DEVELOPMENT OF AUTOMATED HYDROPONIC SYSTEM USING SOLAR PANEL AND ARTIFICIAL INTELLIGENCE FOR AGRICULTURE

KRISTISSWARAN A/L KATHIRESAN

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

DEVELOPMENT OF AUTOMATED HYDROPONIC SYSTEM USING SOLAR PANEL AND ARTIFICIAL INTELLINGENCE FOR AGRICULTURE

KRISTISSWARAN A/L KATHIRESAN

This report is submitted in partial fulfilment of the requirements for the degree of Bachelor of Electronics Engineering Technology (Telecommunications) with Honours

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ABSTRACT

Hydroponic system is the practice of growing plants using only water, nutrients, and a growing medium without using soil which fosters rapid growth, stronger yields, and superior quality. Addressing challenges such as overlooking optimal growth conditions, failing to crop tracking accuracy in hydroponics, lack of reliability in hydroponic system node redundancy, and wasting energy. The project implements Artificial Intelligence (AI) in tracking and analysing crop growth rates using sensor parameters, optimizing communication within the mesh network, and implementing remote control for precise management. Additionally, solar panels are integrated to save energy and promote sustainability in the hydroponic setup to be specific as an eco-friendly. To enhance data accuracy, particularly in monitoring water levels, the project leverages AI algorithms to process sensor data efficiently. The results will be analysed and optimized for better performance of the system. This project uses a microcontroller, ultrasonic sensor, water level sensor and a solar panel. The system will be integrated with a smart phone so that user can monitor and control easily in real time. The approach involves ESP32 nodes connecting to the mesh network and then to a Raspberry Pi 5 via Wi-Fi for wireless communication. Using the MQTT protocol, the nodes transmit data on water levels and crop height, ensuring redundancy in case of node failures. The Raspberry Pi 5 oversees water levels and sends alerts through a Blynk application, activating the water pump to maintain ideal conditions. Data is recorded in ESP32 nodes will be transferred to the Raspberry 5, where the data will be compiled using Python and imported into MATLAB in itself to process the data for creating predictive model. The Blynk application enables real-time monitoring, providing users with insights into the hydroponic system's status. Results from the prediction model, including RMSE = 0.44701, R-squared = 0.81, MSE = 0.19982, and MAE = 0.166649, indicate improved predictive accuracy. Wide Neural Network and the Narrow Neural Network excelled in handling high-dimensional data but Decision Tree outperformed both with its exceptional predictive accuracy, making it the best fit. This comprehensive approach bridges the gap between identified problems and innovative solutions, contributing to the advancement of efficient and resilient hydroponic systems. With the successful completion of the project, it will establish a sustainable agricultural system that improves food security, environmental conservation, and economic viability in the industry.

ABSTRAK

Sistem hidroponik adalah amalan menanam tumbuhan dengan menggunakan air, nutrien, dan medium penanaman tanpa menggunakan tanah yang menggalakkan pertumbuhan pesat, hasil yang lebih kuat, dan kualiti yang unggul. Mengatasi cabaran seperti mengabaikan keadaan pertumbuhan yang optimum, kegagalan dalam ketepatan penjejakan tanaman dalam hidroponik, kekurangan kebolehpercayaan dalam kelebihan node sistem hidroponik, dan pembaziran tenaga. Projek ini melaksanakan Kecerdasan Buatan (AI) dalam menjejaki dan menganalisis kadar pertumbuhan tanaman menggunakan parameter sensor, mengoptimumkan komunikasi dalam rangkaian mesh, dan melaksanakan kawalan jauh untuk pengurusan yang tepat. Selain itu, panel solar disepadukan untuk menjimatkan tenaga dan menggalakkan kelestarian dalam sistem hidroponik sebagai mesra alam. Untuk meningkatkan ketepatan data, terutamanya dalam memantau paras air, projek ini memanfaatkan algoritma AI untuk memproses data sensor dengan cekap. Hasilnya akan dianalisis dan dioptimumkan untuk prestasi sistem yang lebih baik. Projek ini menggunakan mikropengawal, sensor ultrasonik, sensor paras air, dan panel solar. Sistem ini akan diintegrasikan dengan telefon pintar supaya pengguna boleh memantau dan mengawal dengan mudah dalam masa nyata. Pendekatan ini melibatkan nod ESP32 yang menyambung ke rangkaian mesh dan kemudian ke Raspberry Pi 5 melalui Wi-Fi untuk komunikasi tanpa wayar. Menggunakan protokol MQTT, nod menghantar data tentang paras air dan ketinggian tanaman, memastikan kelebihan dalam kes kegagalan nod. Raspberry Pi 5 mengawasi paras air dan menghantar amaran melalui aplikasi Blynk, mengaktifkan pam air untuk mengekalkan keadaan yang ideal. Data yang direkodkan dalam nod ESP32 akan dipindahkan ke Raspberry Pi 5, data akan dikumpulkan menggunakan Python dan diimport ke dalam MATLAB untuk memproses data bagi mencipta model ramalan. Aplikasi Blynk membolehkan pemantauan masa nyata. Hasil daripada model ramalan, termasuk RMSE = 0.44701, R-squared = 0.81, MSE = 0.19982, dan MAE = 0.166649, menunjukkan peningkatan ketepatan ramalan. Wide Neural Networkdan Narrow Neural Network cemerlang dalam mengendalikan data berdimensi tinggi tetapi Decision Tree mengatasi kedua-duanya dengan ketepatan ramalan yang luar biasa. Dengan kejayaan projek ini, ia akan mewujudkan sistem pertanian yang lestari yang meningkatkan keselamatan makanan, pemuliharaan alam sekitar, dan daya maju dalam industri ini.

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CHAPTER 1

INTRODUCTION

1.1 Background

Soil is a common material for growing plants because it supports them and gives those nutrients, air, and water they need to grow. But, sometimes soil can cause problems for plants, like diseases, poor drainage, and erosion. Also, traditional farming in the soil needs a lot of space, work, and water. In cities and places with poor soil, it's hard to grow crops. Plus, it's becoming difficult to find workers for traditional farming. Because of these issues, growing plants without soil, or soil-less farming, is becoming a popular solution[1].

As the population grows, there's a need to produce more food to achieve self-sufficiency and ensure food security. Soil quality and water resources are critical for growing crops, but many lands in places face issues like salt and poor drainage. To meet the nutritional needs of plants and increase crop production, soil-less farming, especially hydroponics, is gaining attention[2].

Hydroponics is a way of growing plants in a controlled environment like a greenhouse, without soil, where you can closely manage how nutrients are given to the plants. The best materials for hydroponics drain well, allow air to reach the roots, hold moisture, are free from harmful substances and weeds, and are affordable. It's also better to use organic materials over synthetic ones. They do not use energy while looking for water and nutrients if these are there to be directly accessed by roots. In this case, they can direct the same towards growth. [3].

In conclusion, this type of cultivation leads to faster growth and a better quality of product. Also, plants do not necessarily require soil for the process of photosynthesis; thus, elimination does not affect plant growth. However, amateur performance of this system as well as a lack of proper knowledge, such as that concerning nutrient monitoring and regulating growing conditions, might influence plant growth and quality of a product; therefore, it typically requires several preliminary steps before the plants may be grown under this system.

1.2 Global and Societal Issues

The project gets into a few key global and social issues of the times because of some of the changes around the earth, the collection of natural resources, and our climate. Human activities such as the burning of fossil fuels, deforestation, and emissions from cars and factories throw the Earth's surface temperature out of balance. The gained temperature negatively affects the traditional crops by overheating and damaging their leaves and internal structures. Also, on account of the heightening warmth levels whip up the water beneath the ground, evaporation takes place much ridged manner, resulting in less and less quantity of the water for the growth of plants through the roots. Gradually, if the scenario persists plants lines their life slowly and eventually dies, while in this project, the plants are cultivated indoors under a controlled environment not to let the excessive fluctuation in temperature act out on plant giving a good quality of healthy food carrying an above sufficient amount of nutrition [4].

In addition, this project can provide solutions to the global and societal problem concerning natural resources and the destruction of the environment, including eradication of a number of species and their habitats. Conventional methods of farming require more land in increasing the crop production, thus causing the deforestation of forests and the displacement of or causing the death of many animal species. This project will not require any soil and land for growing plants and will only rely on water. This business model also results in lesser waste of water as compared to the traditional method of farming because the water is reused and recycled, and thus poses minimal impact on the environment. [5].

Lastly, this project is one of the projects that solve most issues affecting the world and society in improving food safety and public health. Since these plants are grown in a controlled environment and away from pests and wild animals, there are no pesticides and herbicides that are used in the process of outdoor farming. Some of these chemicals may help to protect pest infestations but pose a health hazard to the consumer. This project will ensure high-quality, tasty, and healthy vegetables that are safe and healthier to eat by avoiding these chemicals. [6].

1.3 Problem Statement

Traditional farming methods are usually not well-supervised or controlled. The farmers find it difficult to continually monitor growth factors for plants, such as the condition of water, nutrients, temperature, and humidity of the climate. Inefficiency will result since there is no real-time monitoring to enable a farmer to swiftly alleviate symptoms of nutrient deficiencies or outbreaks. Therefore, there is a requirement for a system that can assure continuous control and monitoring to optimize plant growth and maximize yields[7].

Traditional farming is a very energy-exhaustive process and depends heavily on fossil fuels, which give rise to pollution in the surroundings and generate greenhouses gases. At the same time that traditional methods are reliant upon, this adds up to the operational costs for farmers thereby. However, solar panels will be incorporated as part of hydroponic system to capture renewable energy. A great challenge is being able to have efficient systems designed that will maximize the input from solar energy yet continuously be operational.[8].

In traditional farming, a lot of the experience-based decisions lead to the allocation of resources and productivity that is far from being efficient. Integration of artificial intelligence into hydroponics allows data collection, analysis, and predictive modeling for better decision-making. For this to be achieved, there is a need for state-of-the-art computability technique application coupled with a sound data infrastructure to properly code AI that can predict plant growth, efficiently allocate resources, and adapt to a change in dynamic conditions. [9].

Thus, addressing the challenges regarding limited monitoring and control, energy dependence, and data-driven decision-making is key to the success of the Hydroponic System Project using Artificial Intelligence and Solar Panels in Agriculture. Therefore, the project aims to afford the seamless adoption of agricultural practice, efficient utilization of resources, and an increase in crop yield while reducing negative effects on the environment.

1.4 Project Objective

This project is aimed at developing a sustainable, efficient farming solution that maximizes crop yields and, at the same time, minimizes the use of resources and the impact on the environment. Specific objectives of the following are:

a) To improve automate routine maintenance activities such as water level adjustments, minimizing the need for human involvement and reducing the risk of system failures.

b) To implement and increase the efficiency of Artificial Intelligence in tracking and analysing the crop growth rates on real-time data and enhance the reliability of the communication between devices within the mesh network.

c) To enhance the hydroponic system by adding a solar panel which reduces dependency on external power sources of the hydroponic system.

1.5 Scope of Project

The scope of this project are as follows:

a) Utilization of Raspberry Pi 5 microcontroller as the brain behind the computational tasks for the performance of hydroponic system which is based on mesh configuration and Artificial Intelligence.

b) Incorporate solar panels and energy storage systems into the design to power the system efficiently, with mechanisms for energy monitoring, optimization, and backup solutions.

c) Integration of water level and ultrasonic sensors for detecting nutrients and tracking crop growth via Internet of Things (IoT) to ESP32 microcontroller as sensor nodes.

d) Training a real-time Prediction Model using MATLAB and displaying IoT connectivity via the Blynk application.

e) Aim to make contributive insights into the further development of the agriculture sector.

1.6 Summary

In this chapter, there is a description of the background, global and social issues, problem statement, objective, and scope for the hydroponic system project integration of AI and solar panels. Traditional farming in soil involves several drawbacks such as soil-borne diseases, problems related to waterlogging, exhaustive water, and land resources. Such global challenges as climate change, resource depletion, and environmental destruction make the need in innovative farming solutions even more pressing. The need for an advanced system ensues from the following features of traditional farming: real-time monitoring and control are not available, high-energy supply is entailed, and resources are not rationally allocated. The project develops a sustainable hydroponic system with automated maintenance, efficient AI for crop monitoring, and solar energy utilization. This ranges from the use of Raspberry Pi 5 for all computational purposes to the integration of solar panels to derive simply the energy and even employ IoT connected sensors to monitor nutrients and growth to development of a real-time prediction model using MATLAB. All this goes towards the goal aimed to change agriculture practices by enhancing resource utilization, higher yield from the farms but not at the cost of the environment.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Hydroponics is the growing of crops in a medium in the absence of soil, with a nutrient-rich water source. The use of hydroponics has increased by many advantages, such as maximum crop yield, faster growth rate, and farming in regions with poor soil conditions. However, this traditional hydroponic system presents difficulties because of being controlled and managed manually with monitoring and changing nutrient solutions, leading to inconsistencies and inefficiencies in crop growth [10].

The increasing interest develops in this line of hydroponic systems by integrating mesh networks and artificial intelligence to surmount several limitations. Such advanced systems automate control with real-time monitoring and adjustment of environmental variables, like temperature, humidity, pH level, water level, and nutrient concentration, so as to reduce human errors while enhancing growth. Studies have demonstrated that mesh networking coupled with AI can reduce crop yield suboptimally, enhancing crop yield and crop quality, besides enhancing resource utilization. Again, the use of solar energy overcomes the wastage of power. It will be energy efficient and eco-friendly, a feature that surpasses those that use LEDs or electricity [11].

Consequently, the advanced hydroponic system based on Artificial intelligence, mesh networks powered using solar energy can be one of the ways through which Agriculture can be done differently increasing food production a sustainable and efficient way thus eco-friendly.

2.2 Addressing Agricultural Challenges for a Sustainable Future

Agriculture is a significant means for human existence. Agriculture is known as those practices that involve the growth of crops, rearing of domestic animals, as well as managing the natural resources on the farm. However, there are various challenges facing the agricultural sector.

Obviously, among the most overwhelming challenges facing agriculture today is climate change. These changes result in changes in yield of crops and productivity in domestic animals because of variations in weather patterns, high temperatures, and unpredictable rainfall. These challenges should, therefore, call for adaptation of farmers so that food production remains stable[12].

