Enhanced Wireless End-to-End Iot Hydroponic System

Nur Alisa Ali[1], Abd Shukur Jaafar[2], Nik Mohd Zarifie Hashim[1]
Najmiah Radiah Mohamad[2]

[1]Machine Learning and Signal Processing (MLSP Research Group), [2]Wireless Broadband and Networking (WiBNet), Fakulti Teknologi dan Kejuruteraan Elektronik dan Komputer (FTKEK), Universiti Teknikal Malaysia Melaka
Corresponding Author Email: alisa@utem.edu.my

Abstract

In uncontrolled environments, the effects of global warming present significant challenges to effective plant cultivation. Recent technological advancements have bridged the gap between agricultural practices and IoT technologies, highlighting the importance of precise fertilizer management to optimize production costs. This study proposes an IoT-based system designed for hydroponic agriculture that monitors and regulates fertilizer application. Utilizing ESP32 devices, one endpoint collects data from sensors measuring pH, humidity, and temperature. A master node aggregates this data, displays it on an LCD, establishes a local Wi-Fi connection, and transmits the information to the Cayenne IoT platform for comprehensive monitoring. The system continuously monitors pH levels via a nodeMCU, activating a pump through a relay to dispense precise amounts of fertilizer as needed. This automated system enables convenient data access through the Cayenne dashboard and significantly reduces excessive fertilizer use, proving especially effective in regions with limited Wi-Fi connectivity.

Keywords: Hydroponics, Internet of Things, Wide Range, Monitoring Systems

Introduction

The rapid growth of the global population has heightened the demand for sustainable and efficient agricultural practices. In response, hydroponic systems, which utilize soilless cultivation techniques, have gained significant attention for their potential to enhance food production in urban and resource-limited environments. However, the success of these systems depends on precise monitoring and control of critical environmental parameters such as pH, nutrient levels, and temperature. Traditional monitoring methods are labor-intensive and prone to human error, which can lead to suboptimal crop yield.

Recent advancements on the Internet of Things (IoT) present a transformative solution by enabling real-time monitoring and automation in hydroponic systems. By integrating sensors and communication technologies, IoT systems offer continuous data collection and analysis, ensuring that environmental conditions are maintained within ideal thresholds. This paper explores the design and implementation of an IoT-based hydroponic monitoring system, highlighting its potential to optimize resource use, reduce labor costs, and improve crop quality. The system's ability to provide remote access to data and automated control functions represents a step forward in advancing precision agriculture and promoting sustainability in modern farming practices.

The aims and objectives for this research are to design a prototype for an autonomous IoT hydroponic monitoring system and to develop and monitor the selected features using the designed prototype. This project focuses on building a monitoring system that can detect temperature, humidity, and pH level within the plantation compartment. This can be implemented with a control system to ensure the condition of the plantation is always kept in the best condition with an IoT setup. The chosen physical factors, namely temperature, humidity, and pH level, are monitored using Analog pH water level and Digital Humidity Temperature (DHT11) sensors. The prototype being developed will provide dedicated output for each of these factors, with a pair of sensors to monitor and measure each specific parameter. These sensors will be connected through Wi-Fi module ESP32 and fully developed in Arduino IDE. The ESP32 is the main microcontroller of the circuit in charge of processing the value obtained and producing the output to the respective platform, including serial communication output, LCD screen and Cayenne IoT platform.

This paper is structured as follows. The next Section 2 will provide the reader with related work on the traditional and hydroponic plantation involving IoT monitoring systems. Section 3 will give the reader more details regarding the research methodology used to collect and analyze the data. The results and analysis of the data collected have been discussed in Section 4. Finally, the proposed project is concluded in the last section of this paper.

Research Background
The Fourth Industrial Revolution is bringing new technologies like AI, IoT, and autonomous robots to farming. This helps farmers make better decisions and remain competitive. The goal is to handle the growing population's food needs and address issues like climate change and food waste. Access to healthy food is a big problem for many people today. Farmers have used chemicals that pollute the soil to increase food production. Researchers are looking for better ways to produce safe and healthy food (Loong et.al, 2021; Elnaffars et.al, 2022). One solution is using hydroponic systems. These systems can help address these challenges effectively (Anirudh et al., 2023).

