal environment for every type of crop individually. Farmers can optimize each crop’s unique requirements for light, temperature, humidity, and nutrient levels by utilizing AI to monitor and control the environment. Furthermore, AI-based hydroponic systems can also be developed to replicate various climatic conditions, such as shifting light intensity, temperature, and humidity, enabling farmers to test out numerous crop varieties in the same system. Based on a study, the researchers studied multiple plant species. By using Artificial Intelligence, it evaluates their growth, nutritional quality, and overall system performance, providing insights into maximizing productivity, sustainability, and the potential benefits of diverse crops in hydroponic systems. [28].

2.7 Review on Existing Systems of Hydroponic Systems Based on Artificial Intelligence

2.7.1 Root AI

The AI-based hydroponic system from Root AI is intended to automate the tomato harvesting process in a greenhouse production environment. The system features a robot named “Virgo” that finds and gathers ripe tomatoes using computer vision and machine learning algorithms. The system is integrated with 3D sensors and cameras to gather information about the crops and their surroundings. The computer vision algorithms of the system then use this data to detect and monitor the development of specific tomato clusters. Then, the system’s algorithms can determine the color changes that occur when the tomatoes have ripened. This enables the system to identify when a cluster of tomatoes are ready to be harvested. When a cluster of tomatoes is detected to be ripe, the robotic arm of the system begins to harvest the tomatoes. The robotic arm is incorporated with a combination of sensors and grippers to pick the tomatoes without damaging them. After each harvest, the system gathers information about the crop’s growth patterns throughout time. The machine learning algorithms of the system then analyze this data to find patterns and trends in crop development and modify the harvesting strategy of the system as necessary. The system has a user interface that enables the farmers to check on the system’s functionality and make any necessary configuration modifications if needed [29].

In summary, the main goal of Root AI’s AI-based hydroponic system is to automate tomato harvesting in greenhouse production and boosting productivity. The system’s data analysis skills allow it to continuously optimize crop development and productivity while its computer vision and machine learning algorithms enable it to identify and harvest ripe tomatoes with a high degree of accuracy.

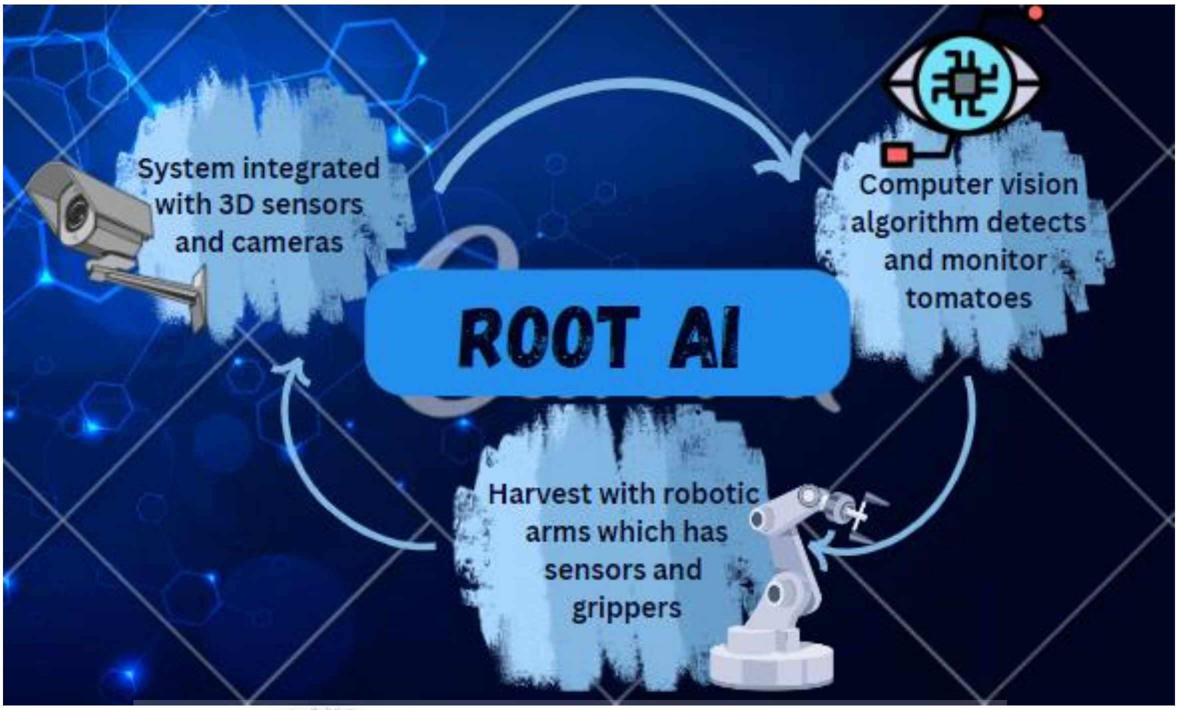

Figure 2.4: The operation of Root AI

2.7.2 Farmbot

Farmbot is an automated, AI-powered, hydroponic precision farming device. The Farmbot uses computer vision to track the development and well-being of crops. It employs cameras to take pictures of crops, which are then analyzed by AI algorithms. This enables the system to identify and treat problems like diseases, pests, and nutrient deficits. Additionally, Farmbot's AI algorithms make use of machine learning strategies. The system can identify patterns and make data-driven decisions by examining the gathered crop data and environmental circumstances. It uses machine learning to personalized guidance and improve crop care procedures. Farmbot automates a variety of hydroponic system chores using AI. Based on the data and analysis produced by the AI algorithms, it can carry out tasks like sowing, watering, fertilizing, weeding, and harvesting. Farmbot's AI algorithms analyze sensor data, including temperature, humidity, and nutrient levels to maximize the effectiveness of the hydroponic system. Farmbot attempts to provide the perfect growth environment for crops, maximizing their yield by continuously monitoring and controlling the parameters [30].

In general, Farmbot uses AI technologies like computer vision, machine learning and automation to track plant health, identify problems, automate farming chores, and enhance hydroponic growing conditions. This makes it possible to cultivate effectively using data, which improves crop yields and reduces resource waste.

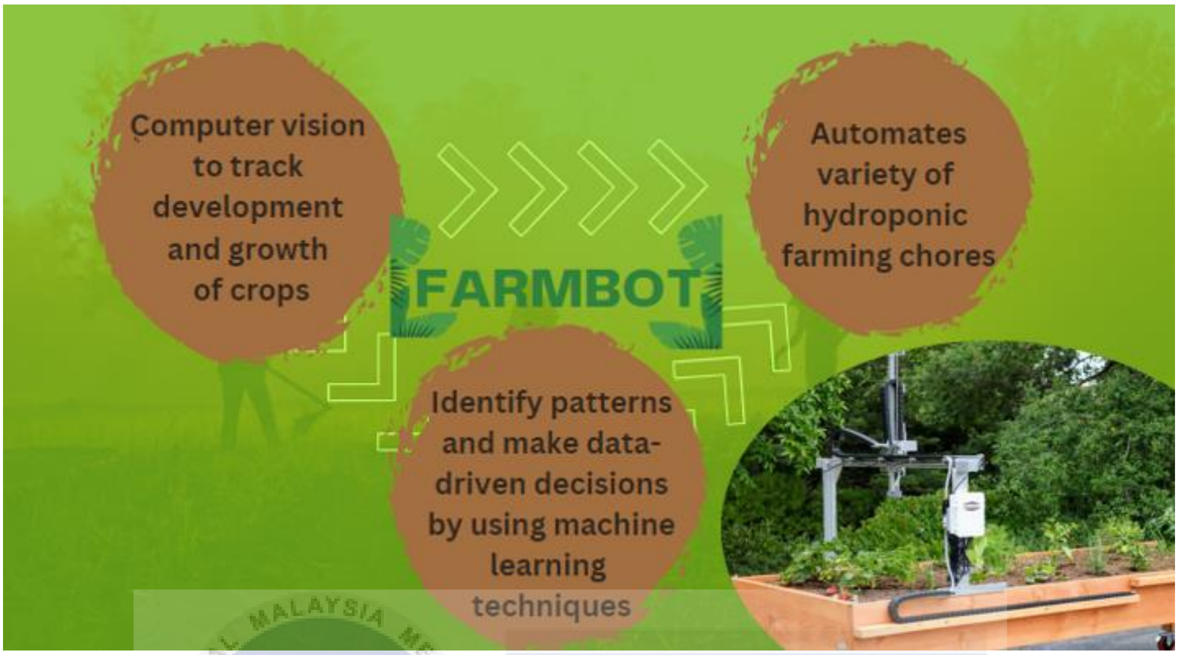

Figure 2.5: The operation of "Farmbot".

2.7.3 Plantix

Plantix is a mobile application that uses AI and machine learning to manage plant disease. Plantix employs computer vision and AI algorithms to diagnose illnesses, pests, and nutrient deficits in crops. The software allows users to snap pictures of the damaged plant sections, and AI technology analyzes the picture to deliver a precise and quick diagnosis. Then, the software also uses deep learning algorithms to identify patterns and traits in photographs of crops. It analyzes the photos with a sizable database of crop diseases and pests to discover the precise problem harming the crops. After analyzing the images, Plantix offers comprehensive details about the found crop diseases, including symptoms, underlying causes, and suggested treatments. The app provides individualized suggestions for managing and controlling the crop issue based on current scientific understanding and industry best practices. Next, Plantix users can monitor the growth and development of their crops through time and keep track of their crop's progress. The software analyzes the development of crops and offers insights into their health and well-being by taking routine images and entering relevant data. A network of crop enthusiasts and experts is fostered by Plantix. Users can interact with one another, share their knowledge about crops and experiences, and ask the community for guidance. Access to a multitude of agricultural information and resources is also made possible through the application. For the purposes of enhancing its AI algorithms and offering helpful information on trends in crop health and disease, Plantix gathers confidential data from user interactions and image data. The application's ability to diagnose diseases is regularly improved with the use of this collected data [31].

In summary, Plantix uses AI and machine learning to help farmers, gardeners and crop enthusiasts accurately identify and treat crop illnesses. The app's AI-based illness recommendations, growth tracking, and community features help users to provide better and more effective crop care.