Secondly, limited resources is also another great challenge that agriculture faces. Influential factors such as water scarcity, land availability, and modern farming technology that are limited in its accessibility can limit agricultural activities, especially in the rural and less developed regions. Long-term agricultural sustainability relies on developing resource optimization within sustainable solutions.

Next, food security and hunger are still very critical and world issues. Millions of people around the world still live without proper and nutritious food, despite the great strides that are made in agricultural practices. The problem of food insecurity can be well catered for by adding more agricultural productivity, effective network distributions, and food resources easily available through a just process of allocation [13].

Then, environmental damage, overuse of resources, and environmental pollution result from unsustainable agriculture. Coupled with intensive methods of farming, an increase in chemical applications, and mono-cropping, the process can result in soil erosion, loss of biodiversity, and water pollution. Some sustainable farming techniques are the use of crop rotation, organic farming, and integrated pest management, among others, by way of bringing about natural resources saving and ecosystem rescuing.

Finally, pollution is a great concern related to the agricultural activities. The potential sources of soil, water bodies, and air major contaminations are chemical fertilisers, pesticides, and domestic animal wastes and may inflict losses upon human health and the environment. Adoption of environment-friendly practices and investment in pollution control measures may reduce risk of loss associated with agricultural pollution [14].

In conclusion, the sustainability of these challenges is only possible through a lot of approaches or the integration of technological innovations, sustainable ways, and effective policies in addressing agriculture. A very promising solution would be the adoption of hydroponic cultivation, offering efficient resource utilization, reduced adverse environmental impact, and continuous cropping. In these innovative ways, the obstacles and their implications can be overcome so that a more resilient and sustainable future in agriculture can be assured.

2.3 Overview of Hydroponic System

Hydroponic System

Hydroponic system function via the fine control of environmental factors such as temperature and pH levels and optimizing sets of conditions for nutrient and water exposure to plants in general. Hydroponics principle of operation basically provide the plant with what it needs at the right time. These systems have highly customized nutrient solutions to individual needs, control of the intensity and duration of light, and continuous monitoring and adjustment of pH levels. This hyper-customization and control elaborates on an ecology that catalyzes the growth of the plant..

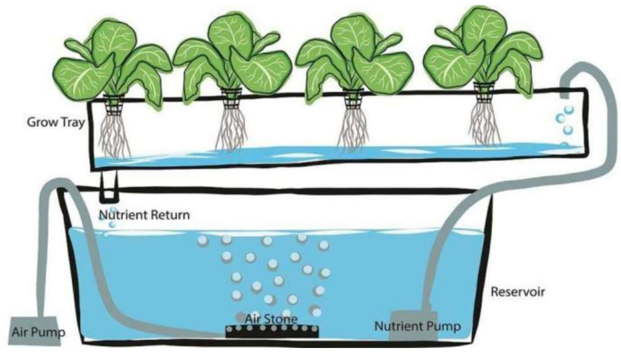

Figure 2.1 : Hydroponic System

Hydroponic production eliminates many of the risks because the plant's environment is controlled. This reduces the worry of soil-borne fungus carrying diseases into hydroponically grown plants. In a similar way, pests and animals that actually destroy the crops will be lessened or avoided. Hydroponics take out the vagaries tied in with outdoor and soil-based growing. Growth is done much faster in the root system of plants than the process of cultivating them in the soil since there are no physical barriers in the soil. Healthy crops of high quality are developed in hydroponic systems since there is less reliance on the pesticides developed since structures to be bypassed are removed; this way, plants tend to grow without any obstacle and also attain a quick growth and rate of spread in the set-up of the vegetation [15].

Advantages and Disadvantages of Hydroponic System

Hydroponic systems have a number of advantages over conventional soil agriculture with notable drawbacks, indicating that their care and management are very important.

One of the most critical merits of hydroponic systems is the fact that they are able to increase crop yields in a very great way. This is majorly attributed to the very high level of fine control on major factors critical for the growth of the crop itself, such as nutrients, light, and temperature, that hydroponic systems are capable of giving. Hydroponic systems fine-tune these elements by optimizing plant-growth conditions to enhance productivity and yield. [16].

Furthermore, Hydroponic systems are more resource efficient compared to the conventional methods of farming, which consume less water and fertilizers not only as operation costs but also to attain environmental sustainability by preventing water use and greenhouse gas emissions. Extensively studied crops under the hydroponic system are lettuce, formulated with far less quantity of water and other resources economically than soil-grown crops, yet yielding high results [17].

Another remarkable advantage is the accelerated growth rates that hydroponic systems provide. Tonight, growing in their ideal growth conditions, with nutrients applied in carefully controlled quantities, hydroponic systems can speed up growth. This fast growth easily accounts for lowered crop cycles, which in turn means high overall productivity, thus a farm for producing hydroponic crops is very interesting to enter high-demand markets or to squeeze for maximum output.

Additionally, Nutrient management in hydroponic systems is controllable and can supply nutrients in desired quantities at each stage of the plant's vegetative cycle. The system is, then, not just conducive to better crop health, but can also increase fruit yields, improve quality, and nutrition. Hydroponic farming can give the ideal balance of nutrients at different stages of the soil to provide healthier and more nutritious crops [18].

Moreover, The controlled environment of hydroponic systems develops a favorable and sustainable method of agriculture that does not permit the usage of pesticides and herbicides. The plants are normally grown in a location where they can comfortably receive their nutrient allocation. There is less danger of pests and diseases, so the application of chemicals as fungicides and pesticides is considerably minimized. This offers better quality crops and saves the surroundings from getting harmed by chemicals; this activity prevents running chemical-infused water into waterways.

Despite these major advantages, there also are some equally notable challenges that hydroponic systems confront and which debe addressed. The major issue is the cost of establishing and maintaining a hydroponic farm. Specialized equipment, such as pumps, grow lights, and nutrient solutions, is very expensive, especially for small farmers or those who want to get started in hydroponic farming. [19].

Furthermore, hydroponic systems require massive energy inputs, such as in artificial lighting, heating, and cooling. Which in turn raises operational costs and environmental impacts if energy is not used efficiently. RE targets and optimisation of energy uses are the main way of addressing these challenges.

The other most important issue is technical preparedness, to be able to effectively operate and manage the hydroponic systems. A lot of understanding from the designing and maintenance to nutrient management and pest control is called for in the principles and practices of hydroponics. The spread of hydroponic farming could be catalyzed through training programs, technical support, and sharing of knowledge[20].

In conclusion, though hydroponic systems offer an advantage in different varieties, increased yield performance, resource utilization, and quality of crops, the major setbacks incurred are proper planning, capital investment, and technical proficiency to avoid cost, energy consumption, and technical proficiency problems. Overcoming the drawbacks and exploiting the attractions of hydroponic farming results in sustainable and worthy agricultural practices in use for the welfare of mankind in the future..

2.4 Solar Panel in Hydroponic System

Figure 2.2 : Solar Panel in Hydroponic System

Nowadays, the agricultural sector has shifted towards new ways of farming that are both sustainable and enhancing for productivity. One such mechanism on which most farmers lay their bets is hydroponics. It is the way of planting using nutrient-rich water solution instead of soil for plants. In either configuration, the use of solar panels helps to overcome the various drawbacks associated with traditional forms of agriculture and paves the way for a more sustainable and green future [21].

One cost-saving benefit of the integration of solar panels in these hydroponic setups. Energy produced from the sun through the photovoltaic panels is a cheap power source in an ecologically friendly way. Thus, a hydroponic farmer will save a great deal of money on electricity bills, translating to the affordability of the practice in terms of profitability, specifically in regions endowed with sunshine. Hydroponics through Solar energy is also environmentally sustainable. The fact that it uses clean solar energy and not the fossil one will help the farmer reduce the carbon footprint and have a say in the crusade for eco-friendly farming. This is in line with climate change and greening of agriculture in the world. Another benefit to the farmer is the scalability of the solar panels in hydroponic systems. That is, systems can be designed to fit from small urban farms to large-scale commercial energy demands. Flexibility in this way allows for stretching without compromising efficiency and sustainability in energy use. [22].

However, There's an issue in the challenge for the initial installation cost of solar infrastructure, even though, in the long run, solar will bring saving. Upfront investments remain high, although government incentives and technology development are making solar installations cheaper. The other challenge is the intermittent nature of solar energy. Power production from renewable energy sources is not constant—as a result of weather and varying daylight hours—leading to uncontrolled power supply. The farmers would be required to have an alternative power source or some sort of energy bank so continuous operation will be maintained. The other key issue is maintaining and enduring. A proper solar panel has to be maintained constantly, and in case of effective maintenance, it is most likely to function efficiently. The use of quality components can enhance system life and operation, keeping downtime with very low and minimal maintenance costs [23].

In conclusion, the huge advantage of solar panels in hydroponic farming is that they can save much of the cost in a sustainable and scalable way. However, it is necessary to negotiate challenges, such as initial investment, energy intermittency, and maintenance. Among new developments, solar-powered hydroponics technologies are turning out to be a great impetus for sustainable agriculture.

2.5 Solar Panel Technologies Suitable for Powering Hydroponic Systems

1. **Photovoltaic (PV) Panels:** These are the most common type of solar panels that are used for generating electricity. PV panels work in such a way that they convert sunlight directly to electrical energy due to the photovoltaic effect. They can be effectively used to provide power to several hydroponics sub-systems components such as pumps, lighting, and environmental control systems [24].

Figure 2.3 Photovoltaic (PV) Panels

2. **Thin-Film Solar Panels:** Thin film solar panels are lightweight and flexible thus can be installed in areas where the conventional rigid panels would be unfeasible. Their efficiency rate is relatively slow compared to the crystalline silicon panels, although they can be suitable for some applications due to versatility [25].

Figure 2.4 Thin-Film Solar Panels

3. **Monocrystalline and Polycrystalline Solar Panels:** These solar panels have been popularly used, made with silicon, for the main purpose of harnessing sunlight into electric power. They have been used in both residential and commercial installations, and they can be adapted for a variety of sizes in hydroponic systems as well. [26].

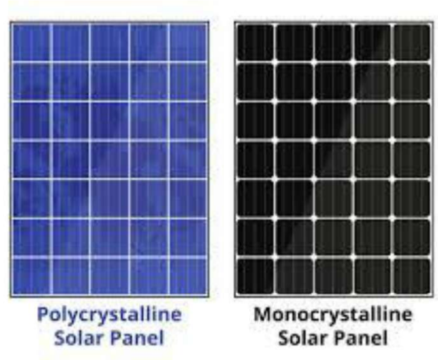

Figure 2.5 Monocrystalline and Polycrystalline Solar Panels

4. **Solar Tracking Systems:** Solar tracking systems help to vary the direction of solar panels to be in favor of sun exposure, and in most cases, they do so in the course of the day, thereby maximizing energy generation. Although these may increase efficiency, they may likewise add complexity and cost to the system [27].

Figure 2.6 Solar Tracking Systems

2.6 Classification in Artificial Intelligence

In today's data-driven world, artificial intelligence plays the role of an invisible hand that arranges the ever-increasing mountains of data into some useful orders. AI classification, dividing data into a predefined number of categories is one of the most basic and impactful applications. It is the algorithm sorting all the photos on your phone by faces, recommending movies on your streaming service, or filtering spam from your inbox.

At its core, the AI classification task simply tries to mimic the hard work of a librarian sorting books onto shelves. However, instead of physical books and labeled categories like "fiction" or "history," AI deals with vast amounts of digital data – text, images, sounds, and even complex scientific datasets. The idea is for algorithms to scan data and spot patterns and features that might differ between categories. Just imagine an AI being shown countless labeled images of dogs and cats, learning very patiently on the visual discriminative cues between the two. Learning the patterns in such examples, it is then able to apply such dissections to the categorization of new, invisible data with surprisingly high accuracy [28].

There are two primary approaches to this learning process, supervised learning and unsupervised learning. Supervised learning is like teaching a student. Here, AI is provided a labeled dataset where each piece of data is already pre-assigned a category. Such an analysis on labeled examples titled AI has to learn and select which are the important characteristics that define under each category. This is similar to showing the student thousands of pictures of both dogs and cats and then patiently explaining which is which. AI consumes thousands or even millions of labeled pictures, learning which visual values matter in distinguishing one furry friend from another. This way, if the AI is trained well enough, it will autonomously classify brand-new, never-before-seen pictures with great accuracy.

Unsupervised learning is like a child being given a room full of unlabelled toys. There is no one to naturally come up with how the underlying structure is and group them according to that. This way of working presents the AI with unlabelled data and a problem to find an arrangement. For instance, AI can group any set of images based on patterns of colors, categorize thousands of customer reviews into positive or negative reviews, or even detect conglomerated similar news within a single day. It enables AI to learn the hidden patterns within the data, with the potential for discovery that a human could oversee.

The cases in which AI classification is applied are, indeed, as diversified as the data itself. Classification is the basis of facial recognition software often used in the interests of security and spam filters, which ensure clean mail. In healthcare, AI can analyze medical images with the purpose of detecting diseases like cancer, while in finance, it can identify fraudulent transactions. E-commerce platforms recommend products to you based on past purchases, and social media firms comb through mountains of content to identify and filter out inappropriate material—all of which, of course, are occasions without limit [29].

However, AI classification is not without issues. The major one is biases in training data, which cause discriminatory results. For instance, an AI trained on a news article dataset with gender bias can create stereotyping in its classification. The other problem is the "black box" nature of AI in its decision-making process. If such AI systems refuse a loan or flag a post on social media, it is very important to understand the reason behind these decisions so that biases can be identified and corrected.

In conclusion, AI is a very powerful tool, though-it is a tremendous revolution in how we really interact with data. That is why it can automate processes, personalize experiences, unlock valuable insights, and, most of all, do that at a very deeper level. Again, there are challenges in all this, which always come along with bias of any sort and explainability. By the same token, by making sure this technology is developed and deployed responsibly, we can get back the power from AI classification as a means to creating a future resplendent with highly efficient intelligent systems that will better all of humanity. The invisible sorter, once known and understood-through the dispensation allowed us-can be used as a mighty tool for progress [30].

2.7 Artificial Intelligence in Hydroponic Systems

Artificial intelligence in modern hydroponic systems has completely transformed crop production. The development of AI technologies in hydroponics brings several advantages and numerous opportunities to allow increased efficiency, productivity, and sustainability.