Hydroponics is a soilless plant growth system that utilizes nutrient-rich water instead of soil, excluding the chemicals found in traditional soil. Techniques like nutrient film technique (NFT), deep flow technique (DFT), and dynamic root floating (DRF) are used in hydroponics to enhance plant growth by providing optimal nutrients. Two types of soilless culture, water culture and substrate culture, are employed. Hydroponic systems promote faster plant growth and better control of output quality compared to soil-based cultivation (Albert et al., 2023). A wide range of crops, including green vegetables, tomatoes, strawberries, peppers,

and cucumbers, can be successfully grown using hydroponics (Marques et.al, 2019). Maintaining proper nutrient composition and pH levels is crucial for optimal plant growth (Nagami et al.,2019). Monitoring pH, humidity, and electrical conductivity (EC) to evaluate nutrient status is common in hydroponic solutions used in greenhouse plant cultivation. Hydroponic systems offer significant water savings in agriculture by recycling excess irrigation water, thus enhancing water efficiency. They also enable cultivation in regions previously unsuitable for traditional agriculture, such as sterile or damaged soil areas. However, the installation of hydroponic systems can be costly and time-consuming (Sekaran et al, 2020; Steven et al., 2023). The Internet of Things (IoT) is a transformative technology with profound technical, social, and economic implications (Revathy et al., 2022). At its core, the IoT involves the widespread presence of interconnected devices collaborating to achieve common goals and impacts many aspects in daily life (Tatas et al., 2022). It also provides new opportunities for developing innovative software applications by harnessing evolving data and computational resources (Swain et al., 2021). In the context of modern agricultural systems, the IoT presents an essential architecture. Previous literature has explored the use of various IoT technologies for environmental monitoring, employing open-source and mobile computing technologies (Herman and Surantha, 2019; Hostalrich et al., 2022). Within the agriculture industry, a significant challenge in plant cultivation lies in the inadequate management of the cultivation environment (Jain, 2020). It is essential to continuously monitor and control the condition of the plantation and its surrounding environment to ensure optimal growth throughout the cultivation process. However, crucial physical factors influencing plant growth are not perceptible to the naked eye, necessitating the use of specialized sensors to gather accurate data (Fadillah et al., 2023).

The integration of Internet of Things (IoT) technology in hydroponics has gained significant attention in recent years, particularly due to its potential to revolutionize agriculture by enabling real-time monitoring, automation, and optimization of plant growth (Bhargava and Chittoor, 2022). Hydroponic systems, which allow plants to grow without soil by using a nutrient solution, are particularly suited for IoT applications, as these systems require precise control over environmental factors such as water quality, temperature, humidity, and light (Elnaffar et al., 2022). This literature review explores various studies that have investigated the use of IoT in hydroponic systems, with a focus on monitoring, automation, and system optimization.

IoT in Hydroponic Systems
Several researchers have developed IoT-based systems for hydroponics, focusing on the ability to monitor and control essential variables that influence plant growth. For instance, (Aliac and Maravillas, 2018) proposed a hydroponics management system that integrates IoT to monitor factors such as pH, water levels, temperature, and humidity, with the goal of optimizing plant growth in urban environments where soil-based farming is challenging (Gokul et al., 2021). This system uses sensors to gather data in real-time and leverages cloud-based technologies for remote monitoring and control.

Similarly, Tatas et al. (2021), introduced *iPONICS*, a low-cost IoT-based monitoring and control system for hydroponics. This system features wireless sensor nodes that monitor water quality, temperature, and humidity, and transmit data to a central unit, allowing for

remote control of the environment via a web interface (Ahmed et al., 2023). The study demonstrates
how IoT can be used to make hydroponic farming accessible to small-scale and hobby farmers through low-cost solutions.

Automation and Control
A key advantage of IoT in hydroponics is the automation of farming tasks, reducing labor costs and improving efficiency. Gokul et al. (2021) explored the use of IoT for automating hydroponic systems, enabling the control of environmental factors such as pH, temperature, humidity, and light. Their system uses ESP32 microcontrollers to automate the monitoring and control of these variables, which helps ensure optimal plant growth conditions (Jayanth, 2023). The system also allows for remote monitoring through mobile applications, enabling users to adjust the system from anywhere.

In a similar vein, Patil et al. (2020) developed an IoT-based hydroponic system that automates irrigation by using sensors to monitor pH, temperature, and humidity. The system aims to address the challenges of traditional farming, such as soil-related diseases and the need for large plots of land, by offering a controlled, automated environment for plant growth. The study emphasizes how IoT can reduce the manual labor required in farming while improving crop yields.