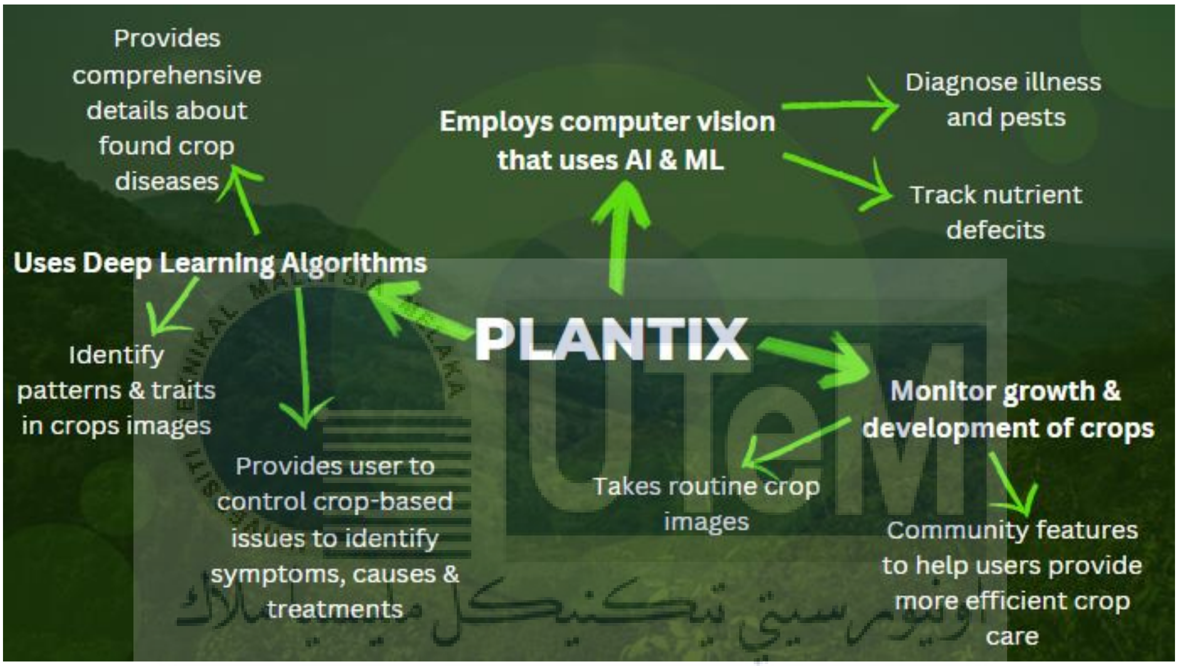

Figure 2.6: Implementation of AI in Plantix mobile application

2.7.4 GreenSense Farm

GreenSense is an organization that uses AI in its hydroponic systems. GreenSense Farms uses AI algorithms to maximize crop growth in hydroponic systems. AI algorithms change ambient conditions in real-time to provide the best conditions for crop growth by analyzing numerous environmental elements like temperature, humidity, carbon dioxide levels, and nutrient concentrations. The goal of this data-driven strategy is to maximize the output and resource effectiveness. At GreenSense Farms, the hydroponic systems are automated using AI. Precision control over factors like lighting, irrigation, and fertlizers supply are made possible by this automation. AI algorithms continuously check and adjust the parameters to give the crops the best environment for growth. GreenSense Farms gather data using sensors installed throughout the hydroponic systems. This data consists of details on nutrient levels, ambient conditions, and crop health. This data is subjected to machine learning algorithms to find patterns and correlations, enabling predictive analytics, and improving decision-making for optimal crop management. GreenSense Farms' AI-based hydroponic systems provide remote management and monitoring. Farmers may obtain real-time information about their crops, get alerts for potential problems, and remotely change system parameters thanks to connected equipment and data analytics. Farmers benefit from the simplicity and flexibility offered by these remote management capabilities. GreenSense Farms use AI to continuously enhance their hydroponic systems. The gathered data and machine learning algorithms allowing for continuous performance analysis, learning, and improvement. Crop yields, resource efficiency, and overall system performance are all improved over time by this iterative process [32].

In summary, GreenSense Farm blends AI technology with hydroponic systems to maximize crop development, automate control systems, making use of sensor data and machine learning, enabling remote monitoring and promote continuous improvement.

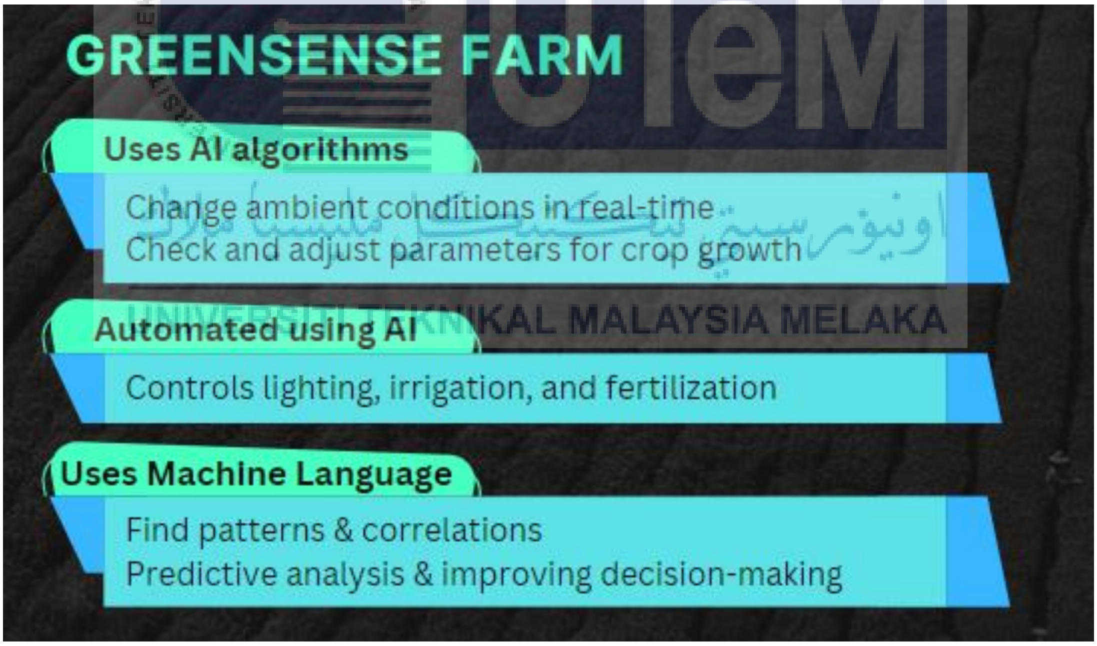

Figure 2.7: AI technologies used by GreenSense Farm

2.8 Mesh Network Concept in Hydroponic Systems

A mesh network is a type of network is a type of network architecture in which numerous devices or nodes are linked together in a topology that resembles a mesh. Multiple communication pathways can be formed between any two nodes in the network by direct connection. This decentralized design features redundancy, self-healing capabilities, and effective data sharing.

A mesh network can be used in the context of hydroponics to improve communication and information exchange between various system components. The mesh network's nodes get information from sensors that track several hydroponic system factors, including temperature, humidity, pH levels, and fertilizer levels.

The mesh network enables real-time sharing and monitoring of the gathered data. The mesh network allows for efficient data transfer and analysis since it allows for smooth connection between the nodes. This makes it possible for growers or operators to carefully monitor and control the hydroponic system and make necessary adjustments based on the data gathered.

Mesh networks include redundancy, which enables the network to reroute communication over several pathways if a node fails or loses connectivity. This guarantees that the hydroponic system runs continuously, and that data is exchanged. Mesh networks are also scalable, enabling the addition of additional nodes to increase network capacity and coverage. [33]

2.9 Review on Existing Systems of Hydroponic Systems Based on Mesh Networks

2.9.1 Smart System for Bicarbonate Control in Irrigation for Hydroponic Precision Farming

Based on a study, the use of a mesh network for precision farming is demonstrated, with an emphasis on the real-time monitoring and management of agricultural factors for designing and implementation of a wireless sensor network (WSN) based on the ZigBee protocol.

The mesh network is made up of numerous sensor nodes that are dispersed over the agricultural area and gather information on different factors like temperature, humidity, light intensity, and soil moisture. Since the nodes communicate with each other in the mesh configuration, this allows for data routing and self-organization within the network.

The benefits of implementing a mesh configuration in precision agriculture are scalability, resilience, and adaptability. Even in areas where there are obstacles or great distances between the nodes, the mesh network offers dependable and effective data transmission.

A gateway node is also implemented to act as a link between the mesh network and a remote server. The gateway node gathers data from the sensor nodes and transmits it to the server for storage and analysis. This enables farmers to remotely manage and monitor the agricultural parameters in real time [34].

In summary, the project offers information for the establishment of a mesh network for precision farming and highlights the advantages and functionality of such a network in the real-time monitoring and management of agricultural parameters.

2.9.2 Intelligent Management of Hydroponic Systems Based on IoT for Agrifood Processes

Based on a research article, it explores the integration of Internet of Things (IoT) devices and mesh networking in hydroponic systems. It highlights the necessity for advanced monitoring and control systems to assure crop health in hydroponic systems and optimize resource utilization. The IoT devices were linked together in a mesh configuration within the hydroponic system [35].

The mesh configuration eliminates the requirement for a central control unit by enabling dependable and effective communication between the nodes. The hydroponic system can take advantage of attributes like redundancy, scalability, adaptability, and increased range by utilizing mesh networks. These qualities improve the system’s dependability, coverage, and overall performance.

This paper also covers the implementation of mesh networks in hydroponic systems as well as the incorporation of various IoT devices and sensors to gather information on variables like temperature, humidity, pH levels, concentration of nutrients, and other environmental factors. The gathered data is processed utilizing advanced algorithms and analytic tools to enhance the functionality of the hydroponic system.

In summary, this research primarily focuses on the benefits of mesh networks in hydroponic systems and illustrates how mesh networks and IoT devices may support intelligent management and optimization of agrifood processes.

2.10 Table of Comparison

Table 2.1: Table of comparison between existing systems based on Artificial Intelligence and Mesh Network

No.	Design	Applications	Advantages	Disadvantages	Features
1	Root AI [29]	Artificial Intelligence	Water-efficiency, Reduced reliance on pesticides, increased productivity, space efficiency	-Susceptible to system failures of -Power dependency	-3D sensors & camera -Computer vision -Robotic automated arm with sensors
2	Farmbot [30]	Artificial Intelligence	-Real-time monitoring and control -Predictive analysis	-Data dependance -Human intervention	-Computer vision -Data-driven decisions using ML technique -Automation for chores
3	Plantix [31]	Artificial Intelligence	-Precision monitoring and control, -Automated decision-making, -Enhanced crop yield and quality.	-Lack of human expertise -System integration to enable effective community features.	-Uses Deep Learning algorithms -Computer vision capabilities.
4	GreenSense Farm [32]	Artificial Intelligence	-Precision monitoring and control, -Automation and efficiency -Data-driven decision-making	- Large scale and complexity	-Deep Learning algorithms -Automated using AI - Machine Language to find pattern and predictive analysis

5	Smart System for Bicarbonate Control in Irrigation for Hydroponic Precision Farming [34]	Mesh network	-Scalability -Reliable communication,	-Complexity -Data congestion	-Scalable - Interconnects devices dynamically - Creating multipaths
6	Intelligent Managemen t of Hydroponic Systems Based on IoT for Agrifood Processes [35]	Mesh network	-Scalability -Reliable communication, -Redundancy	-Maintenance and management.	- Routing based on node identifiers - Robust and scalable

2.11 Summary

All the AI-based hydroponic systems had the same issues with technical dependencies and challenges. This might be because Artificial Intelligence is implemented to collect, store, and analyze a large set of data from the sensors. Managing and analyzing this many data can bring forth technical dependencies issues. Besides that, data communication among the sensors can also give rise to technical complexity issues. This is because hydroponic systems are usually accommodated for future expansions and modifications. Thus, as the system grows and complexity, complex, dependencies may arise between the sensor nodes, making it more challenging to maintain its functionality.