One of the biggest benefits that AI can be integrated into hydroponic systems holds towards resource management. There are sensors of various parameters, measuring water levels, nutrient concentrations, and environmental conditions, among others. AI can amply control the delivery of nutrients, lighting, and temperature, which should be quite efficiently done with real-time data analysis not only of water but also of water usage. High paper precision ensures ideal plant growth conditions, better yields and conserves resources [31].

Furthermore, AI-driven predictive analytics is a game-changer in hydroponics. In that, using machine learning algorithms, it would be easier to predict crop growth patterns, detect any anomalies or potential issues beforehand, and even recommend optimum strategies vis-à-vis crop management. Such predictive ability helps farmers to proactively contain challenges, minimize the associated risks, and make decisions based on data in real-time-after all, for the better health and productivity of the crops [32].

Automation is also another aspect where AI helps in hydroponic farming. The monitoring of the plant's health, environmental variables, as well as nutrient solutions, can be fully automated by AI, thereby reducing human intervention and manual labor to a great extent.

Apart from offering those benefits, however, the application of AI in hydroponic systems also suffers from complexity in the integration, data reliability and accuracy, and the requirement for technical expertise. Overcoming these necessitates investment in education, training, and technological up-scaling for the plausible deployment and management of an AI system in hydroponic systems [33].

In conclusion, the ability of AI in resourcing, efficient management, and sustainability in hydroponic performance through optimal management of resources, predictive analytics, and automated operations paves the way for farmers to ensure higher yields, better crop quality, and contribute to more efficient and sustainable food production. Let alone high yield, quality crops; efficient management of resources; and predictive analytics; IoT technology helps in promoting improved performance in hydroponic farming towards better crop quality, better yield, and a more efficient and sustainable food supply.

2.8 Mesh Network Concept in Hydroponic System.

Mesh network is that form of network architecture in which multiple devices or nodes are connected with each other in the topology of a mesh. Therefore, because of this setup, there are multiple pathways through which any two nodes can communicate, thus ensuring redundancy, self-healing capabilities, and efficient data sharing.

A mesh network can easily be implemented in hydroponics to enable communication and information exchange between the different system components. In a mesh network, nodes collect data from sensors tracking temperature, humidity, pH levels, fertilizer levels, among other parameters, of the hydroponic system [34].

The mesh network allows real-time data sharing and monitoring across the collected data, which can be exchanged between nodes smoothly for transfer and analysis. This allows growers or operators to closely monitor and control the hydroponic system, thus changing the parameters based on the acquired data through the system [35].

Among the significant benefits of mesh networks is their redundancy since in case a node fails or loses connectivity, there are alternative pathways along which communication can be rerouted. This means that operations at the hydroponic system remain uninterrupted and always exchanging data. Mesh networks are also scalable. This means that more nodes can always be added to increase capacity and coverage of the network in case the need arises [36].

2.9 Table of Comparison

Table 2.1 : Table of comparison based on existing systems based on Artificial Intelligence, Solar Panel and Mesh Network

No.	Design	Applications	Advantages	Disadvantages	Features
1	Farmbot [37]	Artificial Intelligence	-Real-time monitoring andcontrol - Predicti ve analysis	-Data dependence -Human intervention	-Computer vision -Data-driven decisions usingML technique -Automation forchores
2	GreenSense Farm [38]	Artificial Intelligence	-Precision monitoring andcontrol, -Automation andefficiency -Data-driven decision-making	- Large scale and complexity	-Deep Learning algorithms -Automated usingAI -Machine Language to find pattern and predictive analysis
3	Heliospectr a [39]	Solar panel	-Energy efficiency. -Reduced heat Output. -Longevity.	-Technology complexity. -Maintenance.	-Smart control systems. -Durability -Research-backed Spectra.
4	Plantix [40]	Artificial Intelligence	-Precision monitoring and control, -Automated decision-making, -Enhanced crop yield and quality.	-Lack of human expertise -System integration to enable effected community features.	-Uses Deep Learning algorithms -Computer vision capabilities.

5	Solargem greenhouse [41]	Solar panel	- Sustainability -Energy Efficiency -All weather growing	-Geographical Limitation -Technical Complexity	-Integrated Solar Panel -Climate Control systems -Modular Design
6	Smart System for Bicarbonate Control in Irrigation for Hydroponic Precision Farming [42]	Mesh network	-Scalability -Reliable communication,	-Complexity -Data congestion	-Scalable -Interconnects devices dynamically -Creating multipaths
7	Intelligent Management of Hydroponic Systems Based on IoT for Agrifood Processes [43]	Mesh network	-Scalability -Reliable communication, -Redundancy	-Maintenance and management.	- Routing based on node identifiers - Robust andscalable

Review on existing Systems of Hydroponic Systems based on Artificial Intelligence and solar panel.

1. **Farmbot**

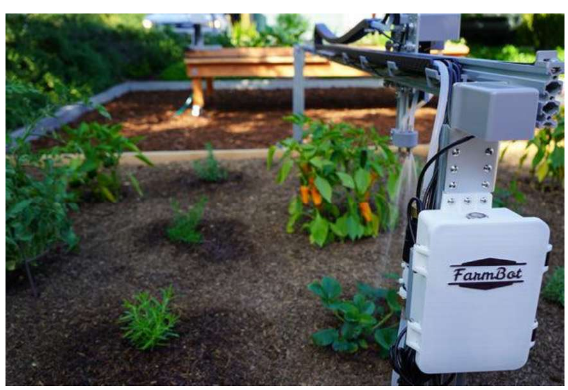

Figure 2.7: Farmbot

Farmbot is a device for automatic hydroponic farming and, using AI technology, intelligently cultivate it. Cropping and health monitoring has been done by computer vision through cameras. Then, all these images were processed with AI's algorithms where it finds the problem, disease, pest, nutrient deficiency, etc. and sends suggestions. In addition, Farmbot AI uses machine learning techniques on crop data and environment to create personalized guidance and coaching being given on optimum crop care.

Through the insights that can be gotten from the AI, the system automates seeding, watering, fertilizing, weeding, harvesting, and so on. The loop keeps monitoring the sensor data for temperature, humidity, nutrient levels, and more to offer a perfect growth environment for the crops, hence gaining maximum yield with minimum resources. : Overall, the Farmbot combines different AI technologies-like computer vision and machine learning-with automation for the promotion of plant health monitoring; thus, it allows the automation of farming processes while optimizing hydroponic grow conditions for a much more effective experience as the farmer enjoys high yields [37].

2. **GreenSense Farm**

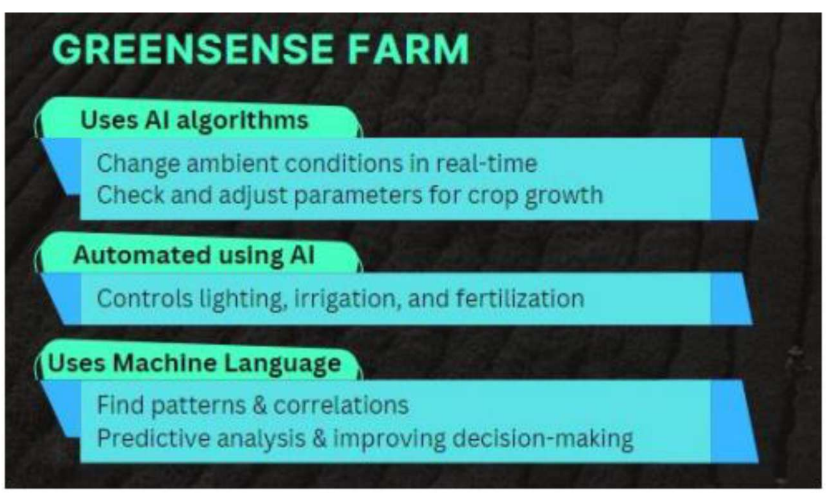

Figure 2.8: GreenSense

GreenSense Farms is a neoteric ways of farming by growing food combining solar panels and artificial intelligence. This solar panel harvests sunlight and, after converting this light into electricity, is used to power its vertical farming system. This energy source reduces their reliance on the traditional sources of power making their farm environmentally friendly or 'green. '.

AI has a very central role to play here in the running of the farm. Data from such sources as sensors, crop monitoring devices implement the AI algorithm. All this helps make decisions that are informed about allocative resources for improvement and management of the crops. It does, for instance, automatically adjust lighting schedules where solar energy is available for this energy. This is meant to ensure the most ideal management of energy and growth of the plant.

Furthermore, AI-based predictive maintenance keeps the plants' solar panels and equipment fully operational. Early identification of problems allows minimizing downtime and maximizes the lifespan of the equipment, which positively impacts the overall productivity of the farm. Applications of AI in crop management mean that AI actively monitors metrics related to plant health and the conditions under which these plants grow. Based on this information, AI systems fine-tune parameters such as irrigation and the supply of nutrients to ultimately give a higher yield, improved quality, and reduced waste.

GreenSense Farms' solar panels provide the alternative of smart farming. The farm achieves profitable growth, but also sustainable one, thanks to renewable energy and AI-powered insights and thus offers an intelligent kind of farming in the modern world [38].

3. Heliospectra

Figure 2.9: Heliospectra

Heliospectra leads in the innovation of advanced horticultural lighting systems through combining new technologies in artificial intelligence with pioneering technologies in the light to optimize plant growth in indoor farming. Built on sustainable agriculture and the powers of plant growth optimization, Heliospectra has emerged as a pioneer in this sector.

The key element of the Heliospectra offer is the AI lighting control technology, which allows growers to have very accurate control over light spectra, intensity, and duration—meeting the specific needs of different plant species at varying growth stages. Using AI algorithms, the lighting systems will mimic the natural conditions of sunlight perfectly, creating a similar optimum condition that occurs with photosynthesis and, in turn, for the general health of plants.

An important advantage of Heliospectra solutions is the efficiency in energy consumption through the incorporation of AI technologies. With their systems, one can dynamically adjust lighting parameters based on real-time environmental data for minimal energy wastage and improved crop productivity. To this end, many of the lighting systems by Heliospectra come with smart sensors and IoT connection properties for remote control of light settings and monitoring.

Incompatible cases are likely Heliospectra's commitment to sustainability, which adopts the use of renewables, further by incorporating most of its lighting systems in association with solar panels in compatibility; hence, it has added a hand in reducing the environmental impact created by indoor farming operations. These integrations into renewable energy sources put Heliospectra in line with endeavors to further eco-friendly agricultural practices.

Heliospectra differentiates itself in the horticulture lighting industry by making a foray into the market for AI-driven products that effectively save on energy, moving fast towards sustainability. With advanced technology for plant biology and environmental stewardship underpinning its products, Heliospectra enables growers all over the world to improve productivity and quality in a sustainable indoor farm setting [39].

4. Plantix

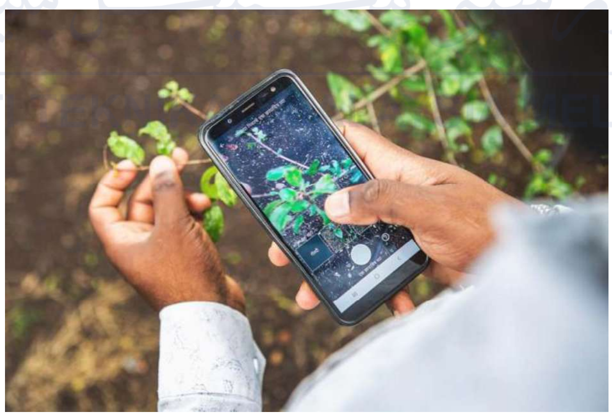

Figure 2.10: Plantix

Plantix is the mobile app. It employs information pertaining to AI and strategies for plant disease management through machine learning. Computer vision and AI algorithms make it possible with this app to diagnose crop problems like diseases, pests, and nutrient deficiencies. Photos of affected plant parts can be taken, uploaded,JOR and the mobile app's artificial intelligence interprets the image to give a fast and accurate diagnosis. The tool uploads the picture of the crop to its deep learning algorithms that recognize the pattern against an extensive, algorithmically-updated database containing every single disease and pest in crops--to arrive at the problem and alert the farmer, along with related symptoms, causes, and treatments recommended by the knowledge and standards in practice within the scientific spheres.

It also lets them know how their crops are growing and developing through the passage of time in the form of updates about their health. This application builds a kind of community of plant lovers and experts in this field where people even share information and experiences and also raise questions to others. It also offers its users a wide range of agricultural information and resources of their use End. Plantix's AI algorithms and disease diagnosis have continuously been improved through the constant collection and analysis of user interaction and image data. "Plantix" summarizes the use of AI and machine learning to help farmers, gardeners and crop enthusiasts identify and cure crop illnesses with high accuracy and precision. Make best of its crop care through AI-powered suggestions, growth tracking and community engagement features [40].

5. **SolarGem Greenhouse**

Figure 2.11: SolarGem Greenhouse

The SolarGem greenhouse is an advanced structure that provides maximum agricultural productivity with minimal energy inputs. Advanced technologies applied include solar panels, efficient insulation of the structure, and smart environmental control.

Basically, it absorbs the Discipline solar energy through strategically placed solar panels on its roof. These are photovoltaic panels that absorb energy from the sun, generating electricity to energize most systems that are used within the greenhouse. They cut dependence on outside energy supply and therefore environmentally friendly solutions. The SolarGem greenhouse has many unique features. First outstanding feature is the insulation. Materials used here, coupled with the construction methods, allow for minimal heat loss during cold seasons, hence allowing one to reach a constant and comfortable temperature inside the house. This helps to control humidity as well. During any sort of plant growth in controlled environments.

Also, the greenhouse incorporates automated intelligent environmental control systems. This technology employs advanced skills smarter than the user to maintain optimal environment conditions such as ideal temperature, humidity and ventilation among others automatically, thus reducing the monotony brought about by frequent adjustment. The SolarGem greenhouse boasts of an exceptionally practical design and environmentally friendly. It supports the notion of sustainable agriculture by offering optimum exploitation of renewable energy sources that naturally exist, like solar power and incorporation of advanced technologies managing the environment. Its microclimate control ability enables crops to be grown all year through, hence solving the seasonal cultivation issues. In general, the SolarGem greenhouse is a milestone in greenhouse technology and a representative of the way modern agricultural facilities can ensure high yields while guiding environment-friendly policies [41].