Remote Monitoring
One of the most significant benefits of IoT in hydroponics is the ability to remotely monitor and manage hydroponic systems. Elnaffar et al. (2022) introduced *Hystorms*, an IoT system designed for remote monitoring of hydroponic environments. The system collects data from sensors and transmits it to a cloud-based platform, where farmers can access real-time information via a mobile app (Khan et al., 2020). The app alerts users to any abnormal conditions, enabling prompt intervention and minimizing crop loss.

In addition to remote monitoring, IoT systems can help ensure optimal crop growth by managing nutrient levels and other environmental factors (Kour et al., 2020). Sekaran et al. (2020) developed an IoT-based smart agriculture system that integrates cloud computing to monitor and control various aspects of crop growth, such as soil moisture, temperature, and humidity. This system not only automates farming processes but also uses data analytics to improve decision-making and crop management.

System Optimization and Efficiency
Beyond automation and remote monitoring, IoT systems also offer opportunities for optimizing hydroponic processes (Khan et al., 2020). Tatas et al. (2022) developed a reliable IoT-based monitoring and control system specifically for hydroponics, designed to tolerate faults without requiring intervention. Their system uses a fuzzy inference engine to determine the duration of plant irrigation, optimizing water usage and ensuring that plants receive the exact amount of nutrients needed.

Similarly, Gokul et al. (2021) and Jayant (2023) emphasized the efficiency of IoT-based hydroponics systems in reducing water usage and optimizing plant growth conditions. Their

system allows for precise control over environmental variables, ensuring that plants grow under ideal conditions with minimal resource waste.

Research Motivation
The integration of Internet of Things (IoT) technology with hydroponics has ushered in a new era of precision agriculture, empowering farmers with real-time insights and automated control over their crops. IoT-powered hydroponic systems leverage a network of sensors to meticulously track essential environmental parameters, encompassing temperature, humidity, pH levels, and nutrient concentrations2. This data is subsequently processed and wirelessly conveyed to a central hub or a cloud-based platform, providing growers with a comprehensive view of their hydroponic setup and facilitating informed decision-making.

Several studies have demonstrated the efficacy of IoT-based hydroponic systems in enhancing crop productivity and resource management. For instance, researchers developed a cost-effective smart hydroponic monitoring and control system using IoT, achieving an accuracy rate of 90% (Ullah et al., 2019; Stevens et al., 2023). The system employed sensor nodes to monitor parameters like water temperature, pH, and nutrient levels, transmitting the data to an MQTT server via NodeMCU ESP826634. Another research project, funded by the Department of Science and Technology in the Philippines, investigated the performance of a low-power wide-area network (LPWAN) for IoT-based hydroponics monitoring (Macayana et al., 2023). These studies underscore the transformative potential of IoT in optimizing hydroponic operations and promoting sustainable food production practices.

Looking ahead, advancements in sensor technology and data analytics are poised to further elevate hydroponic systems' capabilities. Spectroscopic nutrient monitoring systems, for instance, utilize sophisticated sensors to dissect the nutrient composition of the hydroponic solution, enabling even more refined control over nutrient delivery (Wada., 2019; Kour and Aurora., 2020). This level of precision not only optimizes plant nutrition but also minimizes nutrient wastage, contributing to a more sustainable and environmentally-sound approach. The application of machine learning algorithms to analyze historical data and predict future growth trends, nutrient demands, and potential issues presents another exciting frontier in hydroponics (Thambakhe et al., 2020). By harnessing the power of machine learning, growers can preempt potential problems, implement timely interventions, and fine-tune their practices to achieve optimal crop health and yields.

The ongoing evolution of hydroponics, intertwined with the rapid advancements in IoT and data-driven technologies, heralds a future where sustainable and efficient food production systems become a reality (Othman et al., 2019;Nizetic et al., 2020;Vineth and Ananthan, 2023). These innovations empower individuals, communities, and commercial growers to embrace a more resilient and environmentally-conscious approach to agriculture, addressing the pressing
challenges of food security and resource conservation in the face of a growing global population.