Meanwhile, the systems that were constructed in mesh configurations have been proved to offer scalability and produce a robust system which can offer reliable communication between the sensors.

Thus, by integrating Artificial Intelligence and mesh network together, will reduce these issues and will produce a robust hydroponic system which integrates smart and intelligent capabilities to develop an efficient and effective system.

CHAPTER 3

METHODOLOGY

3.1 Introduction

In this project, the Nutrient-Film Technique is used for hydroponics. This method gives the plant roots constant circulation of a thin layer of nutrient-rich water, which gives the roots of the plants oxygen, nutrients, and water. The plants develop in polyethylene layers. This material is frequently used to make troughs or channels that allow water rich in nutrients to flow, exposing plant roots to the elements they need. The nutritional solution is continuously pumped through the layers of polyethylene. This guarantees that nutrients and water reach the plant roots consistently. [36]. This approach combines automation mechanism and AI algorithms to improve functionality and control of the system. AI algorithms analyze sensor data from water level sensors to make intelligent judgments about water level adjustments to promote a faster crop growth rate. The mesh network configuration enables continuous data flow and communication between the ESP32 nodes, ensuring the robustness, scalability, and redundancy of the system.

3.2 Sustainable Development

This project offers implementations and practices that can contribute to the sustainability of this project. Firstly, by implementing this project, water is efficiently conserved. When compared to conventional agriculture using soil, hydroponic systems use water more efficiently. Hydroponics greatly lowers water loss from evaporation or runoff by directly supplying water to the crop roots. By using sensors and automation to precisely monitor and control water levels, ensure proper watering, and reduce water usage, this hydroponic system can further improve water efficiency.

Next, this project conserves resources as the hydroponic system are excellent for urban situations and reduces deforestation because it does not require considerable land use or soil preparation. Additionally, it reduces the need for chemical pesticides and fertilizers, reducing the pollution they cause. Reusing nutrient solutions and generating less trash and both made possible by integration of recycling and waste management techniques into these hydroponic systems.

Then, the project can also reduce carbon footprint. This hydroponic system reduces greenhouse gas emissions by removing the need for transportation and minimizing the usage of inputs derived from fossil fuels, such as fertilizers, and pesticides. Further reducing carbon emissions is achieved by bringing crops closer to larger cities and thereby reducing the transit distance between farm and consumer.

Furthermore, this project offers conservation of land and biodiversity as this project uses less land than conventional farming techniques. It helps preserve natural habitats, safeguard biodiversity, and stop soil erosion by minimizing land use. This is crucial in areas with a lack of available land or when there is a shortage of agriculturally productive land.

Finally, the project promises and offers food security as the hydroponic systems local sourcing by ensuring a steady supply of fresh vegetables regardless of environmental or climatic fluctuations. These methods reduce dependency on long-distance transportation, cut food miles, and aid local economies by enabling local production.

3.3 Block Diagram

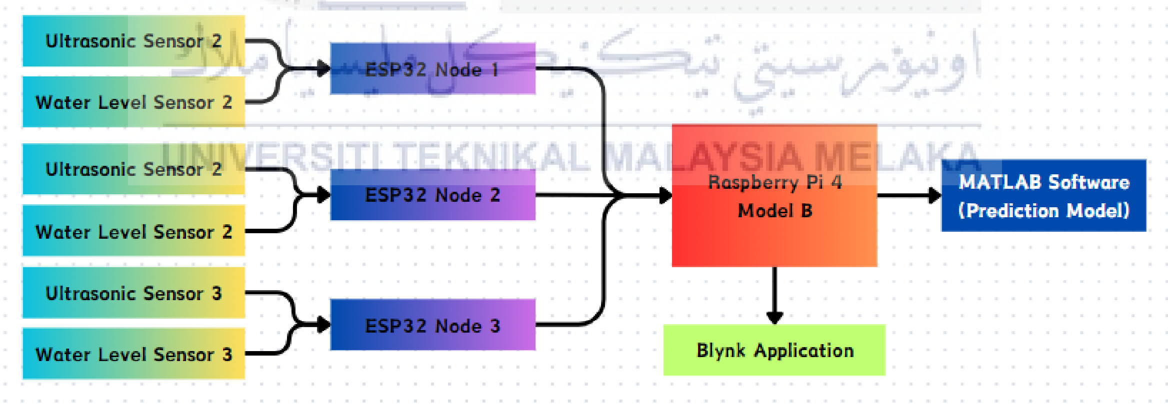

Figure 3.1: Block Diagram

Figure 3.1 shows the complete block diagram of the system. An ultrasonic sensor and water level sensor are connected to one ESP32 node. The ultrasonic sensor will measure the height of the grown crop by emitting ultrasonic signals. Meanwhile, the water level sensor will measure and monitor the water level of the water in the tube of the hydroponic system. There are three sets of the components listed above in the system to construct the mesh topography. The data from all the six sensors will travel to the ESP32 microcontroller.

The ESP32 functions as the mesh nodes of the system, where it receives the data from the sensors and that data will be transmitted in a mesh configuration to all the other ESP32 nodes. The type of mesh configuration and topology that is implemented in the hydroponic system is the full mesh network topology. In this network topology, all three ESP32 nodes are connected to each other. This means that all the nodes are constantly communicating and transmitting data to all the other nodes present in the network as demonstrated in the figure below. Table 2.2 shows the network setup of the system's mesh configuration.

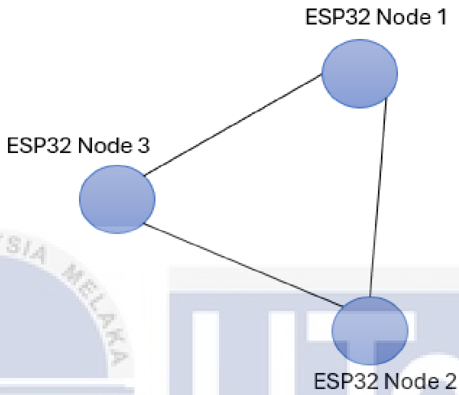

Figure 3.2: Full mesh network topology

Table 2.2: Network Setup of System's Mesh Configuration

Parameter	**Value/ Description**
Simulation Area	300 meters
Simulation Time	300 seconds
Number of Nodes	3
Radio Range	100 meters
Node Speed	0 m/s
Routing Protocol	PainlessMesh
MAC Protocol	CSMA/ CA
Source-Destination Pairs	(Node 2 to Node 1), (Node 3 to Node 1)
Transmitting Capacity	250kbps
Application	Water level and ultrasonic sensor data transmission
Packet Size	128 bytes
Visualization Tool	Serial Monitor (Arduino IDE)

If one of the nodes is down, the other node will still receive the data from the node which sends its data. Furthermore, an IoT connectivity platform will be set up using the Blynk application as well for remote monitoring of the system. Then the data from each ESP32 node will be published to the Raspberry Pi 4 through the (Message Queuing Telemetry Transport) MQTT protocol. In this protocol, The ESP32 nodes are the publisher who publishes the sensor data through the MQTT broker address, which is the IP address of the Raspberry Pi 4. The Raspberry Pi 4 will be the subscriber of the published data from the ESP32. The sensor data from the data transmission from ESP32 nodes will be stored in the Raspberry Pi, which will be used to generate the Prediction Model of the crop growth rate.

3.4 Flow Chart

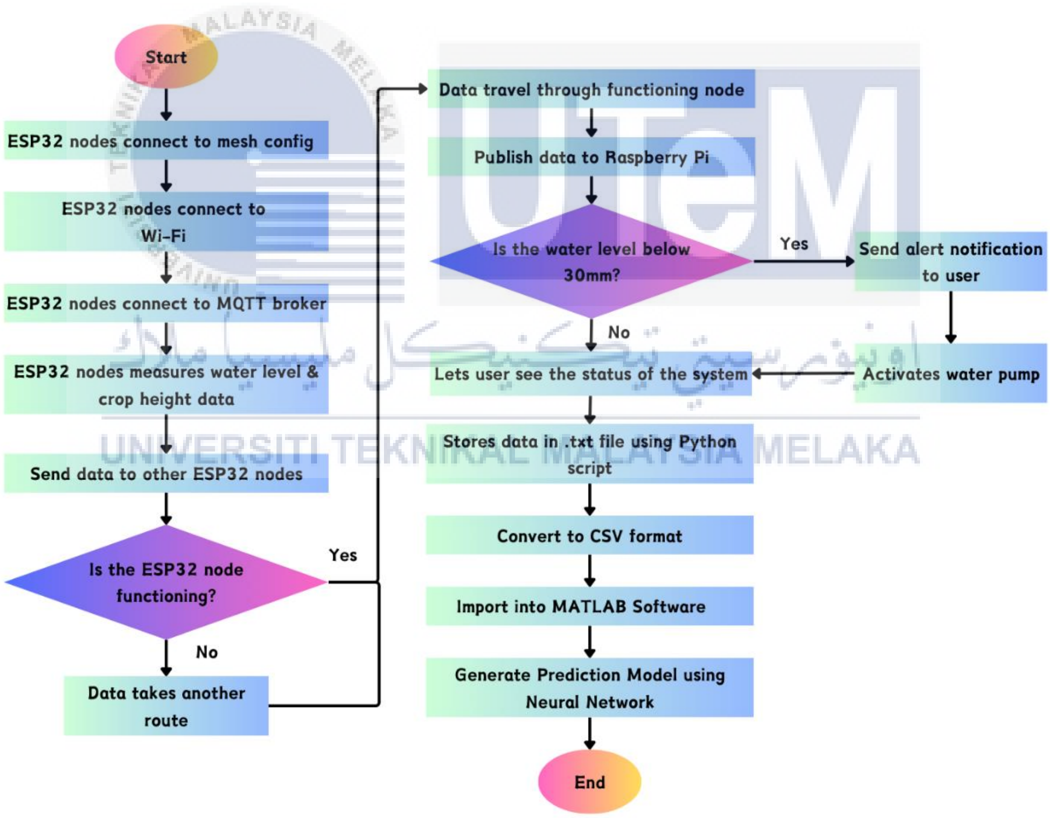

Figure 3.2: Flow Chart

Figure 3.2 shows the process of the system in the form of a flow chart. To begin with, the ESP32 nodes will connect to the mesh network using the mesh configuration which will give access to them to transmit the data to each other. Then, they will connect to the Wi-

Fi to enable the wireless communication with the Raspberry Pi 4. This will be followed by the nodes connecting to the MQTT broker address, which is the IP address of the subscriber or in this case the Raspberry Pi 4 to establish the transmission route of the data from ESP32 to the Raspberry Pi 4. As soon as all the above connections are succesfull, the ESP32 nodes will begin to measure and monitor the water level in each tube of the system and also the height of the crops using the input sensors. Since the water level and crop height data is being monitored, mesh configuration is enabled, the ESP32 can communicate with each other, which gives them the access to transmit and receive the water level and crop height data to and from each other. If along the transmission path, one of the ESP32 node is down, the data will take and travel in another route, where the ESP32 node is functioning. Then this data will be published to the Raspberry Pi 4 using the MQTT protocol which enable the nodes to transmit the data to the message subscriber.