Review on Existing Systems of Hydroponic Systems Based on Mesh Networks

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.

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 [42].

2. Intelligent Managemen t of Hydroponic Systems Based on IoT for Agrifood Processes

Based on a research article, a mesh network operation is applied to the precision farming based on real-time monitoring and management of agriculture factors while designing and implementing a ZigBee-based wireless sensor network (WSN).

In the mesh network, there are c numbers of sensor nodes that are spread over the agricultural field and gather data on different parameters like temperature, humidity, light intensity, and soil moisture. This mesh topology enables data routing as the nodes communicate amongst each other, thereby leading to self-organization in-network.

Advantages of the mesh configuration within the scope of precision agriculture include scalability, resilience, and adjustability. It ensures efficient and reliable transmission of data using the meshing network, even in cases where there are obstacles or distances between all of the nodes.

A gateway node is also implemented to connect the mesh network and access a remote server. The gateway node gathers information from the sensing nodes and forwards it to the server to store and process this information, hence helping farmers monitor and manage agricultural parameters remotely and in real time.

It simply presents some information on the creation of a mesh network for use in Precision Agriculture and demostrates the benefits and operation of such a network in real-time, in monitoring and control of agricultural parameters [43].

Challenges and Future Directions in implementing solar powered AI-driven hydroponic system.

The potential admin with solar power and AI in hydroponic farming systems brings the latest technology in agriculture. They better crop yields while minimizing resource-associated and environmental degradation. However, immense challenges come with their transition to more sophisticated systems.

One of the most important is the unreliability of solar power. This energy resource is innately intermittent, based on the weather and daily cycles in sunlight. Most importantly, that factor demands reliable battery storage to be able to provide continuous energy, including during periods in which there is no direct sun. Currently, high costs and challenges in both of these technologies—batteries and solar—pose major hurdles. Another important question here is that leading a solar-driven, AI-powered hydroponic system is always costly. Usually it turns impossible for the small-scale farmers because of the cost on the installation of high-efficiency solar panels, sophisticated AI algorithms, the hydroponic infrastructure, etc. In addition, the integration of these technologies is quite complex and requires advanced technical skills, which may not be easy to implement for most farms. AI efficiency in operating hydroponic systems depends a great deal on the availability of vast and accurate data. Gathering and treating the data to feed the AI algorithm is an expensive task, aside from being difficult, because poor data deployment implies poor management decisions that cut across productivity in general [44].

Despite this, on the horizon of solar-powered AI-driven hydroponics, things look pretty bright. The increasing yet inevitable technological enhancements to solar efficiency and battery storage may make this technology more feasible for appropriation. Instead, economies of scale could possibly bring costs down in terms of their administration when the technology becomes widespread. AI algorithms could become better and enhance training programs that would equip individuals with skills to improve the adoption and functionality of such systems. With respect to the challenges described and building on the better possibilities presented, solar-powered AI-driven hydroponic systems provide the most outstanding potential for the transformation of modern agriculture into a more sustainable and efficient track for future generations [45].

2.10 Summary

All systems for AI and solar panel based hydroponics seem to suffer from the same drawbacks as far as dependency on technology and intricate issues are concerned. This is mainly due to the fact that Artificial Intelligence is used for gathering, storing and processing the huge amount of data that comes from the many sensors used in these systems. The handling of such huge data brings about the technical issues and dependency on them. Also, as part of highlighting the fact that the systems expandable and modifiable as well, with an increasing number of sensors, communication between all the increased numbers of sensors becomes quite complex, and simply, thus maintaining system functionality is often difficult. Also, this is due to the fact that since the solar panel is energy efficient and durable, need for high maintenance and complexity. However, the mesh network configuration has proved systems to be more scalable and robust, permitting more reliable communication between the different sensors. Thus, Artificial Intelligence with solar panel and a mesh network can ease out these problems and will result in a more efficient hydroponic system whose smart and intelligent features can boost their performance.

CHAPTER 3

METHODOLOGY

3.1 Introduction

The Hydroponics are done by using the Nutrient-Film Technique in this project. Continuously, a thin film of nutrient-rich water is circulated to the roots of the plants, giving them oxygen, nutrients, and water. On layers of polyethylene, the plants are grown. This material has been largely used to form channels or troughs through which nutrient-rich water streams around and exposes the roots of the plants to the elements needed. The polyethylene layers are continuously pounded by the nourishing solution. In turn, providing the plant's roots with the needed water and nutrients at consistent intervals. Functional ability as well as a control system incorporating Artificial Intelligence coupled with a variety of automation mechanisms. This artificial intelligence uses provided by various sensors such as Water level sensor, Ultrasonic sensor intelligently assess and provide the level of water needed to bring about the faster growth of crops. The integration of solar power offers sustainability and seamless operation of the system by converting the solar power to electrical energy and storing this in the power supply. All of this makes this environmentally friendly solution much more suitable for some remote off-grid locations. Due to the Mesh configuration, the constant flow of data and communication amongst the ESP32 nodes will permit redundancy, scalability, and high availability. The mesh configuration permits enclosed integration of these technologies to give a seamless running system where real-time system monitoring automates this type of monitoring.

3.2 Sustainable Development

Building on the same concern, sustainable agriculture can strike a balance between such rising demands of food while keeping the environment safe. Solar panel-driven automated hydroponic support by Artificial intelligence can be an ideal condition. In detail, the paper explains how the proposed approach will lead to sustainable agriculture practice adaptation, the use of renewable energy, land and biodiversity preservation, pollution reduction, and thereby food security for generations.

It means to grow plants without using soil. Water is used with nutrients. Through hydroponics, the surrounding environment is better controlled, leading to quicker plant growth and higher yields. In such automated hydroponics systems, AI controls many factors like levels of nutrients, and exposure to light, so that plants get exactly what is needed, hence minimizing wastage and maximizing their productivity [46].

Solar panels in hydroponic systems are a clean and sustainable form of energy. The panels acquire energy from light and therefore reduce fossil fuel use and greenhouse gas emissions. Solar power can even power the entire system where the sun is in rich supply. It is clean, cheap, and sustainable. Through a Battery storage solutions offer a continuous flow of electricity, the plants have an adequate supply of power.

Hydroponic method needs less space than traditional farming, which helps protect natural habitats and biodiversity. They can be set up in urban areas or even vertically, using space efficiently. Controlled environments reduce the need for pesticides, benefiting wildlife and conserving biodiversity.

Hydroponic systems use a closed-loop system, recycling water and nutrients, which reduces agricultural runoff and water pollution. Precision in nutrient delivery means fewer chemicals are used, lowering pollution levels. Solar-powered systems also produce less air pollution than traditional farming machinery.

Automated hydroponic systems provide consistent, high-quality food production regardless of external conditions. They can grow crops year-round, enhancing food availability and stability. This efficiency helps meet the needs of urban populations and reduces the carbon footprint of food transportation.

Automated hydroponic systems using solar panels and Artificial Intelligence offer a sustainable approach to agriculture. They optimize resources, conserve land, reduce pollution, and enhance food security, supporting a more resilient and environmentally friendly food system for the future [47].

3.3 Block Diagram

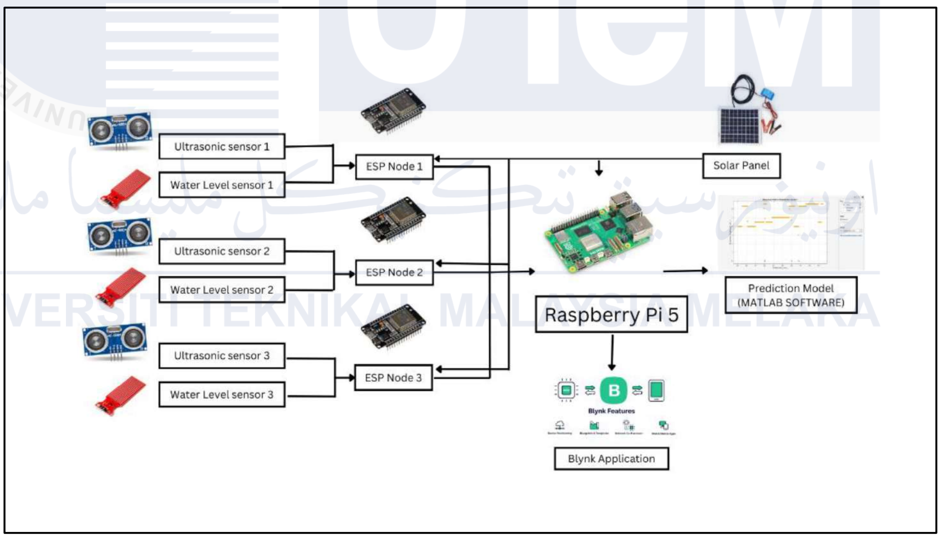

Figure 3.1: Block Diagram

Figure 3.1 shows the block diagram which represents the integration of various sensors and components in an automated hydroponic system managed by a Raspberry Pi 5. Ultrasonic Sensors (three in total) are responsible for measuring the height of the plants. They are Connected to the respective water level sensors and ESP32 nodes. Water Level Sensors (three in total), they measure the Water levels in the hydroponic system. Every water level sensor is connected to an ultrasonic sensor and also ESP32 node. There are three ESP32 nodes, every ESP32 node is connected by a pair of ultrasonic and water level sensors. These nodes collect data from the sensors and send it to the central Raspberry Pi 5. The system's central point is the Raspberry Pi 5. It collects data from the ESP32 nodes. Raspberry Pi 5 processes the collected data and utilizes a prediction model as created using MATLAB to research and further make decision on the gathered information from the sensors. The Blynk application is also incorporated with the Raspberry Pi 5. Hence, it is connected as if which user can easily control and monitor the hydroponic system with a mobile device. This application is embedded with live updating and alert mechanisms, which thus allows easy control of the system by the user to easily manage.Finally, solar panels convert sunlight into electricity, which is regulated by a charge controller to provide stable power. This power is then delivered to microcontrollers, ensuring they operate efficiently while enabling sustainable and off-grid functionality. In Summary, this complex interlinked hydroponic system in which the sensors gather the vital data that the ESP32 nodes send to the main control Raspberry Pi interprets the data through a predilection model and delivers the status of the system and its data to the user through the Blynk application for easy management and maintenance.

Table 3.1 : 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)

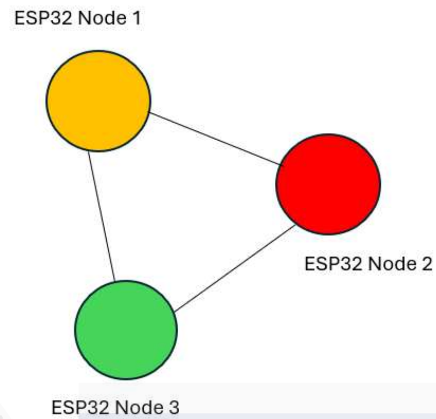

Figure 3.2: Full mesh network topology

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 3.1 shows the network setup of the system's mesh configuration.

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 5 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 5. The Raspberry Pi 5 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

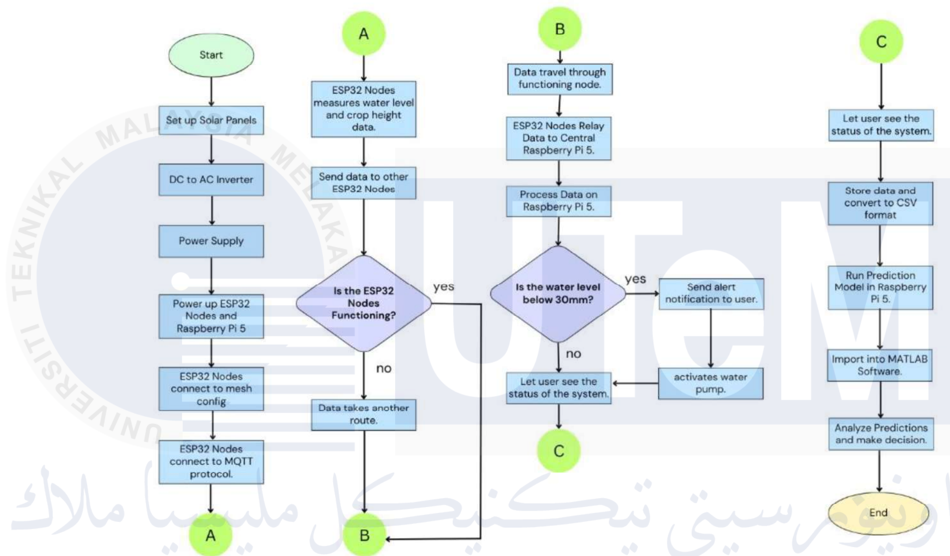

Figure 3.3: Flow Chart

Figure 3.3 shows a flowchart describing a system designed for monitoring and managing water levels and crop height using ESP32 nodes and a Raspberry Pi 5, all powered by renewable solar energy. The process begins with setting up solar panels to generate energy. The direct current (DC) produced by the panels is converted to alternating current (AC) using an inverter, which powers the entire system. The power supply activates the ESP32 nodes and Raspberry Pi 5, essential components of the setup. Once powered on, the ESP32 nodes connect to a mesh network configuration for seamless communication. They also establish a connection using the MQTT protocol, which facilitates efficient data transmission between nodes. The ESP32 nodes are programmed to measure vital parameters, such as water levels and crop height. This data is then transmitted to other ESP32 nodes within the network. A check is performed to determine whether all the ESP32 nodes are functioning correctly. If the nodes are operational, the data continues to travel through the network. If any node fails, the data takes an alternate route to ensure the system remains functional.

The collected data is relayed to the central Raspberry Pi 5, where it is processed. A critical check is then performed to assess whether the water level is below 30mm. If the water level is insufficient, an alert notification is sent to the user, and the water pump is activated to address the issue. If the water level is adequate, the system status is displayed to the user for monitoring purposes. The system also stores the collected data, converting it into a CSV format for further analysis. The Raspberry Pi 5 runs a prediction model to analyze trends and patterns in the data, which is then imported into MATLAB software for advanced analysis. Based on the insights gained, decisions are made to optimize the system's performance and support efficient agricultural practices, marking the end of the process.