Methodology
Based on Figure 1 project overall flow, the project is started by preparing the components needed for the circuit. The components prepared are analog pH level sensor, Digital Humidity

Temperature DHT11 sensor, microcontroller board ESP32, relay and LCD screen. With these components, a schematic design is developed and simulated to test its functionality. In the first stage, the inputs are pH level sensor and Digital Humidity Temperature (DHT 11). The Wi-Fi module ESP32 is used as general-purpose microcontroller to receive and transmit data between input and output. The output is master node. The second stage represents the input is from ESP32 (1). The Wi-Fi module ESP32 (2) is used a microcontroller to receive and transmit data between input and output. The outputs used consists of IoT platform (Cayenne) and LCD screen. While Figure 2 shows the proposed of prototype diagram.
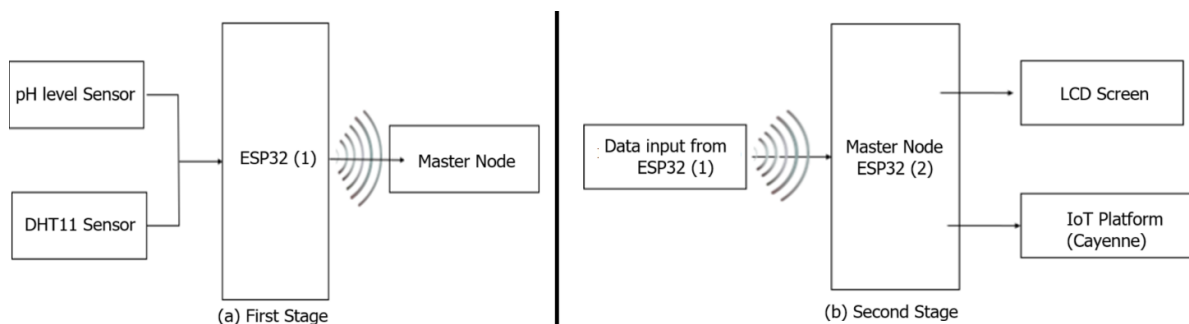
Figure 1: The proposed hydroponics monitoring system block diagram
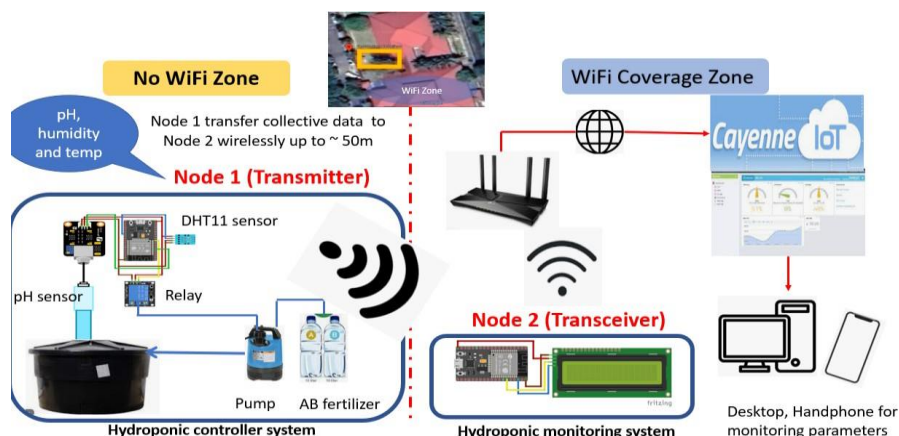
Figure 2: The proposed prototype of hydroponics monitoring system diagram

This project has two stages. First stage is for Sensor 1 and 2 with SPDT relay. Second stage is for data input that get from stage 1 and go to IoT platform. The system will first collect the data of temperature and humidity. After that, it will check pH sensor. If the system receives pH value < 5, the system will turn on the relay. Hence, it will turn on the pump at the same time, fertilizer A&B will flow into the tank. Otherwise, the system will continue to check the desired pH sensor. After turning on the relay, the system will delay for 10 seconds. Then, the system will check again whether the pH value >5. If the pH value > 5, it will turn off the relay and send the pH, temperature, and humidity to the Master Node. If the pH value < 5, the system will continue running. Next, the connection with internet stage will take place. Then, there is condition whether system receive the input data from ESP32 (1). If the conditions do not meet, the system will continue to reconnect to the internet until the conditions are met. After done, it will attempt into connect to Middleware platform. The system will go to next level, which will ask if the connection succeed, when succeed the display result will be on IoT dashboard. This flow is presented in the following Figure 3.
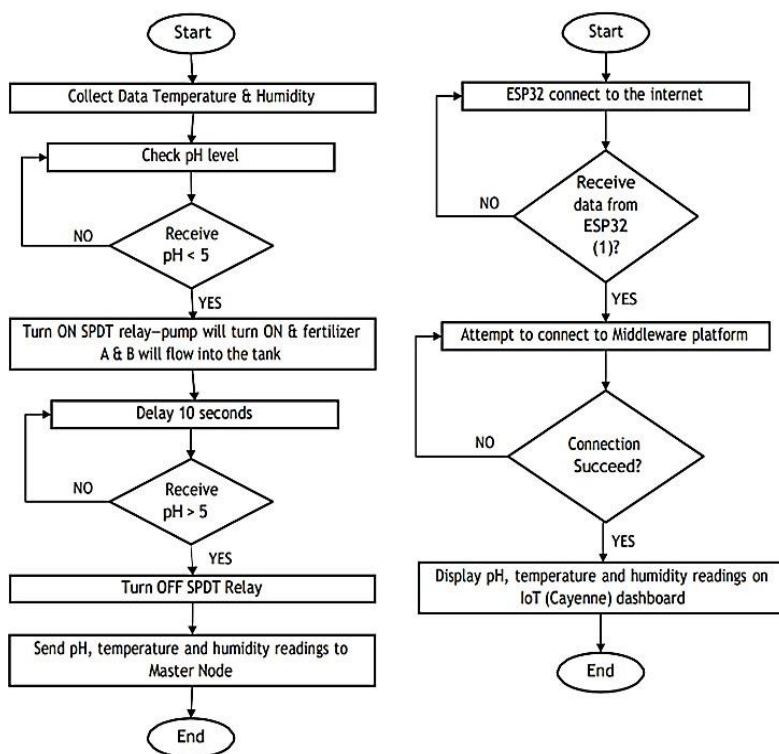
Figure 3: The proposed prototype of hydroponics monitoring system diagram