Once, the data reaches the Raspberry Pi, the water level data from each node will be monitored. If the water level in either of the nodes, the Raspberry Pi will alert the user via the Blynk Application and activates the water pump to supply the required water level. The Blynk application will enable the user to monitor the status of the hydroponic system. The received data will be stored in a csv file which will be compiled using the Python script coding software known as Geany. This CSV file is imported into the MATLAB Software to generate the predicition model of the crop growth rate using the Neural Network.

3.5 ESP32 Nodes Configuration

```cpp
#include <painlessMesh.h>
#include <WiFi.h>
#include <PubSubClient.h>
#define BLYNK_TEMPLATE_ID "TMPL6FF8p9uTk"
#define BLYNK_TEMPLATE_NAME "FYP Hydroponic System"
#define BLYNK_AUTH_TOKEN "TZCnFdh8HITuTs8n7pikER8qu5MSXgwD"
#include <BlynkSimpleEsp32.h>

const char* ssid = "OPPO A77s";
const char* password = "2444666668888888";

#define MESH_PREFIX     "yourMeshPrefix"
#define MESH_PASSWORD   "yourMeshPassword"
#define MESH_PORT       5555

const int sensorPin = 34;
const int ultrasonicTrigPin = 14;
const int ultrasonicEchoPin = 12;

Scheduler userScheduler; // To control your personal task
painlessMesh mesh;

float waterLevel; // Declare waterLevel as a variable
float cropHeight; // Declare cropHeight as a variable

void sendMessage();
void receivedCallback(uint32_t from, String &msg);
void newConnectionCallback(uint32_t nodeId);

Task taskSendMessage(TASK_SECOND *1, TASK_FOREVER, &sendMessage);

// MQTT settings
const char* mqttServer = "192.168.249.76";
const int mqttPort = 1883;
const char* mqttUser = "navin27";
const char* mqttPassword = "navin27";
const char* mqttTopicWaterLevel = "node2/waterLevel";
const char* mqttTopicCropHeight = "node2/cropHeight";

// Blynk settings
char auth[] = "BLYNK_AUTH_TOKEN";  // Replace with your Blynk authentication token
#define BLYNK_PRINT Serial

WiFiClient wifiClient;
PubSubClient client(wifiClient);

void setup() {
  Serial.begin(115200);
```

```cpp
  mesh.setDebugMsgTypes(ERROR | STARTUP);

  mesh.init(MESH_PREFIX, MESH_PASSWORD, &userScheduler, MESH_PORT);
  mesh.onReceive(&receivedCallback);
  mesh.onNewConnection(&newConnectionCallback);

  userScheduler.addTask(taskSendMessage);
  taskSendMessage.enable();

  pinMode(sensorPin, INPUT);
  pinMode(ultrasonicTrigPin, OUTPUT);
  pinMode(ultrasonicEchoPin, INPUT);

  // Connect to Blynk
  Blynk.begin(auth, ssid, password);
}

void loop() {
  mesh.update();
  userScheduler.execute();

  // Water level sensor code
  int sensorValue = analogRead(sensorPin);
  waterLevel = sensorValue / 100.00; // Convert to millimeters
```

```cpp
  // Measurement of crop height using ultrasonic sensor
  cropHeight = measureCropHeight();

  Serial.print("Node 2 - Water Level (mm): ");
  Serial.println(waterLevel);
  Serial.print("Node 2 - Crop Height (cm): ");
  Serial.println(cropHeight);

  // Publish data to MQTT topics
  if (client.connected()) {
    client.publish(mqttTopicWaterLevel, String(waterLevel).c_str());
    client.publish(mqttTopicCropHeight, String(cropHeight).c_str());
  }

  // Send data to Blynk
  Blynk.virtualWrite(V1, waterLevel);

  delay(1000);
  Blynk.run();
}
```

```
float measureCropHeight() {
  digitalWrite(ultrasonicTrigPin, LOW);
  delayMicroseconds(2);
  digitalWrite(ultrasonicTrigPin, HIGH);
  delayMicroseconds(10);
  digitalWrite(ultrasonicTrigPin, LOW);

  unsigned long duration = pulseIn(ultrasonicEchoPin, HIGH);
  float sensorDistance = 15; // Distance from ground
  float ultrasonicReading = duration * 0.034 / 2.0;

  float cropHeight = sensorDistance - ultrasonicReading;

  return cropHeight;
}

void sendMessage() {
  // Create a message with water level and crop height information
  String msg = "Water level data from Node ";
  msg += mesh.getNodeId();
  msg += ", Water Level: " + String(waterLevel) + ", Crop Height: " + String(cropHeight);

  // Send the message to all nodes in the mesh
  mesh.sendBroadcast(msg);
  taskSendMessage.setInterval(random(TASK_SECOND * 1, TASK_SECOND * 5));
}

void newConnectionCallback(uint32_t nodeId) {
  Serial.printf("New Connection, nodeId = %u\n", nodeId);
}
```

Figure 3.3: Coding of ESP32 Node 2

```
#include <painlessMesh.h>
#include <WiFi.h>
#include <PubSubClient.h>
#define BLYNK_TEMPLATE_ID "TMPL6FF8p9uTk"
#define BLYNK_TEMPLATE_NAME "FYP Hydroponic System"
#define BLYNK_AUTH_TOKEN "TZCnFdh8HITuTs8n7pikER8qu5MSXgwD"
#include <BlynkSimpleEsp32.h>
```

Figure 3.4: Defining the libraries.

Figure 3.4 shows the libraries required for Wi-Fi connectivity, MQTT communication (*PubSubClient*), mesh networking (*painlessMesh*), and Blynk integration are included in this section. For connecting to the Blynk server, the constants *BLYNK_TEMPLATE_ID*, *BLYNK_TEMPLATE_NAME*, and *BLYNK_AUTH_TOKEN* is defined.


```
const char* ssid = "OPPO A77s";
const char* password = "2444666668888888";
```

Figure 3.5: Wi-Fi configuration.

These lines configure the ESP32's Wi-Fi settings, including the password and SSID, for a local network connection.

```
#define MESH_PREFIX     "yourMeshPrefix"
#define MESH_PASSWORD   "yourMeshPassword"
#define MESH_PORT       5555
```

Figure 3.6: Mesh configuration

The network prefix, password, and port number are among the defined parameters for the mesh network. These parameters are the known that groups the nodes in a mesh network topology. These parameters must be the same for the other two nodes to enable mesh configuration between them.

```
const int sensorPin = 34;
const int ultrasonicTrigPin = 14;
const int ultrasonicEchoPin = 12;
```

Figure 3.7: GPIO pins configuration

The GPIO pins for the ultrasonic sensor echo, ultrasonic sensor trigger, and water level sensor are assigned by these lines. The water level sensor pin for nodes 1,2 and 3 are pins 33,34 and 35. Meanwhile the ultrasonic sensor pins for the three nodes are the same, where the trigger pin is connected to pin 14 and the echo pin is connected to pin 12.

```
Scheduler userScheduler; // To control your personal task
painlessMesh mesh;
```

Figure 3.8: Scheduler for user configuration

To manage the mesh network, an instance of the scheduler and the *painlessMesh* object are created.

```
float waterLevel; // Declare waterLevel as a variable
float cropHeight; // Declare cropHeight as a variable
```

Figure 3.9: Declaration of terms for data

These variables will store the water level and crop height data after both are measured and monitored by their respective sensors.


```
void sendMessage();
void receivedCallback(uint32_t from, String &msg);
void newConnectionCallback(uint32_t nodeId);
```

Figure 3.10: Declaration of functions

Assigning function prototypes of the *sendMessage*, *receivedCallback*, and *newConnectionCallback* functions as well as a task scheduler for *sendMessage*'s recurring execution.

```
const char* mqttServer = "192.168.249.76";
const int mqttPort = 1883;
const char* mqttUser = "navin27";
const char* mqttPassword = "navin27";
const char* mqttTopicWaterLevel = "node2/waterLevel";
const char* mqttTopicCropHeight = "node2/cropHeight";
```

Figure 3.11: MQTT configuration

The MQTT configuration lines consist of the important parameters to enable the MQTT communications. The MQTT server or also known as the broker address, is the IP address of the Raspberry Pi which will function as the transport medium which carries the data from the ESP32 nodes to the Raspberry Pi. MQTT port, username and password is for security and authorization purposes. The topics that will be published by the nodes will be water level topic and crop heigh topic from node 2.

```
char auth[] = "BLYNK_AUTH_TOKEN";  // Replace with your Blynk authentication token
#define BLYNK_PRINT Serial

WiFiClient wifiClient;
PubSubClient client(wifiClient);
```

Figure 3.12: Blynk configuration

The Blynk authentication token, Blynk print settings, and Wi-Fi and MQTT client objects are initialized in these lines.

```
void setup() {
  Serial.begin(115200);

  mesh.setDebugMsgTypes(ERROR | STARTUP);

  mesh.init(MESH_PREFIX, MESH_PASSWORD, &userScheduler, MESH_PORT);
  mesh.onReceive(&receivedCallback);
  mesh.onNewConnection(&newConnectionCallback);

  userScheduler.addTask(taskSendMessage);
  taskSendMessage.enable();

  pinMode(sensorPin, INPUT);
  pinMode(ultrasonicTrigPin, OUTPUT);
  pinMode(ultrasonicEchoPin, INPUT);

  // Connect to Blynk
  Blynk.begin(auth, ssid, password);
}
```