3.5 Solar Energy Setup

3.5.1 Solar Panel

Figure 3.4: Solar Panel 12V

solar panels are essential in providing energy to the hydroponic system [48]. Made up of photovoltaic cells, they produce electricity from sunshine. It is a native, non-polluting source of energy, which is useful in regions that have no hopes of getting the usual power supply. Solar panels bring a reduction in energy expenses and dependence on fossil fuel, hence, making it environmentally friendly. In such a system, continuous power availability from solar panels is required to run pumps, fans, and other necessary accessories continuously.

3.5.2 DC to AC inverter

Figure 3.5: DC to AC inverter

The form of energy generated by the solar panels is DC. Most electrical equipment, however, uses AC [49]. DC to AC inverter is a must, therefore, be installed such that the DC power generated from Solar Panel is changed into AC. This would enable the electricity generated from the Solar Panel to be used in standardized and general household equipment and items. In general, an inverter is vital for the hydroponic system's efficiency and operation.

3.5.3 Power Supply

Figure 3.6: 12V Battery

The power supply unit is responsible for the distribution of the converted AC power to other parts of the hydroponic system [50]. This unit assures proper electricity to devices numbering from sensors to microcontrollers and all the way to pumps. A reliable power supply is very critical as far as the stability of the system is concerned and prevention of problems related to power that might harm plant growth .

3.6 ESP32 Node Configuration

```
#include <painlessMesh.h>
#include <WiFi.h>
#include <PubSubClient.h>
#include <BlynkSimpleEsp32.h> // Include the Blynk library

// Define Blynk template and auth token
#define BLYNK_TEMPLATE_ID "TMPL68yV-1Fgm"
#define BLYNK_TEMPLATE_NAME "FYP Hydroponic system"
#define BLYNK_AUTH_TOKEN "IBDLbv50l6FxnvSNnA9nvMkGIeF_DPAI"
#define BLYNK_PRINT Serial

// Wi-Fi credentials
const char* ssid = "Kriss_Mesh";
const char* password = "kristisswaran";

// Mesh network settings
#define MESH_PREFIX "Kriss_Mesh"
#define MESH_PASSWORD "2444666668888888"
#define MESH_PORT 5555

// Pin definitions
#define echoPin 2               // Echo pin of ultrasonic sensor
#define trigPin 4               // Trigger pin of ultrasonic sensor
#define POWER_PIN  17           // Power pin for water level sensor
#define SIGNAL_PIN 36           // Analog signal pin for water level sensor
#define sensorPin SIGNAL_PIN    // Alias for water level sensor signal pin
#define ultrasonicTrigPin trigPin  // Alias for ultrasonic trigger pin
#define ultrasonicEchoPin echoPin  // Alias for ultrasonic echo pin

```

```
// Variables
long duration, height;
int waterLevel = 0;  // Variable to store water level sensor value
float waterlevel;
float cropHeight;

// Scheduler and mesh objects
Scheduler userScheduler;
painlessMesh mesh;

// MQTT settings
const char* mqttServer = "192.168.218.233";
const int mqttPort = 1883;
const char* mqttUser = "kriss02";
const char* mqttPassword = "kriss02";
const char* mqttTopicWaterLevel = "node3/waterLevel";
const char* mqttTopicCropHeight = "node3/cropHeight";

// Blynk auth token
char auth[] = "IBDLbv50l6FxnvSNnA9nvMkGIeF_DPAI";

WiFiClient wifiClient;
PubSubClient client(wifiClient);

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

```

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

  // Mesh network setup
  mesh.setDebugMsgTypes(ERROR | STARTUP);
  mesh.init(MESH_PREFIX, MESH_PASSWORD, &userScheduler, MESH_PORT);
  mesh.onReceive(&receivedCallback);
  mesh.onNewConnection(&newConnectionCallback);

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

  // Pin configurations
  pinMode(sensorPin, INPUT);
  pinMode(ultrasonicTrigPin, OUTPUT);
  pinMode(ultrasonicEchoPin, INPUT);

  // Blynk initialization
  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

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

  // Print sensor readings
  Serial.print("Node 3 - Water Level (mm): ");
  Serial.println(waterlevel);
  Serial.print("Node 3 - 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; // Convert to centimeters
  float ultrasonicReading = duration * 0.034 / 2.0;

  float cropHeight = sensorDistance - ultrasonicReading;

  return cropHeight;
}

void sendMessage() {
  String msg = "Water level data from Node ";
  msg += mesh.getNodeId();
  msg += ", Water level: " + String(waterlevel) + ", Crop Height: " + String(cropHeight);

  mesh.sendBroadcast(msg);
  taskSendMessage.setInterval(random(TASK_SECOND * 1, TASK_SECOND * 5));
}

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 3.7: Coding of ESP32 Node

```
#include <painlessMesh.h>
#include <WiFi.h>
#include <PubSubClient.h>
#include <BlynkSimpleEsp32.h> // Include the Blynk library

// Define Blynk template and auth token
#define BLYNK_TEMPLATE_ID "TMPL68yV-1Fgm"
#define BLYNK_TEMPLATE_NAME "FYP Hydroponic system"
#define BLYNK_AUTH_TOKEN "IBDLbv50l6FxnvSNnA9nvMkGIeF_DPAI"
#define BLYNK_PRINT Serial
```

Figure 3.8: Defining the libraries.

Figure 3.8 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.


```
// Wi-Fi credentials
const char* ssid = "Kriss_Mesh";
const char* password = "kristisswaran";
```

Figure 3.9: Wi-Fi configuration.

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

```
// Mesh network settings
#define MESH_PREFIX "Kriss_Mesh"
#define MESH_PASSWORD "2444666668888888"
#define MESH_PORT 5555
```

Figure 3.10: 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.

```
// Pin definitions
#define echoPin 2                // Echo pin of ultrasonic sensor
#define trigPin 4                // Trigger pin of ultrasonic sensor
#define POWER_PIN  17            // Power pin for water level sensor
#define SIGNAL_PIN 36            // Analog signal pin for water level sensor
#define sensorPin SIGNAL_PIN     // Alias for water level sensor signal pin
#define ultrasonicTrigPin trigPin  // Alias for ultrasonic trigger pin
#define ultrasonicEchoPin echoPin  // Alias for ultrasonic echo pin
```

Figure 3.11: GPIO pins configuration

The GPIO pin assignments in the provided code define the connections for ultrasonic sensors and water level sensors in the system. For the ultrasonic sensors, all three nodes use the same GPIO pins: the trigger pin is connected to GPIO 14, and the echo pin is connected to GPIO 12. For the water level sensors, each node is assigned a unique GPIO pin for its signal: GPIO 33 for Node 1, GPIO 34 for Node 2, and GPIO 35 for Node 3. The code uses aliases such as *ultrasonicTrigPin* and *ultrasonicEchoPin* for the ultrasonic trigger and echo pins, respectively, and *sensorPin* as an alias for the water level sensor's signal pin. These aliases and definitions improve code readability and ensure consistency in assigning and managing hardware-specific GPIO connections.

```
// Scheduler and mesh objects
Scheduler userScheduler;
painlessMesh mesh;
```

Figure 3.12: Scheduler for user configuration

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

```
// Variables
long duration, height;
int waterLevel = 0;  // Variable to store water level sensor value
float waterlevel;
float cropHeight;
```

Figure 3.13: 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 3.14: Declaration of functions

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

```
// MQTT settings
const char* mqttServer = "192.168.218.233";
const int mqttPort = 1883;
const char* mqttUser = "kriss02";
const char* mqttPassword = "kriss02";
const char* mqttTopicWaterLevel = "node3/waterLevel";
const char* mqttTopicCropHeight = "node3/cropHeight";
```

Figure 3.15: 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 3.

```
// Blynk auth token
char auth[] = "IBDLbv50l6FxnvSNnA9nvMkGIeF_DPAI";

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

Figure 3.16: 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 network setup
  mesh.setDebugMsgTypes(ERROR | STARTUP);
  mesh.init(MESH_PREFIX, MESH_PASSWORD, &userScheduler, MESH_PORT);
  mesh.onReceive(&receivedCallback);
  mesh.onNewConnection(&newConnectionCallback);

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

  // Pin configurations
  pinMode(sensorPin, INPUT);
  pinMode(ultrasonicTrigPin, OUTPUT);
  pinMode(ultrasonicEchoPin, INPUT);

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


Figure 3.17: 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

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

  // Print sensor readings
  Serial.print("Node 3 - Water Level (mm): ");
  Serial.println(waterlevel);
  Serial.print("Node 3 - 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 3.18: 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; // Convert to centimeters
  float ultrasonicReading = duration * 0.034 / 2.0;

  float cropHeight = sensorDistance - ultrasonicReading;

  return cropHeight;
}
```

Figure 3.19: 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() {
  String msg = "Water level data from Node ";
  msg += mesh.getNodeId();
  msg += ", Water level: " + String(waterlevel) + ", Crop Height: " + String(cropHeight);

  mesh.sendBroadcast(msg);
  taskSendMessage.setInterval(random(TASK_SECOND * 1, TASK_SECOND * 5));
}
```

Figure 3.20: 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 3.21: 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 2 utilize the same coding template except for the changes in the water level sensor pins, virtual pins for Blynk connections and the declaration of "node3".

3.7 Raspberry Pi Configuration

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

# MQTT settings
mqtt_broker = "192.168.218.233"
mqtt_port = 1883
mqtt_user = "kriss02"
mqtt_password = "kriss02"

# Blynk settings
blynk_auth_token = "IBDLbv50l6FxnvSNnA9nvMkGIeF_DPAI"

# Blynk initialization
blynk = Blynk(blynk_auth_token)

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

```

```python
# 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]

```

```python
# 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 = "cropHeight"
    unit = ""

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

```

```python
# Check if both measurements are available for the node
if "waterlevel" in node_measurements[node_number] and "cropHeight" in node_measurement[node_number]:
    # Print the fromatted message
    formatted_message = f"Node {node_number} - waterlevel: {node_measurements[node_number]}"
    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]

```

```python
# 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 CSV file
def append_to_csv(data):
    csv_file_path = "node_data.csv"

# 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"])
```

```python

# 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 relavant information
def parse_data(data):
    parts = data.split(" - ")
    node_number = parts[0].split(" ")[-1]
    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