The sender schematic diagram for all the components connection is shown in the Figure 6. ESP32 has both analog and digital inputs. The pH pin is connected to pin A35 on ESP32. The digital input of DHT11 is connected to pin D4 on ESP32. The SPDT relay is connected to pin D26 on the ESP32. All the input voltage (Vin) of DHT11, analog pH and SPDT relay are connected to the input voltage pin (Vin) on ESP32. All the ground pins for all components are connected to ground pins on ESP32. As for the receiver part, the ground of LCD is connected to pin ground on ESP32. The input voltage connected to ESP32 (Vin). The input is connected to pin D22 on ESP32 and lastly connected to pin RX0 on ESP32. Figure 4 illustrates schematic diagram of this proposed system.
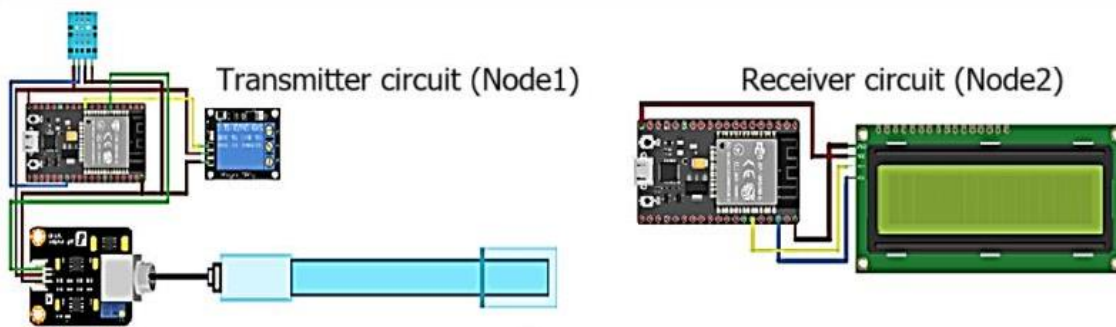

Figure 4: Schematic Diagram

The Autonomous Wireless Hydroponic System consists of two types of sensors. The sensors used are pH sensor (sensor 1) and Digital Humidity Temperature (sensor 2). This project has two output displays: Cayenne and LCD screen. The first flowchart represents the beginning process of this project. This project used two sensors to read readings to turn ON the SPDT