Figure 3.13: Void setup configuration

The task scheduler, GPIO pins, mesh network, serial communication, and connection to the Blynk server are all initialized by the setup function.

```
void loop() {
  mesh.update();
  userScheduler.execute();

  // Water level sensor code
  int sensorValue = analogRead(sensorPin);
  waterLevel = sensorValue / 100.00; // Convert to millimeters

  // Measurement of crop height using ultrasonic sensor
  cropHeight = measureCropHeight();

  Serial.print("Node 2 - Water Level (mm): ");
  Serial.println(waterLevel);
  Serial.print("Node 2 - Crop Height (cm): ");
  Serial.println(cropHeight);

  // Publish data to MQTT topics
  if (client.connected()) {
    client.publish(mqttTopicWaterLevel, String(waterLevel).c_str());
    client.publish(mqttTopicCropHeight, String(cropHeight).c_str());
  }
```

```
  // Send data to Blynk
  Blynk.virtualWrite(V1, waterLevel);

  delay(1000);
  Blynk.run();
}
```

Figure 3.14: Void loop configuration

The loop function manages the mesh network, executes scheduled tasks, reads sensor data, publishes data to MQTT topics, and sends data to Blynk.

```
float measureCropHeight() {
  digitalWrite(ultrasonicTrigPin, LOW);
  delayMicroseconds(2);
  digitalWrite(ultrasonicTrigPin, HIGH);
  delayMicroseconds(10);
  digitalWrite(ultrasonicTrigPin, LOW);

  unsigned long duration = pulseIn(ultrasonicEchoPin, HIGH);
  float sensorDistance = 15; // Distance from ground
  float ultrasonicReading = duration * 0.034 / 2.0;

  float cropHeight = sensorDistance - ultrasonicReading;

  return cropHeight;
}
```

Figure 3.15: Measurement of crop height

This function is defined to compile the codes for the measurement of the height of the crop by using an ultrasonic sensor.

```
void sendMessage() {
  // Create a message with water level and crop height information
  String msg = "Water level data from Node ";
  msg += mesh.getNodeId();
  msg += ", Water Level: " + String(waterLevel) + ", Crop Height: " + String(cropHeight)

  // Send the message to all nodes in the mesh
  mesh.sendBroadcast(msg);
  taskSendMessage.setInterval(random(TASK_SECOND * 1, TASK_SECOND * 5));
}
```

Figure 3.16: Defining the *sendMessage* function.

A defined function is defined to generate and broadcast messages with crop height and water level data. This is for sending the data to the other nodes using mesh network configurations.

```
void receivedCallback(uint32_t from, String &msg) {
  Serial.printf("Received from %u msg=%s\n", from, msg.c_str());
}

void newConnectionCallback(uint32_t nodeId) {
  Serial.printf("New Connection, nodeId = %u\n", nodeId);
}
```

Figure 3.17: Defining the *receivedCallback* and *newConnectionCallBack* functions.

A defined callback function is used to handle and execute messages received from other mesh nodes. A callback function is also executed when a new node connects to the mesh is defined.

This code provides the framework for communication, remote monitoring, and data exchange between nodes in the mesh network by integrating mesh networking, MQTT, and Blynk for a hydroponic system. The code performs tasks like handling incoming messages, managing new mesh connections, and periodically broadcasting data. It also includes the use of sensors to measure crop height and water level. ESP32 Node 1 and Node 3 utilize the same coding template except for the changes in the water level sensor pins, virtual pins for Blynk connections and the declaration of “node2”.

3.6 Raspberry Pi 4 Model B+ Configuration

```python
import paho.mqtt.client as mqtt
import csv
import os
from blynklib import Blynk

# MQTT settings
mqtt_broker = "192.168.249.76"
mqtt_port = 1883
mqtt_user = "navin27"
mqtt_password = "navin27"

# Blynk settings
blynk_auth_token = "TZCnFdh8HITuTs8n7pikER8qu5MSXgwD"  # Replace this placeholder w

# Blynk initialization
blynk = Blynk(blynk_auth_token)

# Dictionary to store measurements for each node
node_measurements = {}

# Callback when the client connects to the broker
def on_connect(client, userdata, flags, rc):
    print(f"Connected with result code {rc}")

    # Subscribe to topics from Node 1, Node 2, and Node 3
    client.subscribe("node1/waterLevel")
    client.subscribe("node1/cropHeight")
    client.subscribe("node2/waterLevel")
    client.subscribe("node2/cropHeight")
    client.subscribe("node3/waterLevel")
    client.subscribe("node3/cropHeight")

# Callback when a message is received from the broker
def on_message(client, userdata, msg):
    # Parse the node number from the topic
    node_number = msg.topic.split("/")[0][-1]

    # Determine the measurement type and unit
    if "waterLevel" in msg.topic:
        measurement_type = "waterLevel"
        unit = "mm"
    elif "cropHeight" in msg.topic:
        measurement_type = "cropHeight"
        unit = "cm"
    else:
        measurement_type = ""
        unit = ""

    # Store measurements in the dictionary
    if node_number not in node_measurements:
        node_measurements[node_number] = {}
    node_measurements[node_number][measurement_type] = float(msg.payload.decode())

    # Check if both measurements are available for the node
    if "waterLevel" in node_measurements[node_number] and "cropHeight" in node_meas
        # Print the formatted message
        formatted_message = f"Node {node_number} - waterLevel: {node_measurements[r
        print(formatted_message)

        # Check water level and activate pump if below 30mm
        if node_measurements[node_number]['waterLevel'] < 30:
            activate_water_pump()

        # Append the data to a CSV file
        append_to_csv(formatted_message)

        # Clear the stored measurements for that node
        del node_measurements[node_number]

# Function to activate the water pump (modify as needed)
def activate_water_pump():
    # Add your Blynk virtual pin for controlling the water pump
    virtual_pin = 0
    blynk.virtual_write(virtual_pin, 1)  # Turn on the water pump

# Function to append data to a CSV file
def append_to_csv(data):
    csv_file_path = "node_data.csv"
```

```python
    # Check if the file already exists
    file_exists = os.path.isfile(csv_file_path)

    # Append data to the CSV file
    with open(csv_file_path, mode='a', newline='') as file:
        writer = csv.writer(file)

        # Write header if the file is newly created
        if not file_exists:
            writer.writerow(["Node", "Water Level", "Crop Height"])

        # Parse data and write to the CSV file
        node_number, water_level, crop_height = parse_data(data)
        writer.writerow([node_number, water_level, crop_height])

# Function to parse data and extract relevant information
def parse_data(data):
    parts = data.split(" - ")
    node_number = parts[0].split(" ")[-1]
    water_level = parts[1].split(": ")[1].split(" ")[0]
```

```python
    water_level = parts[1].split(": ")[1].split(" ")[0]
    crop_height = parts[2].split(": ")[1].split(" ")[0]
    return node_number, water_level, crop_height

# Create a client instance
client = mqtt.Client()

# Set the callback functions
client.on_connect = on_connect
client.on_message = on_message

# Set the username and password for the broker
client.username_pw_set(mqtt_user, mqtt_password)

# Connect to the broker
client.connect(mqtt_broker, mqtt_port, 60)

# Loop to listen for messages
client.loop_forever()
```

Figure 3.18: Python script coding

The code starts by importing the necessary libraries, specifically the MQTT client library *paho.mqtt.client*, *csv* for handling CSV files, and *os* for interacting with the operating system.

The script then defines the MQTT settings, including the broker's IP address, port, username, and password. Additionally, a dictionary named *node_measurements* is initialized to store measurements for each node.

The script proceeds to define callback functions for connecting to the MQTT broker *on_connect* and processing received messages *on_message*. In the *on_connect* callback, the script subscribes to specific topics related to water level and crop height for nodes 1, 2, and 3. This establishes a connection with the broker upon execution.

The *on_message* callback is responsible for parsing the received MQTT messages. It extracts the node number, measurement type, and unit (either millimeters or centimeters) from the topic. The measurements are then stored in the *node_measurements* dictionary. If both water level and crop height measurements are available for a specific node, the script prints a formatted message, appends the data to a CSV file using the *append_to_csv* function, and clears the stored measurements for that node.

The *append_to_csv* function handles the appending of data to a CSV file named *node_data.csv*. It checks whether the file already exists and, if not, writes a header with column names (Node, Water Level, Crop Height). It then parses the data using the *parse_data* function and writes the relevant information to the CSV file.

The *parse_data* function is a utility function that extracts node number, water level, and crop height from a formatted message.

Lastly, the main part of the script creates an MQTT client instance, sets the callback functions, and establishes a connection to the broker. The script then enters a loop *client.loop_forever( )* to continuously listen for incoming MQTT messages.

The Python script above can receive measurements of crop height and water level from multiple nodes, process and store the data, print formatted messages, append the data to a CSV file, and clear the stored measurements for each individual node. It is designed to subscribe to specific MQTT topics. The script shows how to handle MQTT messages in an Internet of Things context in a straightforward but efficient manner.

The Blynk library is imported, and a Blynk instance is initialized with your Blynk authentication token. The *on_message* callback function, triggered when a message is received from the MQTT broker, has been extended to check if the water level is below 30mm. If so, the *activate_water_pump* function is invoked, sending a virtual write command to a specified Blynk virtual pin (in this case, virtual pin 0) to activate the water pump. It's essential to replace the placeholder Blynk authentication token with your actual token and adjust the virtual pin according to your Blynk project configuration. This addition enables the Raspberry Pi to respond to low water levels by activating the water pump through Blynk integration.

3.7 Prediction Model (MATLAB Software)

The prediction model was trained using sensor data, which was collected from the water level sensor and ultrasonic sensor by using the Raspberry Pi. The simulation was performed in the MATLAB Software in the Regression Learner application by importing the sensor data which is in csv format into the MATLAB editor and the data was saved in the Workspace [42] ash shown in Figure 3.19.

```
data = readtable("node_data.csv");

```

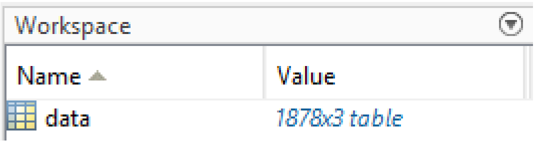

Figure 3.19: Sensor data stored in Workspace.

The Regression learner application uses the data from the workspace to plot the response curve. The ultrasonic sensor which compiles the measurement of the crop height was defined as the dependent variable and as the response from the model, while the water level data was defined as the predictors.