```

```python
# 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 3.22: 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 giving notification for on the water pump.

3.8 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 3.23.

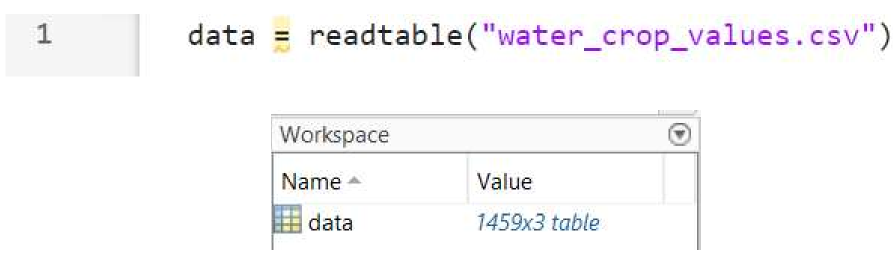

Figure 3.23: Sensor data stored in Workspace.

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.

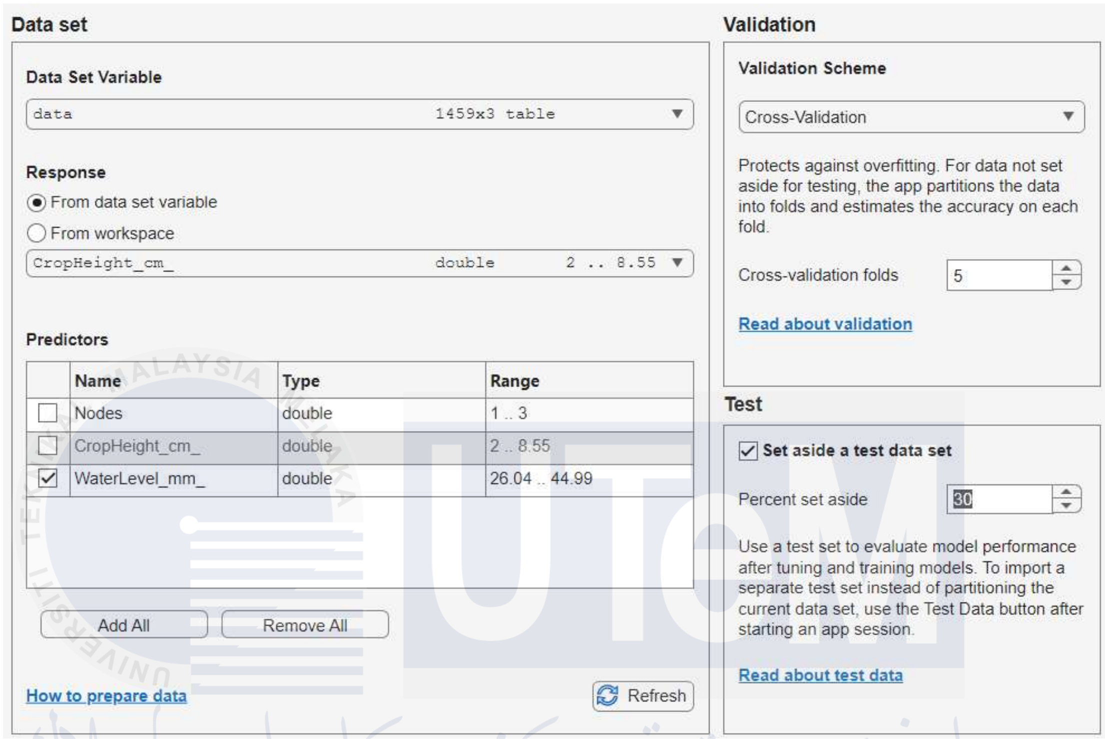

Figure 3.24: Regression Model configuration.

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.

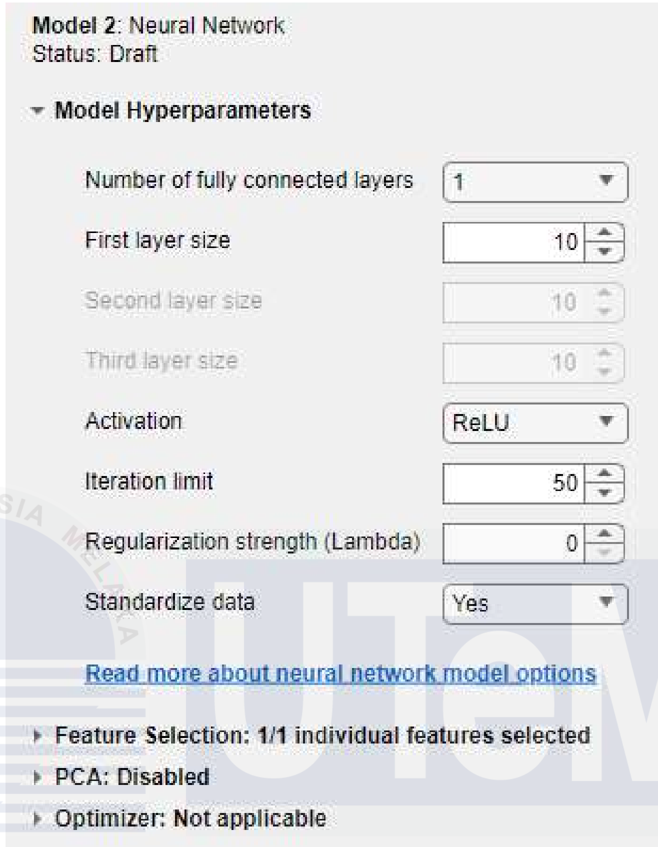

Figure 3.25: Narrow Neural Network configuration.

The model is trained using the Narrow Neural Network as shown in Figure 3.25. 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.

3.9 Smart Plug

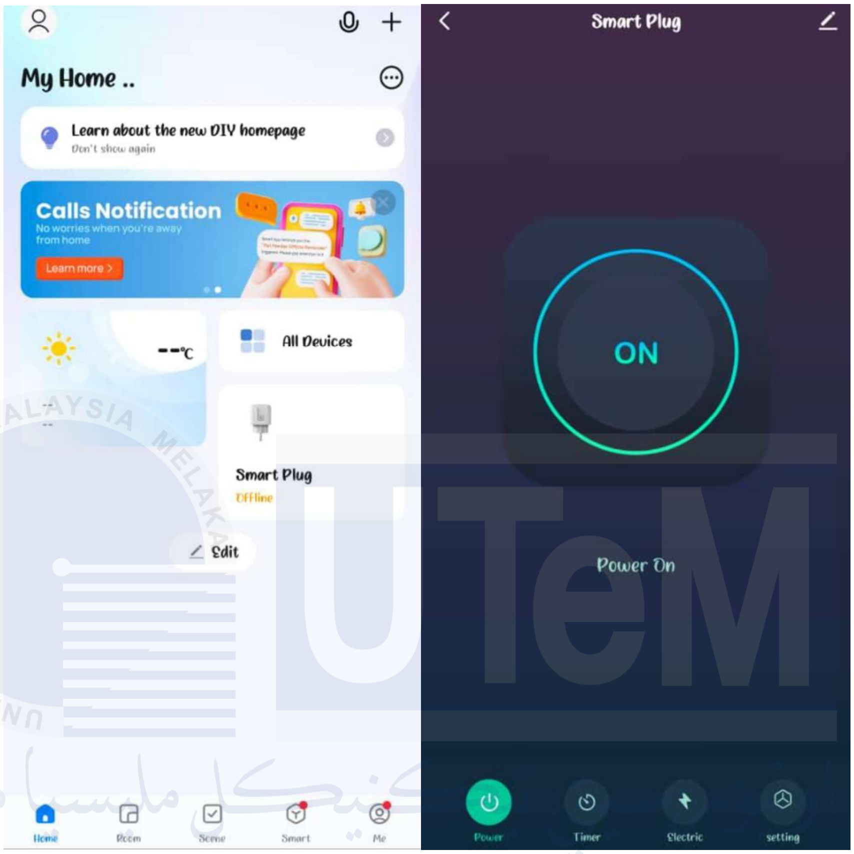

Figure 3.26: smart plug Dashboard

I set up a smart plug controlled by the Smart Life app to automate the operation of a water pump in my hydroponic system. The smart plug was connected to the internet, allowing me to remotely turn the pump on or off using my phone. The system works in coordination with sensors connected to ESP32 nodes, which monitor the water level in the hydroponic system. These sensors are integrated with the Blynk app, which sends notifications to my phone whenever the water level is low. Upon receiving a notification, I turn on the water pump via the smart plug to refill the water. Once the water reaches the required level, I turn off the pump using the app. This setup ensures efficient water management and allows remote control, providing convenience and reliability for maintaining the hydroponic system.

3.10 Summary

This project uses the Nutrient-Film Technique (NFT) for hydroponics, using polyethylene channels to continuously supply a thin layer of nutrient-rich water over plant roots. Water level sensors collect data to optimize growth by adding the right amounts of nutrients and water. This system is powered via solar panels that convert sunlight into electricity to that end, reducing fossil fuel reliance. The inverter then uses this power-to-power ESP32 nodes and a Raspberry Pi 5. ESP32 nodes mesh to create a strong network of communication. Information from sensors is sent to the Raspberry Pi 5 for analysis. The central unit, with a MATLAB-developed machine learning model, predicts and makes any necessary adjustments needed to achieve and sustain optimal conditions. A smart plug is integrated into the system to automate the operation of the water pump based on notifications from the Blynk app. Through the integration of hydroponics, AI, solar energy, and sensor networking, this truly sustainable solution for professional agriculture conserves and minimizes pollution while offering stable food production.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Introduction

This section presents the results and discussion of the outputs from various components of the system, including the serial monitor of the Arduino IDE, the terminal of the Raspberry Pi, and the outcomes of the prediction model. The prediction model was developed using test data collected from the water level sensor and ultrasonic sensor. The simulation was conducted in MATLAB Software using the Regression Learner application. For this, the sensor data, organized in a CSV file, was imported into the MATLAB editor and saved in the Workspace. The Regression Learner application then used the data from the Workspace to plot a response curve [51].

The primary goal of this simulation was to create an accurate prediction model capable of estimating crop height based on sensor data within the hydroponic system. The analysis of the results provides valuable insights into the effectiveness and efficiency of the prediction model in achieving the objectives of the hydroponic system.

4.2 Results and Analysis

4.2.1 Hydroponic System Setup

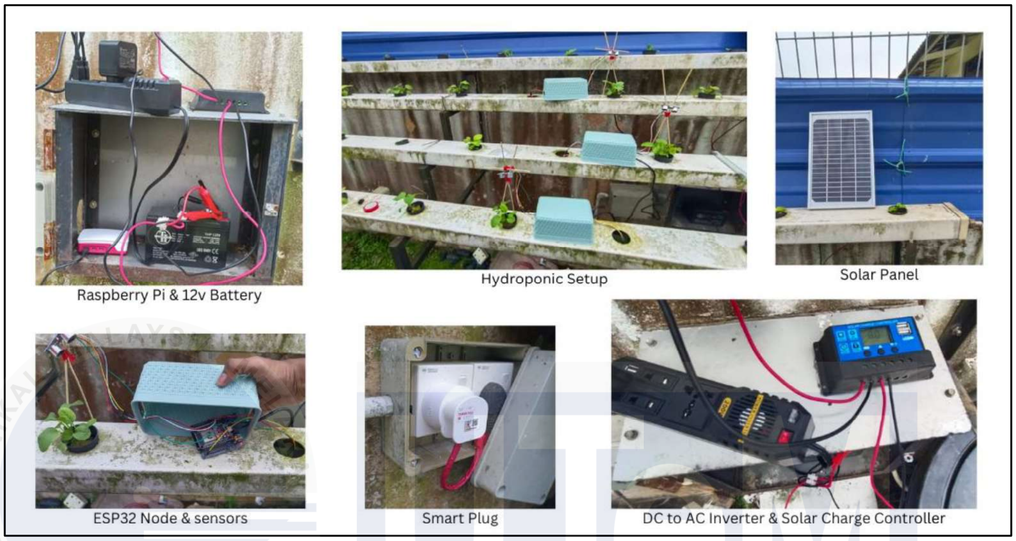

Figure 4.1: Hydroponic System Setup at Pertubuhan Kebajikan Villa Harapan, Melaka

Figure 4.1 shows the hydroponic system setup at Pertubuhan Kebajikan Villa Harapan, which was setup to measure the crop height and the water level of it. The system features a Raspberry Pi as the main computational connected to a 12V battery for central control, 3 ESP32 microcontrollers integrated with ultrasonic sensors and water level sensors to monitor the variables, crop height and water level, and a smart plug for remote water flow in the tank. Solar panels provide renewable energy, which is regulated through an DC to AC inverter and a solar charge controller for efficient power conversion and storage. This hydroponic system are aligned to provide a soil-less growing environment, with nutrient-rich water flowing through them to support plant health and growth. This setup demonstrates a practical and eco-friendly approach to modern farming, combining technology and sustainability.

4.2.2 ESP32 Nodes

```
Output    Serial Monitor ×
Message (Enter to send message to 'ESP32 Dev Module' on 'COM3')
                                          Message (Enter to send message to 'ESP32 Dev Module' on 'COM3')
00:30:39.475 -> Received from 3583384193 msg=Water level [illegible] mm, Crop Height: 5.48 cm
00:30:39.475 -> Node 1 - Water Level (mm): 33.63
00:30:39.475 -> Node 1 - Crop Height (cm): 4.51
00:30:40.490 -> Received from 3583383613 msg=Water level data from Node 3583383613, Water level: 37.95 mm, Crop Height: 2.83 cm
00:30:40.490 -> Node 1 - Water Level (mm): 34.90
00:30:40.490 -> Node 1 - Crop Height (cm): 4.53
00:30:41.479 -> Received from 3583384193 msg=Water level data from Node 3583384193, Water level: 14.75 mm, Crop Height: 4.48 cm
00:30:41.479 -> Node 1 - Water Level (mm): 40.40
00:30:41.517 -> Node 1 - Crop Height (cm): 4.85
00:30:42.489 -> Received from 3583383613 msg=Water level data from Node 3583383613, Water level: 44.22 mm, Crop Height: 1.45 cm
00:30:42.536 -> Node 1 - Water Level (mm): 38.38
00:30:42.536 -> Node 1 - Crop Height (cm): 4.85
00:30:43.544 -> Node 1 - Water Level (mm): 35.15
00:30:43.544 -> Node 1 - Crop Height (cm): 4.85
00:30:44.562 -> Node 1 - Water Level (mm): 25.83
00:30:44.562 -> Node 1 - Crop Height (cm): 4.85
00:30:45.566 -> Node 1 - Water Level (mm): 16.85
00:30:45.566 -> Node 1 - Crop Height (cm): 4.87
00:30:46.545 -> Received from 3583384193 msg=Water level data from Node 3583384193, Water level: 14.35 mm, Crop Height: 4.48 cm
00:30:46.578 -> Received from 3583383613 msg=Water level data from Node 3583383613, Water level: 31.67 mm, Crop Height: 1.13 cm
00:30:46.578 -> Node 1 - Water Level (mm): 47.38
00:30:46.578 -> Node 1 - Crop Height (cm): 4.87
00:30:47.606 -> Node 1 - Water Level (mm): 25.45
00:30:47.606 -> Node 1 - Crop Height (cm): 8.83
```

Figure 4.2: Results of Serial Monitor

The Serial Monitor output from the Arduino IDE, as shown in the figure, demonstrates the expected results configured in Figure 3.7. It displays water level data (in millimeters) and crop height data (in centimeters) from Node 1 of the ESP32 system, with a 1-second delay between updates. After some time, the Serial Monitor indicates, "New Connection has been established," referring to connections with ESP32 Node 2 and Node 3. This confirms that Node 1 successfully interconnects with the other nodes, forming a functional mesh network. Once this message appears, Node 1 begins receiving water level and crop height data from the other two nodes. The output also identifies the source of the transmitted data, further proving that data generated by Node 1 is equally shared with the other nodes. This simultaneous communication and data exchange between nodes create a robust hydroponic system with improved redundancy.

The implementation of the ESP32 mesh configuration significantly enhances the reliability of the wireless communication network within the hydroponic system. The mesh network ensures robustness against individual node failures or communication disruptions.

Even if one node encounters an issue, the overall network remains operational, which is vital for uninterrupted monitoring and control in agricultural applications.

Furthermore, the mesh configuration supports scalability, allowing sensor nodes to be added or removed easily without compromising network performance. This adaptability is essential for accommodating system expansion or modifications, ensuring the hydroponic system evolves seamlessly with changing requirements.

Lastly, the mesh topology offers redundancy and resilience. With multiple communication paths between ESP32 nodes, the network can reroute data if one path is obstructed. This redundancy ensures continuous transmission of water level and crop height data, strengthening the system's resilience in challenging environmental conditions and maintaining consistent data monitoring within the hydroponic setup.

4.2.3 Raspberry Pi 5

```
Node 1 - waterLevel: 33.17 mm - cropHeight: 12.38 cm
Node 2 - waterLevel: 34.14 mm - cropHeight: 13.35 cm
Node 3 - waterLevel: 27.06 mm - cropHeight: 13.33 cm
Node 1 - waterLevel: 33.11 mm - cropHeight: 12.38 cm
Node 2 - waterLevel: 34.11 mm - cropHeight: 13.35 cm
Node 3 - waterLevel: 27.14 mm - cropHeight: 13.33 cm
Node 1 - waterLevel: 33.28 mm - cropHeight: 12.38 cm
Node 2 - waterLevel: 34.02 mm - cropHeight: 13.35 cm
Node 3 - waterLevel: 27.43 mm - cropHeight: 13.33 cm
Node 1 - waterLevel: 33.86 mm - cropHeight: 12.36 cm
Node 2 - waterLevel: 34.07 mm - cropHeight: 13.35 cm
Node 3 - waterLevel: 27.44 mm - cropHeight: 13.33 cm
Node 1 - waterLevel: 33.10 mm - cropHeight: 12.36 cm
Node 2 - waterLevel: 34.03 mm - cropHeight: 13.35 cm
Node 3 - waterLevel: 27.52 mm - cropHeight: 13.33 cm
Node 1 - waterLevel: 33.16 mm - cropHeight: 12.38 cm
Node 2 - waterLevel: 33.57 mm - cropHeight: 13.35 cm
Node 3 - waterLevel: 27.98 mm - cropHeight: 13.33 cm
Node 1 - waterLevel: 33.10 mm - cropHeight: 12.38 cm
Node 2 - waterLevel: 33.93 mm - cropHeight: 13.35 cm
Node 3 - waterLevel: 27.87 mm - cropHeight: 13.33 cm
Node 1 - waterLevel: 33.12 mm - cropHeight: 12.36 cm
Node 2 - waterLevel: 33.94 mm - cropHeight: 13.35 cm
```

Figure 4.3: 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 3.22 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.