relay. The function of SPDT relay allows the motor to pump in the fertilizers A & B. The fertilizers will keep neutral pH level in order to prevent the plants from dying. If the pH level reaches the desired pH level for the plants, the SPDT relay will turn OFF the motor and it will send all the reading such as pH level, Humidity and Temperature. Next, all the readings that have been received will be collected. The other microcontroller will get all the readings from the master node. All the readings are collected using ESPNOW. The function of ESPNOW is connectionless communication between one ESP to another ESP. Lastly, there will be a manual button for the SPD relay that will be displayed on both IoT platform (cayenne) and LCD. It will help user to turn ON or turn OFF the SPDT relay. Then, it will return to start to read back the pH level and continue looping the process. Cayenne has developed an IoT platform that is ideal for any IoT project. The platform was created to help with the internet integration of data from sensors. Data collection and storage from IoT devices has become a lot easier and this Cayenne platform is used to display the reading of pH level, Humidity and Temperature measured by the proposed system. Figure 5 shows the completed hardware of Sender and Receiver part. While Cayenne of IoT platform displays in Figure 6.
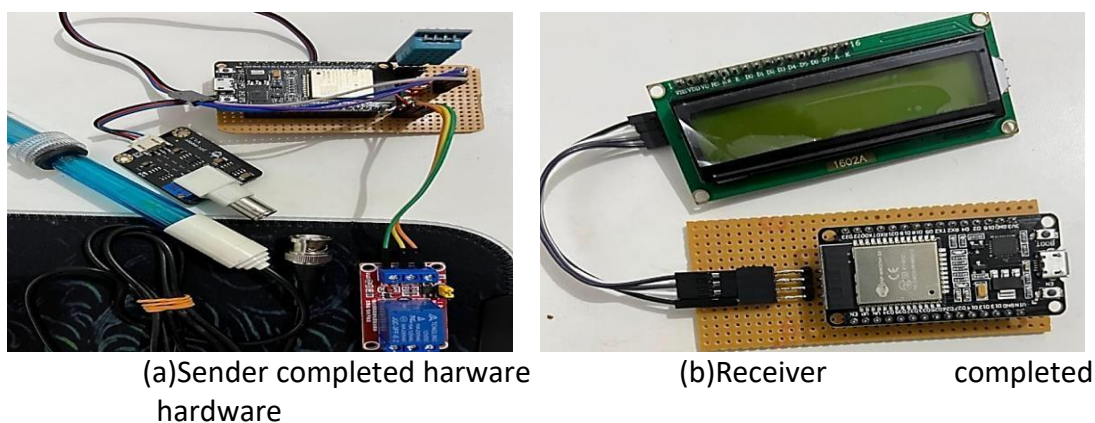

(a)Sender completed harware hardware   (b)Receiver completed

Figure 5. completed hardware circuit for Sender and Receiver

Figure 6. Cayenne platform

Finding

This is a collected data for 1 hour. As stated, pH value for a plant is between 5-7. From Figure 8, it shows that the pH value readings are stable for the project to be developed. If the pH value keeps reducing, SPDT relay will be turned ON and motor will pump fertilizer A and B to neutralize the pH value. This can be seen in the graphs (Figure 7 (a) till (c)). In Figure 8 (a)- (c), it can be seen the pH value has a sudden drop from suitable temperature which is 7.20 to

5.26. Hence, it is expected that SPDT relay is turned ON and fertilizers A and B neutralized the pH value, and it will stop when the pH value has been back to neutral. The system will keep on running until pH value is unnaturalized or the system is forced to stop.
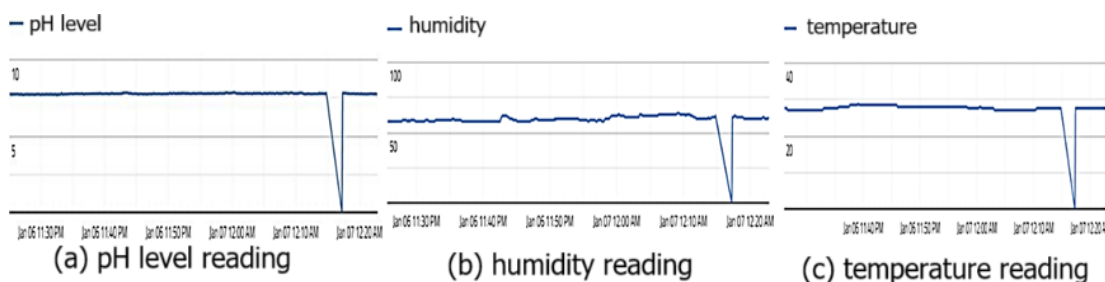

Figure 7. Reading data within one hour

All the data have been analyzed throughout the finalized system. Then, there are a few analyses that have been made. This analysis data to analyze the best performance of the proposed system. Besides, the data and analysis are taken from using components that have been used, which compares the actual reading on theory and the measurement taken. From the result obtained, the pH level sensor can read from the water solution. In conclude, the best pH level for plant in hydroponic system is between 5.00 to 6.00. It is functioned to use this pH sensor so the relay will turn on the pump to flow the fertilization A and B. The data of pH value (sensor 1) and DHT11 (sensor 2) have been taken when the system is running. When sensor 1 met certain condition that has been decided below pH 5.00 hence, the SPDT relay will turn ON. Thus, the summaries of this project are as elaborated.