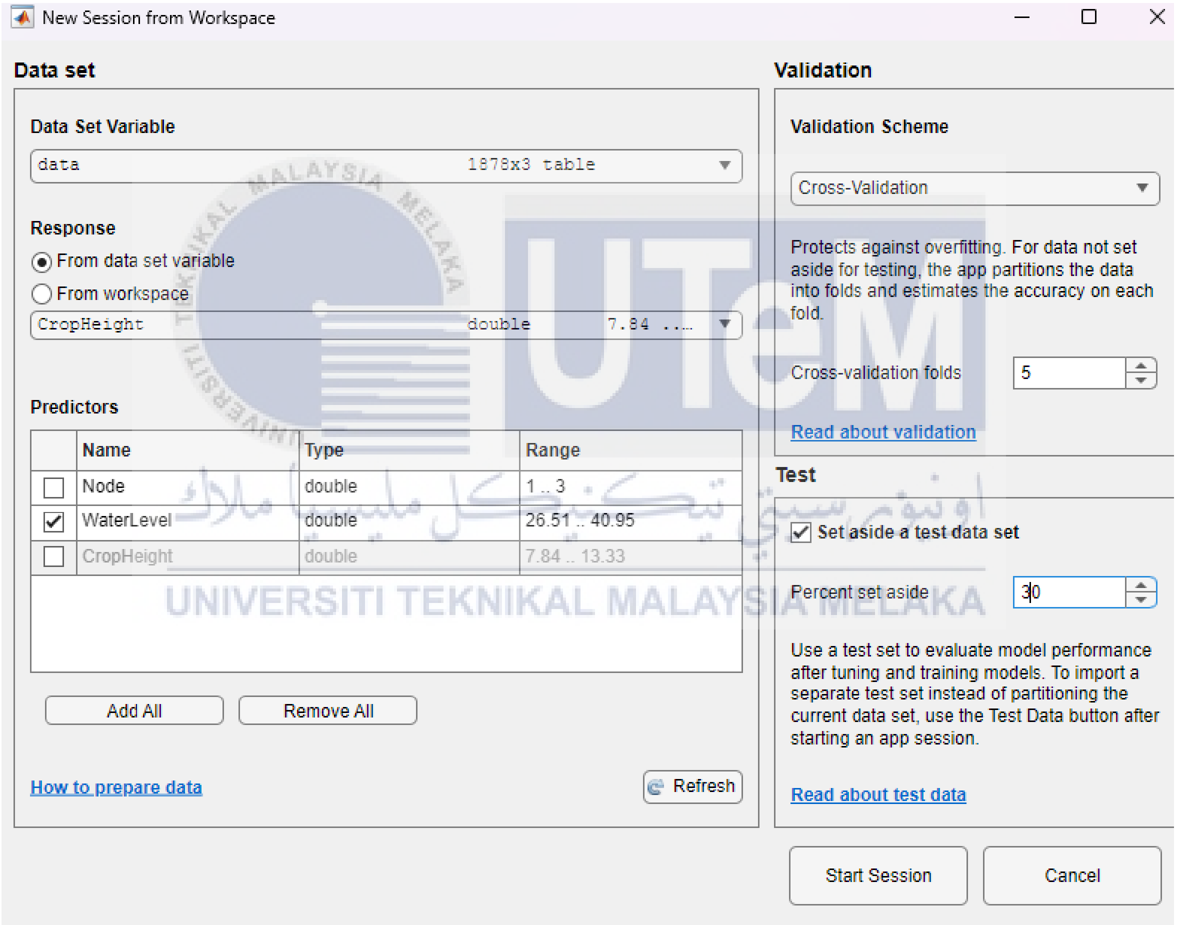

Figure 3.20: Regression Model configuration.

Based on the figure above, the predictors are the dataset which will affect the response output. By using this data, the model aims to establish a relationship between the water level in the hydroponic system and the resulting crop height. The model will assess the correlation between the two data. It will identify whether there is a statistically significant relationship between them.

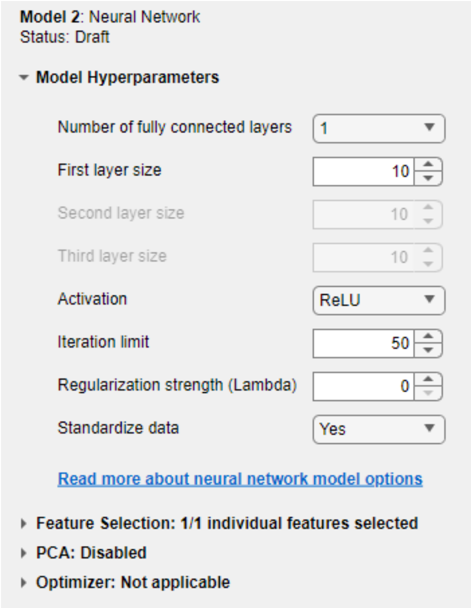

Figure 3.21: Narrow Neural Network configuration.

The model is trained using the Narrow Neural Network as shown in Figure 3.21. Once trained, the prediction model will have the ability to make predictions about crop height based on new water level data. Thirty percent of the data stored will be used for testing the trained model. By understanding the relationship between the two data, the model can contribute to the optimization of growth conditions.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Introduction

In this section, the results, and discussions on the output of the serial monitor of the Arduino IDE, the output of the terminal of the Raspberry Pi and the outcomes and analysis of the Neural Network prediction model for the system are presented. The prediction model was trained using test sensor data, which was collected from the water level sensor and ultrasonic sensor. The simulation was performed in the MATLAB Software in the Regression Learner application by importing a tabulated sensor data which is in csv format into the MATLAB editor and the data was saved in the Workspace [42]. The Regression learner application uses the data from the workspace to plot the response curve.

The main goal of this simulation is to create a precise prediction model that will predict the crop height based on the sensor data in the hydroponic system. The analysis of the results provides insights and understandings of the functionality and the efficiency of the prediction model in achieving the object within the hydroponic system.

4.2 Results and Analysis

4.2.1 ESP32 Nodes

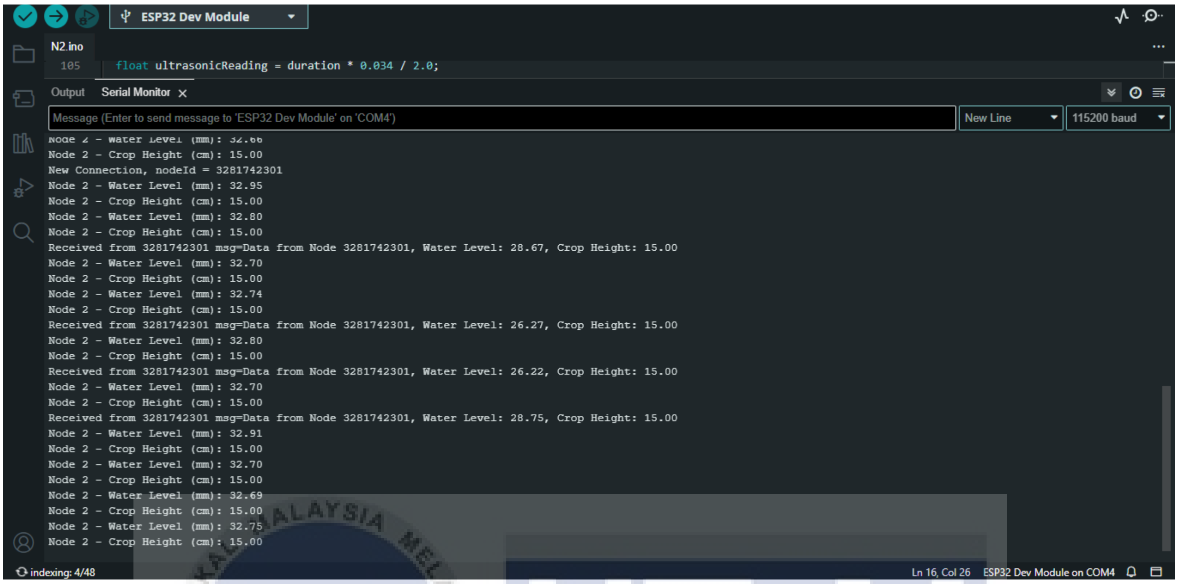

Figure 4.1: Results of Serial Monitor

The figure above shows the output results on the Serial Monitor of Arduino IDE. The output result as configured in Figure 3.14, displays the data from Node 2 as intended. It displays its water level data in millimeters and crop height in centimeters of the ESP32 node with a delay of 5 seconds. After some time, the Serial Monitor shows that "New Connection has been established" which is referring to ESP32 node 1 and node 3. The ESP32 node 2 has successfully interconnected with the other nodes to form the mesh configuration. After receiving the display message, Node 2 starts to receive the water level data and crop height data from the other two nodes. The output even shows the source of data transmitted from. At the same time, this evident that the data produced from Node 2 will also be received by the other two nodes. This communication and transmission of data will occur simultaneously in each node producing a robust hydroponic system with better redundancy performance.

Based on the development of the system with the mesh configuration of ESP32 nodes have enhanced the reliability of the wireless communication network within the hydroponic system. The mesh network provides robustness against the ESP32 node failures or communication disruptions, ensuring that even if one node encounters issues, the overall network remains intact. This reliability is crucial for continuous monitoring and control in agriculture applications.

Next, the development of this mesh configuration supports scalability, allowing to easily add or remove ESP32 sensor nodes without compromising the overall network performance. This feature is crucial when the hydroponic system is subjected to expansion or evolution. This feature provides the framework that accommodates the changing needs of the hydroponic system.

Finally, the network topology of mesh configuration offers redundancy and resilience. The multiple communication paths between the ESP32 nodes contribute to network redundancy, ensuring that the water level and crop height data can find alternative routes if one path is obstructed. This redundancy enhances the overall resilience of the system, which is crucial for maintaining connectivity in challenging environment conditions that might hinder the progress of data monitoring within the hydroponic system.