```
Node 1 - waterLevel: 33.19 mm - cropHeight: 12.38 cm
Node 3 - waterLevel: 27.68 mm - cropHeight: 13.33 cm
Node 1 - waterLevel: 33.25 mm - cropHeight: 12.38 cm
Node 3 - waterLevel: 27.87 mm - cropHeight: 13.33 cm
Node 1 - waterLevel: 33.83 mm - cropHeight: 12.38 cm
Node 3 - waterLevel: 27.17 mm - cropHeight: 13.33 cm
Node 1 - waterLevel: 33.14 mm - cropHeight: 12.36 cm
Node 3 - waterLevel: 26.87 mm - cropHeight: 13.33 cm
Node 1 - waterLevel: 33.12 mm - cropHeight: 12.38 cm
Node 3 - waterLevel: 26.66 mm - cropHeight: 13.33 cm
Node 1 - waterLevel: 33.12 mm - cropHeight: 12.38 cm
Node 3 - waterLevel: 26.91 mm - cropHeight: 13.33 cm
Node 1 - waterLevel: 33.25 mm - cropHeight: 12.38 cm
Node 3 - waterLevel: 26.86 mm - cropHeight: 13.33 cm
Node 1 - waterLevel: 33.38 mm - cropHeight: 12.38 cm
Node 3 - waterLevel: 27.31 mm - cropHeight: 13.33 cm
Node 1 - waterLevel: 33.14 mm - cropHeight: 12.38 cm
Node 3 - waterLevel: 27.19 mm - cropHeight: 13.33 cm
Node 1 - waterLevel: 33.06 mm - cropHeight: 12.38 cm
Node 3 - waterLevel: 27.37 mm - cropHeight: 13.33 cm
Node 1 - waterLevel: 32.99 mm - cropHeight: 12.38 cm
Node 3 - waterLevel: 27.54 mm - cropHeight: 13.33 cm
Node 1 - waterLevel: 33.13 mm - cropHeight: 12.38 cm
```

Figure 4.4: 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 ESP32 nodes 1 and 3 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	Nodes	Crop Height (cm)	Water Level (mm)
2	1	7.01	26.04
3	1	8.55	26.04
4	3	6	26.05
5	3	7.01	26.05
6	3	8.55	26.06
7	2	8.55	26.1
8	2	8.3	26.11
9	1	7.01	26.12
10	3	8.55	26.12
11	3	8.3	26.14
12	2	8.3	26.15
13	2	8.3	26.15
14	1	8.55	26.16
15	3	6.5	26.17
16	1	7.01	26.17
17	1	6	26.18
18	3	6.5	26.18
19	1	7.01	26.2
20	2	8.3	26.21
21	3	8.55	26.21
22	1	8.55	26.27
23	3	7.01	26.28
24	1	7.01	26.29
25	3	8.3	26.31
26	1	6.5	26.32

Figure 4.5: 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.

4.2.4 Prediction Model

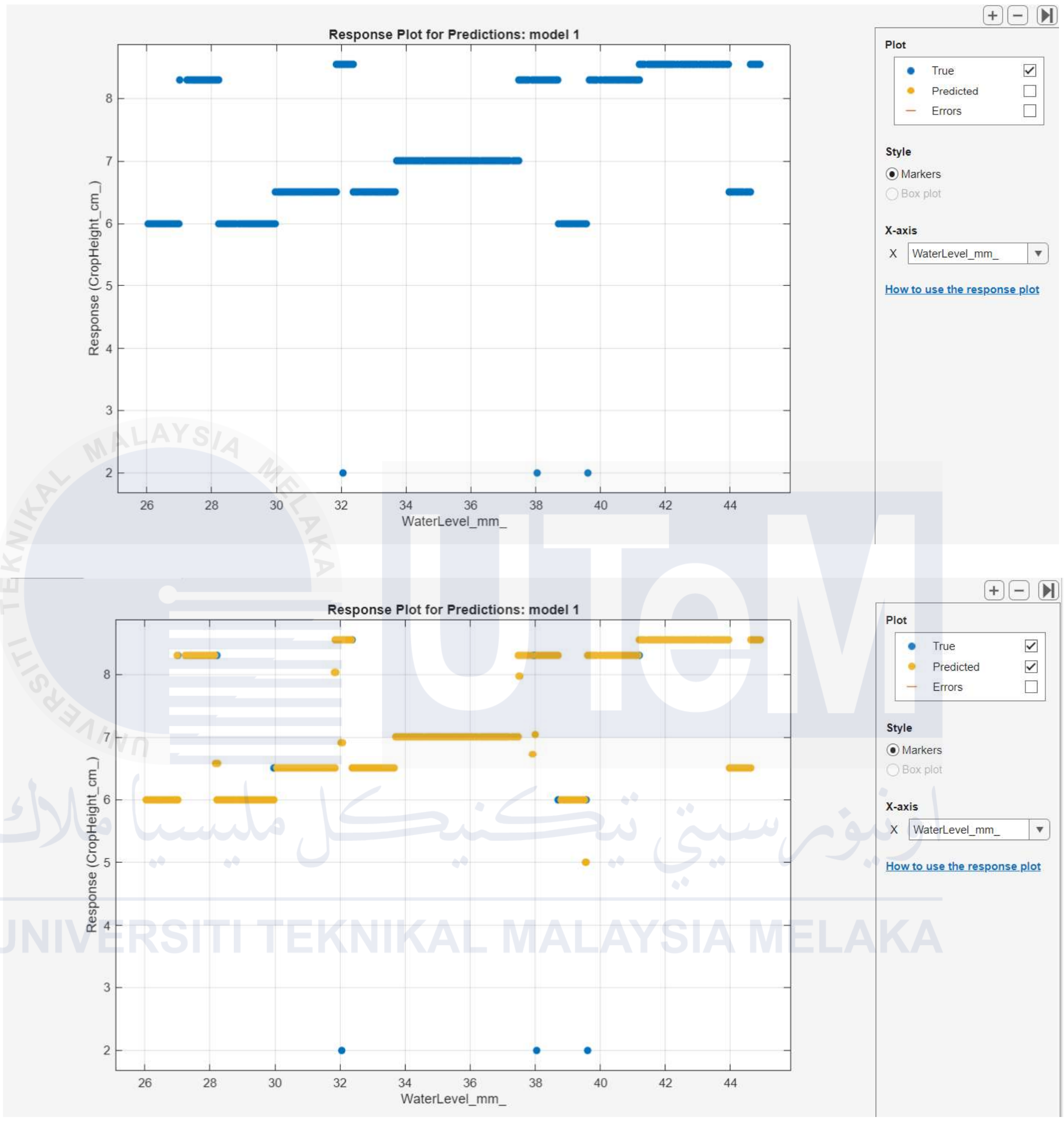

Figure 4.6:Prediction model of system

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 1: Tree
Status: Tested

Training Results

RMSE (Validation)	0.43351
R-Squared (Validation)	0.82
MSE (Validation)	0.18793
MAE (Validation)	0.059623
MAPE (Validation)	1.5%
Prediction speed	~130000 obs/sec
Training time	0.90943 sec
Model size (Compact)	~7 kB

Test Results

RMSE (Test)	0.24120
R-Squared (Test)	0.94
MSE (Test)	0.058179
MAE (Test)	0.036229
MAPE (Test)	0.5%

Figure 4.7: 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 0.43351 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 0.24 units from the actual crop height.

Then, the R-squared value of 0.82 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 0.82 suggests that approximately 82% of the variability in crop height is accounted for by the water level. This indicates that there are other minor factors influencing the 18% of the crop height beyond the water level.

Next, the MSE of 0.058179 is the average of the squared differences between predicted and actual values. Like RMSE, it provides a measure of prediction error. In this context, the

MSE indicates that, on average, the squared prediction errors amount to 0.05, emphasizing the significance of minimizing both large and small errors.

Finally, the MAE of 0.036229 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 0.05 units from the true crop height.

4.2.5 Blynk Application

Figure 4.8: 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/683666/global/devices/1/organization/683666/devices/2932470/dashboard .

Firstly, a new template was created and was named “FYP Hydroponic System”. Then, new data streams were created based on three water level and ultrasonic sensors. Each of the data streams were assigned with virtual pins from V1 to V6. 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 and crop height readings of each sensor. A new device was named after the user’s name “FYP Hydroponic System”.

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.

4.2.6 Solar Energy

Figure 4.9: Solar Charge Controller

The device shown in Figure 4.10 is a solar charge controller, an essential component of solar-powered systems. Its primary role is to regulate the voltage and current from solar panels to ensure the safe and efficient charging of batteries. By doing so, it prevents issues like overcharging or over-discharging, which could potentially damage the batteries and reduce their lifespan. Additionally, the solar charge controller ensures the stability of the system by managing power output to connected devices, often incorporating safeguards like automatic cut-off to protect the battery from over-discharge.

This specific model features an LCD screen that displays real-time data, including the battery's current voltage (shown as 11.1V), system load status, and other settings. The buttons below the display allow users to adjust operational parameters, such as voltage thresholds and timer settings. Moreover, the battery is sufficient for the four devices to operate. Additionally, the solar panel will collect power during the day, even at sunset. In case the battery is depleted, the Blynk app will display the values as 0. This will help me understand that there's a power shortage, so I can visit the site and charge the battery.

This solar charge controller is being utilized in this project which plays a critical role in powering the ESP32 Nodes and the Raspberry Pi using solar energy, making the setup energy-efficient and environmentally friendly. By incorporating this device, the system operates autonomously, reducing dependency on traditional power sources and promoting sustainable agriculture practices.

4.2.7 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, Wide Neural Network, and Narrow 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: Prediction Models Performances Model/ Parameters	Tree	Wide Neural Network	Narrow Neural Network
RMSE	0.44701	0.50542	0.78144
R Squared	0.81	0.76	0.42
MAE	0.066649	0.23856	0.53145
MSE	0.19982	0.25545	0.61066
Prediction Time (obs/ sec)	92000	75000	32000
Training Time (sec)	1.8805	6.3115	4.3243

Table 4.1 : Prediction Models Performances

Table 4.1 shows the 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, Wide Neural Network, and Narrow Neural Network were assessed to achieve this goal. The Wide Neural Network demonstrated competitive accuracy metrics with a Root Mean Squared Error (RMSE) of 0.50542 and an Absolute Error (MAE) of 0.23856, demonstrating its interpretability and simplicity. Although a little less precise, the Narrow Neural Network demonstrated its usefulness in high-dimensional spaces.

However, the sophisticated AI Decision Tree was the clear winner, including an astounding Mean Absolute Error (MAE) of 0.066649, a Root Mean Squared Error (RMSE) of 0.44701, and the highest R-squared value of 0.81, 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 Decision Tree 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, 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 Comparison Between Previous Works and Proposed Hydroponic System

Aspect	**Previous Work** [51]	**My Work**
Tools/Equipment	- Raspberry Pi 4 - ESP32 nodes - Water level and ultrasonic sensors - MATLAB for prediction modeling - Blynk app	- Raspberry Pi 5 - ESP32 nodes - Water level and ultrasonic sensors - Solar panels - MATLAB for prediction modeling with enhanced algorithms - Blynk app for monitoring - Smart Plug For controlling
Challenges Faced	- Ensuring node redundancy in the mesh network - Accurate crop tracking - Remote adaptive control for watering	- Energy dependence on non-renewable sources - Maintaining continuous monitoring and control - Need for efficient resource allocation and sustainability
Methodology	- Implementation of a mesh network for IoT device communication - Data transmission using MQTT protocol - Neural Network prediction	- Integration of solar energy for powering the system - Enhanced mesh network communication using MQTT - Combination of Neural Networks and decision-tree algorithms for

	models for crop growth analysis - Real-time monitoring via Blynk app	better predictive accuracy - Real-time monitoring and control via Blynk app
Key Innovation	- Robust mesh network ensuring system resilience - AI for analyzing growth rates - Remote-controlled precise watering	- Solar panels for sustainable energy - Advanced predictive modeling using hybrid AI techniques - Focus on eco-friendly, energy-efficient agriculture
Results Achieved	- RMSE: 0.51387 - R-squared: 0.35 - MSE: 0.26407 - MAE: 0.34951 - Improved crop tracking and system resilience	- RMSE: 0.44701 - R-squared: 0.81 - MSE: 0.19982 - MAE: 0.166649 - Enhanced predictive accuracy, reduced energy costs, and sustainable agriculture practices

Table 4.2 : Comparison Between Previous Works and Proposed Hydroponic System

Table 4.2 shows the comparison which highlights the evolution from the previous project to my current proposed work. Both projects focus on automating hydroponic systems using Artificial Intelligence (AI) and mesh networks. However, this current work introduces significant advancements which makes the project more development [52]. The results achieved in this project demonstrate significant improvements over the previous work. The Root Mean Square Error (RMSE) saw a reduction from 0.51387 to 0.44701, representing a 13.0% improvement in predictive accuracy. The R-squared value, which measures the goodness of fit for the prediction model, increased dramatically from 0.35 to 0.81, indicating a 131.4% enhancement in the model's ability to explain variance in the data. Similarly, the (MSE) decreased from 0.26407 to 0.19982, showing a 24.3% reduction in error. Furthermore, the MAE was reduced by 52.3%, dropping from 0.34951 to 0.166649. These improvements collectively highlight the project's success in advancing predictive accuracy, reducing error, and achieving greater efficiency compared to the previous work.

My hydroponic project and Heliospectra also share a vision of optimizing agricultural efficiency but diverge in focus and implementation. My work emphasizes sustainability through the integration of solar energy and artificial intelligence (AI), addressing challenges like energy dependence, continuous monitoring, and efficient resource allocation. By employing hybrid AI techniques, such as neural networks combined with decision-tree algorithms, my system achieves enhanced predictive accuracy for crop growth. The use of solar panels, mesh networks, and IoT devices ensures eco-friendliness and accessibility for small to medium-scale farmers, making my solution ideal for sustainable urban agriculture. Heliospectra, on the other hand, specializes in intelligent LED lighting systems tailored for large-scale commercial horticulture. Their systems leverage machine learning to dynamically adjust light intensity and spectra, promoting optimal plant growth while reducing energy consumption by up to 50% compared to traditional methods. While my project provides a holistic approach to hydroponics by integrating energy sustainability and AI-driven decision-making, Heliospectra focuses on precision lighting and cloud-based environmental monitoring for advanced greenhouses. Both solutions contribute significantly to sustainable farming, with my project excelling in energy independence and adaptability for smaller operations, and Heliospectra leading in large-scale commercial efficiency [39].

4.4 Summary

In summary, the crop height estimation using the Decision Tree prediction model for the hydroponic system has shown encouraging results. Model functionality and efficiency are some of those insights that can be learned through the performance evaluation of the model using the RMSE, R-squared, and MAE metrics. The overall performance of our prediction model is good, with low RMSE and MAE values. But if the value for R-squared is a bit low, then this still shows the capacity that the model has to explain substantial variance within crop heights. In view of the hydroponic system, the findings justify each aspect of the model as this will permit the real-time monitoring for well-informed decision-making under the best possible development and management of crops.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

In conclusion, the development of an automated hydroponic system using solar panels and artificial intelligence has successfully achieved the project's objectives, paving the way for a more efficient and sustainable approach to modern agriculture. This project has addressed key challenges in traditional hydroponics by automating routine maintenance activities, increase efficiency of artificial intelligence for real-time crop monitoring, and integrating renewable energy sources to enhance system reliability.

Firstly, the automation of routine maintenance activities, such as water level adjustments, has been effectively implemented. By minimizing the need for human intervention, the system has significantly reduced the risk of failures and operational inefficiencies. This advancement ensures the seamless functioning of the hydroponic system, fostering a more resilient and self-sufficient design.

Secondly, artificial intelligence has been successfully integrated to track and analyze crop growth rates based on real-time data. The AI-driven system has enhanced decision-making accuracy and provided valuable insights for optimizing plant health and yield. Additionally, the reliability of communication within the mesh network has been improved, ensuring uninterrupted data exchange between devices, which is critical for maintaining optimal growth conditions.

Furthermore, the incorporation of a solar panel has achieved the objective of reducing dependency on external power sources. This renewable energy solution not only lowers operational costs but also aligns with environmentally friendly practices, making the hydroponic system more sustainable and energy-efficient.

Overall, this project has demonstrated that combining automation, artificial intelligence, and renewable energy can revolutionize agricultural practices. The successful achievement of these objectives underscores the potential of innovative technologies in advancing sustainable agriculture and addressing the challenges of food security in the future.

5.2 Potential of Commercialization

The hydroponic system developed in this project holds significant commercialization potential, extending its applications beyond traditional agriculture into diverse and impactful areas. Currently, the system is implemented at Kebajikan Villa Harapan in Ayer Molek, Melaka, an orphanage supporting individuals with mental health challenges. This initiative not only provides a sustainable supply of fresh produce for the residents but also offers therapeutic benefits through horticultural activities. Such an approach aligns seamlessly with the growing societal emphasis on wellness and holistic care.

Furthermore, the project envisions integration within residential communities, presenting a collaborative, community-driven model. Residents can collectively establish and maintain these hydroponic systems, fostering a spirit of self-sufficiency and togetherness. Beyond offering environmental and health advantages, the surplus produce can be sold, generating a sustainable income source for the community. This initiative enhances food security while empowering individuals to play an active role in their economic growth.

The system's scalability and adaptability position it as a viable and socially impactful commercial solution. By merging technological innovation with community development, this hydroponic system exemplifies how cutting-edge advancements can contribute to a more sustainable, inclusive, and self-reliant future.

5.3 Future Works

In The future development of the hydroponic system project includes several important steps to improve its capabilities and impact. One key step is adding more sensors, such as those for temperature, humidity, pH, and electrical conductivity. These sensors will provide a broader range of data, helping to better understand the hydroponic system. By using advanced data analysis techniques, the project aims to improve predictive models and make the system more accurate in monitoring and responding to environmental changes.

Another focus is creating optimization algorithms that use machine learning. These algorithms will automatically adjust watering, nutrients, and environmental conditions to save resources and boost crop yields. This will result in a smarter system that adapts to real-time data and keeps improving its efficiency over time.

Improving the user interface on platforms like Blynk is also a priority. A more detailed and interactive interface will make it easier for users to monitor and control the system. Features like data visualization and historical tracking will help users make better decisions and manage the system more effectively. The project also plans to expand the mesh network to support larger-scale setups, such bigger agricultural projects. This scalable design will ensure reliable communication as new nodes are added.

Lastly, the project will explore growing a wider variety of crops. By adapting the system for different plants, users will have more options and flexibility, making it useful in many farming scenarios. A commercialization strategy will also be developed, including market research and partnerships, to make the system accessible in modern agriculture.

In summary, these plans aim to improve the system's technology, expand its use, and prepare it for wider adoption. Through these efforts, the project will support sustainable farming, community growth, and innovative agricultural solutions.

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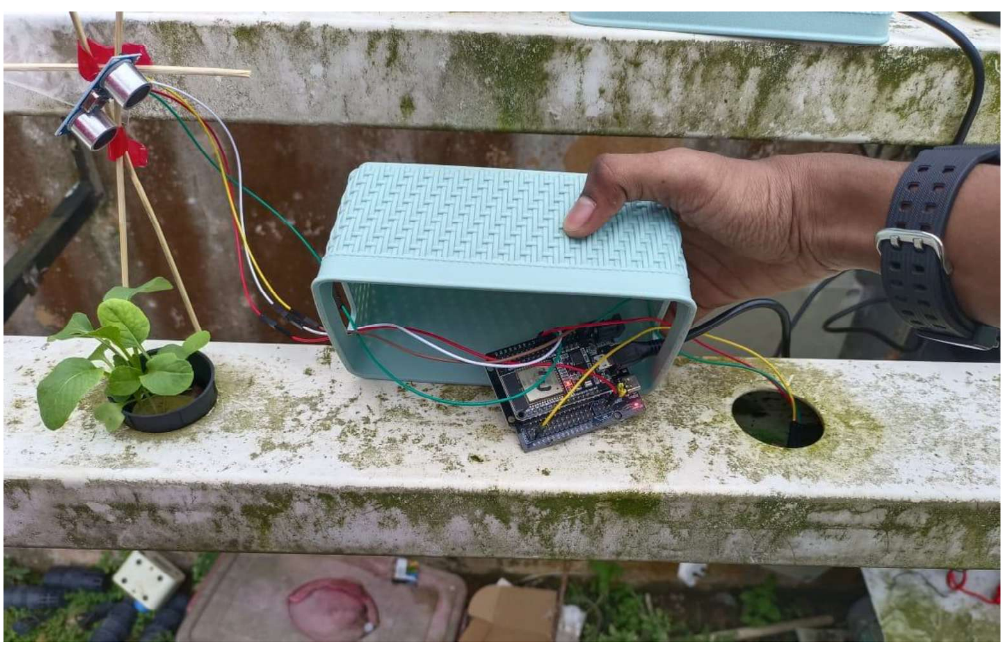
APPENDICES

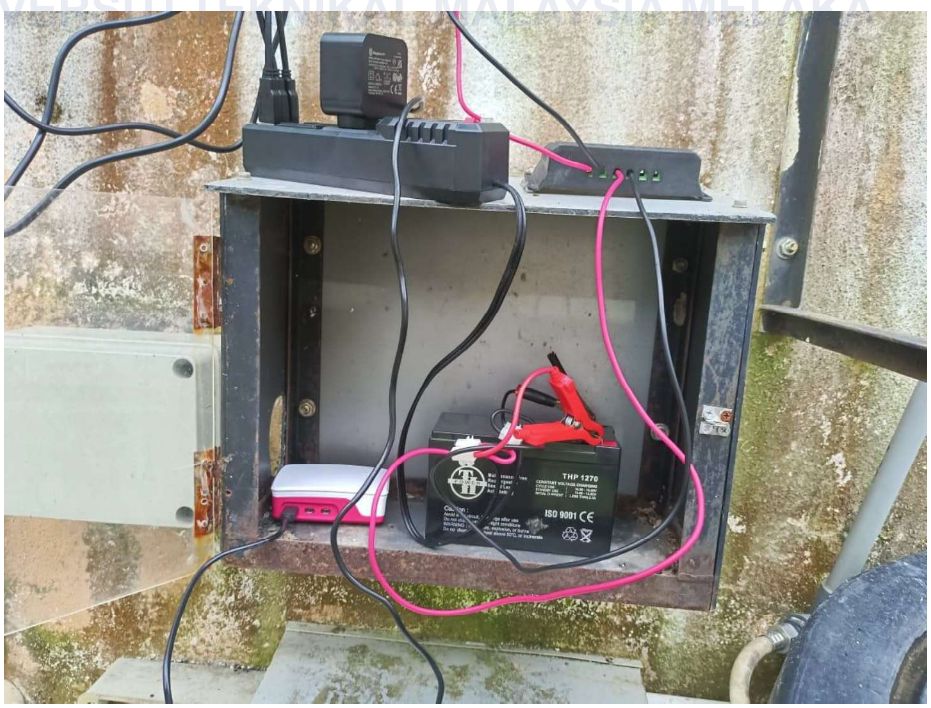
Appendix A Hydroponic System

Appendix B ESP32 Node setup with Ultrasonic and Water Level Sensor



Appendix C Solar Panel Setup

Appendix D 12V Battery and Raspberry Pi 5



Appendix E DC to AC Inverter and Solar Charge Controller

Appendix F Smart Plug Setup

Appendix G Fertilizer Water Tank

Appendix H ESP32 Node Configuration