ESPNOW is being used on ESP8266. ESP32 is a new thing, and it has another function which is Bluetooth. The codes for ESP8266 and ESP32 are different, and the libraries are different too. On the other side, for the hardware development. There is an error reading on pH level value during the early stage of hardware development. There is a minimum error value on pH level that can be ignored since the value is small. After that, to combine between hardware and software to make it a whole system was hard. It took a plenty of time for it to function as a whole system. After doing a lot of reading and research on the hardware. The problem has been solved. This result run on ESPNOW is shown in Figure 8.

Figure 8. Comparison of Reading data

Figure 9-12 show the process of producing cayenne's output. Cayenne will read all the readings that have been sent from sender code. As shown in Figure 9(a), is a sender COM 4 that has successfully delivered. The delivery shows that the data has successfully sent to the receiver.

Receiver is COM3 in Figure 9(b). COM3 will produce output as shown in the flowchart which it displays on the LCD screen and cayenne platform.

The other three figures show the other readings. The figures show that the cayenne can read actual readings. This process shows when pH changed its values, and all the other readings can be read with its actual values. There is no error in getting actual values. All these results came out from the transmitter's readings, and it showed on the serial monitor COM 4 as in Figure 11(a) as a sender and COM 3 in Figure 11(b) as a receiver that also display on the LCD screen.
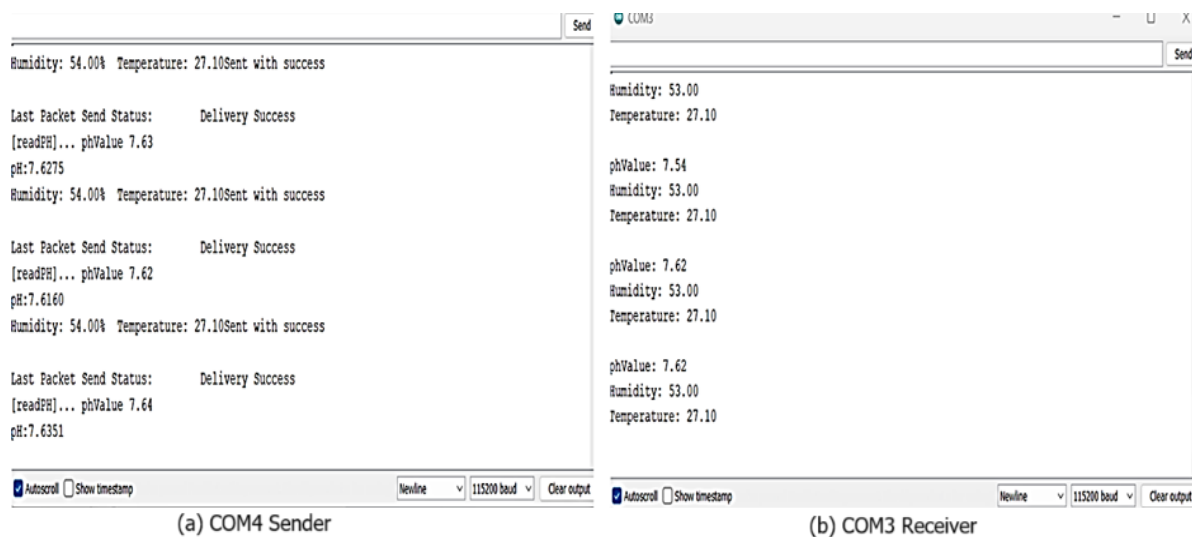

Figure 9. The serial monitoring of sender and receiver
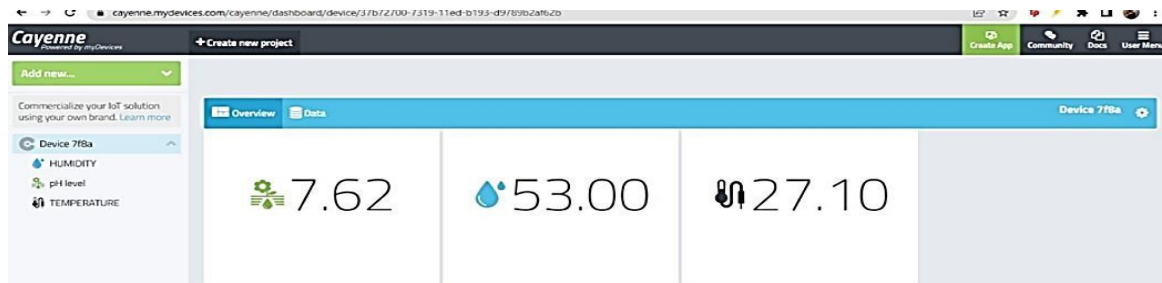