4.2.2 Raspberry Pi

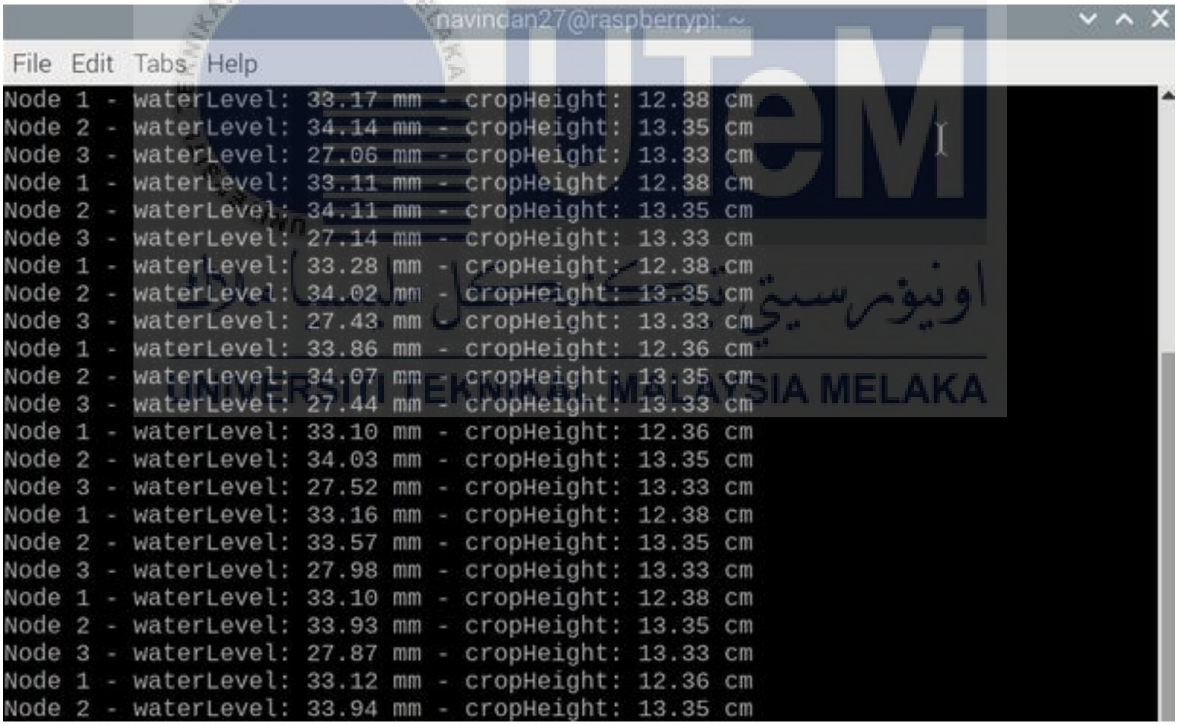

Figure 4.2: Output terminal when all ESP32 nodes are up.

The figure above shows the results displayed in the command terminal of Raspberry Pi desktop. The MQTT protocol is enabled allowing the sensor data from all three nodes to be published to the subscriber. At the beginning of the coding, a line of code must be typed into the command terminal which is *python3 pi,py*. Since the python scripting was developed to enable the MQTT protocols, the *python3* word has been defined in the line of code. The *pi.py* is the name of the saved Python script which compiles the coding shown in Figure 3.18 along with the python script extension *xx.py*.

After running the line of code, the first message displayed will be “Connected with result code 0”. This indicates that the publisher and the subscriber have successfully connected to the MQTT broker address with proper authorization which is defined by the *mqtt_username* and *mqtt_password*. Based on the figure above, it is evident that the subscriber has successfully subscribed to the published topics of the water level data and crop height data from each ESP32 nodes.

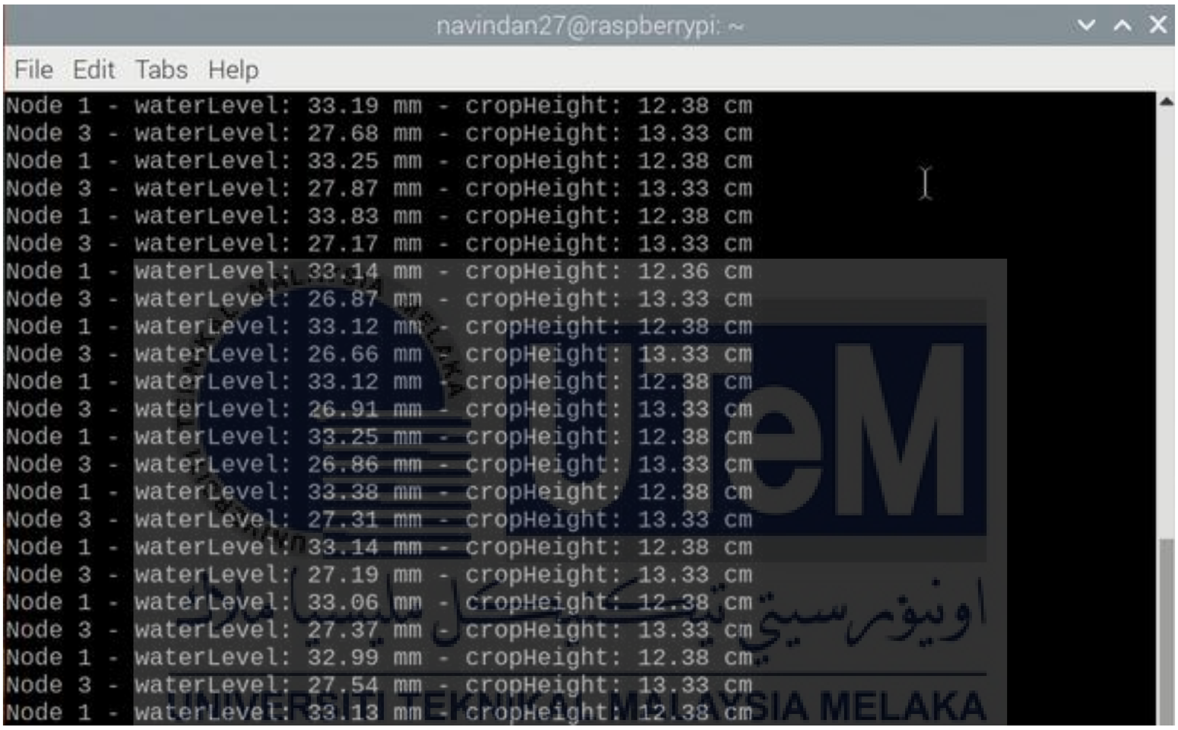

Figure 4.3: Output terminal when ESP32 node 2 is down.

Figure 4.3 shows the results displayed in the command terminal if ESP32 node 2 is down. Even though node 2 is down, the data from ESP 32 nodes 1 and 2 are still being subscribed to the data topics. The monitoring of the system will not be disturbed because of the node 2 failure. The system will continue to monitor the water level and crop height data to be used for the prediction model. This data will immediately be stored into a CSV file entitled “node_data” as shown in Figure 4.4.

	A	B	C
1	Node	Water Level (mm)	Crop Height (cm)
2	3	30.78	7.84
3	3	29.71	7.84
4	2	31.84	10.44
5	3	29.88	7.84
6	2	31.8	10.44
7	3	27.23	7.84
8	2	31.71	10.44
9	2	40.9	12.7
10	1	40.95	13.03
11	3	36.05	13.33
12	2	40.8	12.7
13	1	40.95	13.01
14	3	36.2	13.33
15	2	40.8	12.7
16	1	40.95	13.03
17	3	36.19	13.33
18	2	40.5	12.7
19	1	40.95	13.03
20	3	36.15	13.33
21	2	40.59	12.7
22	3	36.02	13.33
23	1	40.95	13.01

Figure 4.4: CSV file where sensor data is stored.

Based on the results above, the MQTT is suitable for real-time communication. In a hydroponic system, real-time updates on water levels and crop heights are crucial for timely decision making and intervention. The protocol enables quick and reliable data exchange between devices. The protocol ensures that messages are delivered with the desired level of assurance with high Quality of Service (QoS) levels. Moreover, MQTT's low-latency characteristics ensure minimal delay in delivering the messages. This is vital for maintaining responsiveness of the system and enabling quick responses to change in the hydroponic system.

4.2.3 Prediction Model

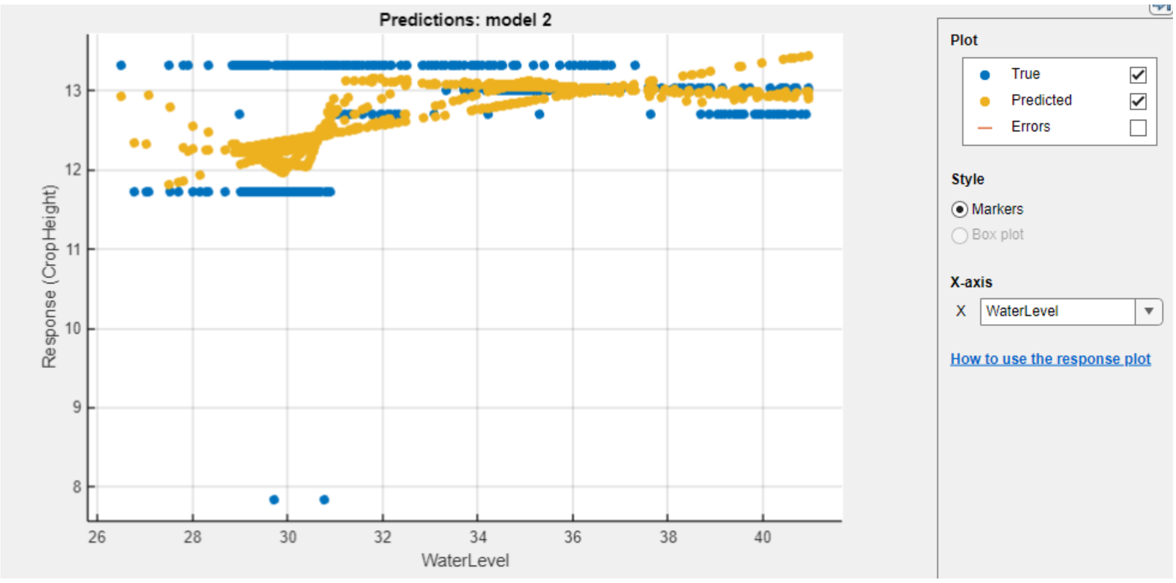

Figure 4.5 Prediction model of system

Figure 4.5 shows the prediction model of the system based on the trained data. The blue points indicate the true data and yellow points indicate the predicted outcomes from the model.

Model 2: Neural Network
Status: Trained

Training Results

RMSE (Validation)	0.52606
R-Squared (Validation)	0.34
MSE (Validation)	0.27674
MAE (Validation)	0.3581
Prediction speed	~8600 obs/sec
Training time	14.244 sec

Test Results

RMSE (Test)	0.59256
R-Squared (Test)	0.34
MSE (Test)	0.35113
MAE (Test)	0.39261

Figure 4.6: Analysis of the Neural Network Model

Figure 4.6 shows the results and analysis of the prediction model. The training results consist of Root Mean Square Error (RMSE), R-squared, Mean Squared Error (MSE) and Mean Absolute Error (MAE).

Firstly, the RMSE of 0.59256 represents the square root of the mean squared differences between predicted and actual crop height values. This metric indicates the average magnitude of prediction errors. A lower RMSE suggests better RMSE suggest better accuracy and in this case, it indicates that on average, predictions deviate by approximately 0.59 units from the actual crop height.