```
#include <painlessMesh.h>
#include <WiFi.h>
#include <PubSubClient.h>
#include <BlynkSimpleEsp32.h> // Include the Blynk library

// Define Blynk template and auth token
#define BLYNK_TEMPLATE_ID "TMPL68yV-1Fgm"
#define BLYNK_TEMPLATE_NAME "FYP Hydroponic system"
#define BLYNK_AUTH_TOKEN "IBDLbv50l6FxnvSNnA9nvMkGIeF_DPAI"
#define BLYNK_PRINT Serial

// Wi-Fi credentials
const char* ssid = "Kriss_Mesh";
const char* password = "kristisswaran";
```

```
// Mesh network settings
#define MESH_PREFIX "Kriss_Mesh"
#define MESH_PASSWORD "2444666668888888"
#define MESH_PORT 5555

// Pin definitions
#define echoPin 2              // Echo pin of ultrasonic sensor
#define trigPin 4              // Trigger pin of ultrasonic sensor
#define POWER_PIN  17          // Power pin for water level sensor
#define SIGNAL_PIN 36          // Analog signal pin for water level sensor
#define sensorPin SIGNAL_PIN    // Alias for water level sensor signal pin
#define ultrasonicTrigPin trigPin  // Alias for ultrasonic trigger pin
#define ultrasonicEchoPin echoPin  // Alias for ultrasonic echo pin

// Variables
long duration, height;
int waterLevel = 0;  // Variable to store water level sensor value
float waterlevel;
float cropHeight;
// Scheduler and mesh objects
Scheduler userScheduler;
painlessMesh mesh;

// MQTT settings
const char* mqttServer = "192.168.218.233";
const int mqttPort = 1883;
const char* mqttUser = "kriss02";
const char* mqttPassword = "kriss02";
const char* mqttTopicWaterLevel = "node3/waterLevel";
```

```
const char* mqttTopicCropHeight = "node3/cropHeight";

// Blynk auth token
char auth[] = "IBDLbv50l6FxnvSNnA9nvMkGIeF_DPAI";

WiFiClient wifiClient;
PubSubClient client(wifiClient);

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

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

  // Mesh network setup
  mesh.setDebugMsgTypes(ERROR | STARTUP);
  mesh.init(MESH_PREFIX, MESH_PASSWORD, &userScheduler, MESH_PORT);
  mesh.onReceive(&receivedCallback);
  mesh.onNewConnection(&newConnectionCallback);
  userScheduler.addTask(taskSendMessage);
  taskSendMessage.enable();

  // Pin configurations
  pinMode(sensorPin, INPUT);
  pinMode(ultrasonicTrigPin, OUTPUT);
  pinMode(ultrasonicEchoPin, INPUT);

  // Blynk initialization
  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

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

  // Print sensor readings
  Serial.print("Node 3 - Water Level (mm): ");
  Serial.println(waterlevel);
  Serial.print("Node 3 - 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; // Convert to centimeters
  float ultrasonicReading = duration * 0.034 / 2.0;
  float cropHeight = sensorDistance - ultrasonicReading;
  return cropHeight;
}

void sendMessage() {
  String msg = "Water level data from Node ";
  msg += mesh.getNodeId();
  msg += ", Water level: " + String(waterlevel) + ", Crop Height: " + String(cropHeight);
  mesh.sendBroadcast(msg);
  taskSendMessage.setInterval(random(TASK_SECOND * 1, TASK_SECOND * 5));
}

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);
}
```

Appendix I Raspberry Pi Configuration

```
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 = "kriss02"
mqtt_password = "kriss02"

# Blynk settings
blynk_auth_token = " IBDLbv50l6FxnvSNnA9nvMkGIeF_DPAI "
# 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 = "cropHeight"
unit = ""

# Store measurement in the dictionary
if node_numbe 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_measurement
   # Print the fromatted message
   formatted_message = f"Node {node_number} - waterlevel:
{node_measurements[node_number]}
```

```
    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 CSV file
 def append_to_csv(data):
 csv_file_path = "node_data.csv"

 # 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 relavant information
def parse data(data):
parts = data.split(" - ")
node_number = parts[0].split(" ")[-1]
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()
```

Appendix J   Final Year Project Completion