Then, the R-squared value of 0.34 signifies the proportion of variance in the crop height explained by the water level predictor. While R-squared provides an understanding of how well the model captures variability. The R-squared value of 0.34 suggests that approximately 34% of the variability in crop height is accounted for by the water level. This indicates that there are other factors influencing the crop height beyond the water level.

Next, the MSE of 0.35113 is the average of the squared differences between predicted and actual values. Similar to RMSE, it provides a measure of prediction error. In this context, the MSE indicates that, on average, the squared prediction errors amount to 0.35, emphasizing the significance of minimizing both large and small errors.

Finally, the MAE of 0.39261 represents the average absolute difference between the predicted and actual crop height values. This metric provides a straightforward understanding of the magnitude of errors. In this case, the model's predictions deviate, on average by approximately 0.39 units from the true crop height.

4.2.4 Blynk Application

Figure 4.7: Mobile dashboard setup of the Blynk application.

The Blynk application is utilized for the remote monitoring of the hydroponic system. The Blynk is initialized by the coding done in the ESP32 nodes. The configuration of the administration was done using the Blynk cloud website, https://blynk.cloud/dashboard/426387/templates .

Firstly, a new template was created and was named "FYP Hydroponic System". Then, new data streams were created based on three water level sensors. Each of the data streams were assigned with virtual pins from V0 to V2. Next, the web dashboard was set up by placing three gauges. Each gauge is assigned with the respective data stream virtual pins which will display the water level readings of each sensor. A new device was named after the user's name "Navin Raj".

Finally, the mobile dashboard was set up like the layout of the web dashboard as shown in Figure 4.7. Once the configuration on the website is done, the template ID, name and the Blynk authentication code will be generated by the website. Besides this, the Blynk application will also be linked with the Raspberry Pi to monitor the water level. If the water level is below 30mm, the system will send a notification to the user via the mobile application while controlling the water pump to add more water until it reaches the required level. Figure 4.8 shows the notification alert from the system to the application via Blynk application.

Figure 4.8: Notification alert from system

4.2.5 Comparison Work of the System with Existing System

In hydroponic farming, where accuracy and productivity are critical, incorporating cutting-edge technologies becomes essential. To predict crop height in a hydroponic system, this study compares regression models using the vital parameter of water level. The main goal is to use sensor data to precisely track and analyze crop growth rates through the application of Artificial Intelligence (AI). The effectiveness of three important regression models—Decision Tree, Support Vector Machine (SVM), and Neural Network—in terms of maximizing predictive accuracy is assessed.

In addition to improving hydroponic farming techniques, this comparison supports the larger goal of utilizing AI to provide smart, data-driven agricultural solutions. The results have the potential to fundamentally alter our understanding of and improvements upon crop growth dynamics within the framework of contemporary, technologically advanced agriculture. Table 2.3 shows the ….

Table 2.3: Prediction Models Performances

Model/ Parameters	**Tree**	**Support Vector Machine**	**Neural Network**
RMSE	0.662827	0.668788	0.592563
R Squared	0.175018	0.160112	0.340653
MAE	0.376342	0.494823	0.392610
MSE	0.439340	0.447278	0.351131
Prediction Time (obs/ sec)	7,943.876962	5,012.210354	27,412.166420
Training Time (sec)	11.6667046	21.8382681	8.9907509

Comparing regression models in the hydroponic system to predict crop height based on water level has produced insightful information that is in line with the main goal of using AI to track and analyze crop growth rates using sensor parameters.

Three regression models which are Decision Tree, Support Vector Machine (SVM), and Neural Network were assessed to achieve this goal. The Decision Tree demonstrated competitive accuracy metrics with a Root Mean Squared Error (RMSE) of 0.6628 and an Absolute Error (MAE) of 0.3763, demonstrating its interpretability and simplicity. Although a little less precise, the Support Vector Machine (SVM) demonstrated its usefulness in high-dimensional spaces.

However, the sophisticated AI model Neural Network was the clear winner, including an astounding Mean Absolute Error (MAE) of 0.3926, a Root Mean Squared Error (RMSE) of 0.5926, and the highest R-squared value of 0.3407, it showed exceptional predictive accuracy. This model's capacity to identify complex patterns fits in well with the main goal of the project, which is to use cutting-edge AI methods to analyze the dynamics of hydroponic crop growth.

The discussion highlights the trade-off between interpretability and predictive accuracy in models, recognizing that the complexity of the Neural Network is justified by its improved performance when it comes to monitoring and assessing crop growth rates. This discovery is essential to achieving the project's larger goals because it offers important new information about how advanced AI models, in particular neural networks, can be used to optimize hydroponic farming techniques. The outcomes highlight how AI helps achieve precise and accurate analyses in the hydroponic system, greatly advancing the field of smart agriculture.

4.3 Summary

In this hydroponic system project, the mesh configuration, MQTT protocol and the prediction model analysis collectively form a robust framework for monitoring and managing crop growth. The mesh configuration facilitates a dynamic mesh network among ESP32 node, ensuring reliable connections and seamless data exchange. The MQTT protocol enhances real-time communication, enabling nodes to efficiently transmit water level data and crop height data to the Raspberry Pi, which acts as a central hub. This MQTT-based communication, coupled with the publish-subscribe architecture, and monitoring process. The prediction model, utilizing a narrow neural network, offers insights into predicting crop height based on water level. With an RMSE of 0.59256 and R-squared of 0.34, the model exhibits moderate accuracy, providing valuable information for hydroponic system optimization. The convergence of mesh networking, MQTT protocol and predictive modeling establishes a scalable, efficient, and data-driven approach to hydroponic cultivation, contributing to informed decision making and improved crop growth rate.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

In conclusion, this project has aimed to develop a robust automated hydroponic system based on mesh networks and Artificial Intelligence. Through extensive and deep research, design and implementation, the objectives of this project have been achieved successfully.

Firstly, a hydroponic system which can be controlled and supervised by using the Internet of Things (IoT) devices using mesh configuration was designed. The hydroponic system that integrates mesh network configuration for efficient communication and data exchange between sensor nodes was designed. Moreover, the system will also ensure reliable and robust connectivity between the sensor nodes, minimizing the communication failures and interferences within the hydroponic system. The mesh network will also allow for the scalability and expansion of the hydroponic system which will allow the system to accommodate additional sensors and actuators if needed. The flexibility of the system will enable customization of multi-farming systems.

Next, Artificial Intelligence in tracking and analyzing the growth for the crops by using the Narrow Neural Network prediction model was implemented. The system will offer real-time monitoring, control, and remote access capabilities. The utilization of the AI will enable precise and adaptive control of environmental parameters. The integration of AI and automation will optimize crop growth conditions like water management. Through the implementation of prediction model and machine learning, the system will continuously analyze sensor data and predict crop growth patterns.

Finally, the integration of the Blynk platform in the hydroponic system project has successfully enabled a remote-control system for precise and adaptive watering. Leveraging Blynk's user-friendly interface, users can remotely monitor watering parameters, fostering adaptability and precision in irrigation management. This implementation enhances overall control and responsiveness, contributing to the efficiency and optimization of the hydroponic cultivation process.

5.2 Potential for Commercialization

The commercialization potential of this hydroponic system extends beyond traditional agriculture, finding impactful applications in diverse settings. This project as of now is implemented at an orphanage caring for mentally ill individuals called, Kebajikan Villa Harapan, Ayer Molek, Melaka. This not only ensures a sustainable source of fresh produce for the residents but also promotes therapeutic engagement through horticulture. This holistic approach aligns with the societal shift towards wellness-focused initiatives.

Additionally, envisioning the project in housing areas introduces a community-centric model. Residents can establish and manage these hydroponic systems collaboratively, fostering a sense of community and self-sufficiency. Beyond the environmental and health benefits, the surplus crops can be sold, creating a sustainable source of income for the community. This approach not only promotes food security but also empowers residents to actively contribute to their economic well-being. The scalability and adaptability of the technology make it a viable and socially impactful commercial venture, bridging technological innovation with community development for a more sustainable and inclusive future.

5.3 Future Works

The future development of the hydroponic system project encompasses a strategic roadmap aimed at enhancing its capabilities and impact. Firstly, the integration of additional sensors, including temperature, humidity, pH, and EC sensors, is envisioned. This expansion aims to create a more comprehensive dataset, allowing for a better understanding of the hydroponic environment. Coupled with advanced data fusion techniques, this initiative seeks to refine predictive models and improve the accuracy of the system in predicting crop behavior based on various environmental factors.

Secondly, the project aims to delve into the development of optimization algorithms that leverage machine learning techniques. These algorithms will dynamically adjust watering schedules, nutrient delivery, and environmental conditions to maximize resource efficiency and crop yield. The goal is to create an intelligent, adaptive system that continuously optimizes its operations based on real-time data and machine learning insights.

Then, the enhancements to the user interface on platforms like Blynk represent another crucial aspect of future work. By providing users with more detailed insights, analytics, and control options, the improved interface ensures an ideal and user-friendly experience. Visualization tools and historical data tracking will empower users to make informed decisions about system management, contributing to a more user-centric approach.

Next, the expandable mesh network capabilities are pivotal for accommodating the potential growth of the hydroponic system in larger agricultural settings or community projects. The scalability of the mesh network ensures a robust and reliable communication infrastructure, facilitating the seamless integration of additional nodes for extended coverage.

Furthermore, diversifying the crops that can be cultivated using the hydroponic system is a key area of exploration. Researching and adapting the system to accommodate different plant species will provide users with a more diverse range of options for cultivation. This expansion aligns with the goal of creating a versatile hydroponic solution applicable to various agricultural contexts.

Finally, the project will embark on the development of a comprehensive commercialization strategy. This includes conducting thorough market research, scalability assessments, and exploring potential partnerships with agricultural organizations, community development projects, and businesses interested in sustainable farming technologies. The aim is to position the hydroponic system as a commercially viable and socially impactful solution that addresses the evolving needs of modern agriculture.

In summary, these future endeavors collectively shape a trajectory for the hydroponic system project, propelling it towards greater sophistication, inclusivity, and commercial success. Through continuous innovation and strategic planning, the project aims to contribute significantly to sustainable agriculture, community development, and advancements in therapeutic horticulture.

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APPENDICES

Appendix A   Hydroponic system at Kebajikan Villa Harapan

Appendix B ESP32 Node 1 Setup with Ultrasonic and Water Level Sensor 1

Appendix C ESP32 Node 3 Setup with Ultrasonic and Water Level Sensor 3

Appendix D ESP32 Node 2 Setup with Ultrasonic and Water Level Sensor 2

Appendix E Raspberry Pi Setup

Appendix F Fertilizer Water Tank

Appendix G Final Year Project Completion