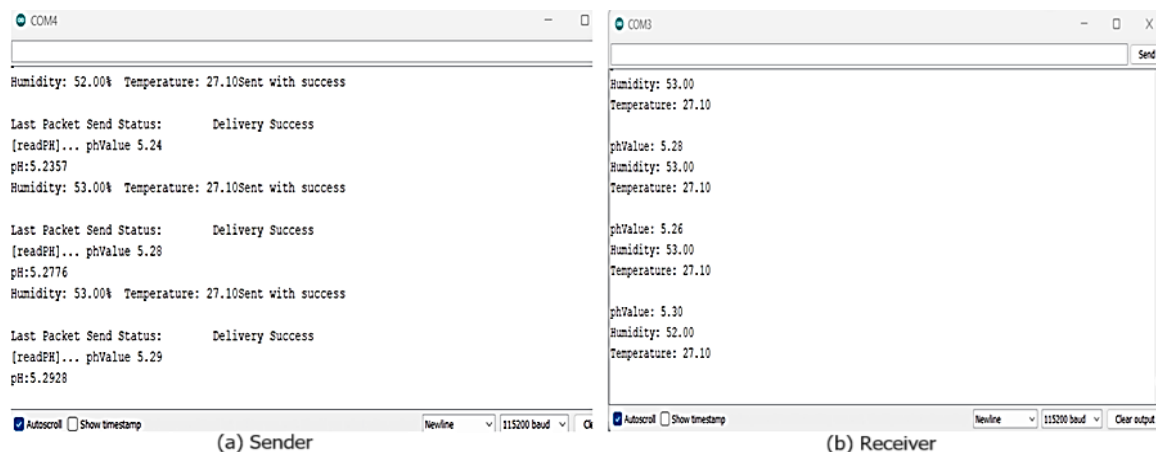Figure 10. Cayenne platform showing the reading of all sensors

Figure 11. The serial monitoring of sender and receiver

Figure 12. Comparison of Cayenne platform showing the reading of all sensors

Conclusion and Future Work

At the end of the project, the objective of the Autonomous IoT Hydroponic System was achieved. Both hardware and software were implemented successfully to achieve the functionality that was expected. This project is a combination of the Arduino IDE software, Fritzing for the Hardware Circuit design and prototype. The Autonomous Hydroponic System with Arduino Technology might bring more advantages to little farmers or some people that have limited spaces and places to plant some organic plant. With this project, it can manage the time consuming for monitoring and watering the plant and can improve the accuracy of pH level and will produce healthier plants. This project is developed for the functioning system of An Autonomous Hydroponic System.

Some recommendations so the project can be upgraded in the future is to be able to save data in the data logger using Microsoft Excel in a (.xlsl) format. When users use the monitoring gadget, the data logger will allow the user to observe the system in their daily data. Aside from that, it may also be improved by incorporating an alarm system which notifies the user about when the level of water or pH is below the minimum or the hydroponic system is not working as desired. After that, adding more sensors such as electrical conductivity to monitor the available nutrients reading for the plant. The higher the electrical conductivity value, the more nutrients that are available for a plant. Other than that, light sensors such as red, green and blue (RGB) light sensors can be added to measure the light intensity. The light intensity needs to be measured since the amount of light that is received by the crop could affect the growth of a plant.

Acknowledgment

References

Aliac, C. J. G., Maravillas, E. (2018). IOT Hydroponics Management System. 2018 IEEE 10th International Conference on Humanoid, Nanotechnology, Information Technology,Communication and Control, Environment and Management (HNICEM).

Ahmed, M., Reddy, S. M. (2023). Smart Hydroponic System and Monitoring of Plant's Health through Machine Learning. International Journal for Research in Applied Science and Engineering Technology.

Albert, M. C., Hans, H., Karteja, H., Widianto, M. H. (2023). Development of Hydroponic IoT-based Monitoring System and Automatic Nutrition Control using KNN. 2023 International Conference on Computer Science, Information Technology and Engineering (ICCoSITE).

Anirudh, P., Kumar, G., Vidyadhar, R. P., Pranav, G., Kumar, B. A. (2023). IoT Based Hydroponic System. 9th International Conference on Advanced Computing and Communication Systems (ICACCS).

Bhargava, Y., Chittoor, P. K., B. C. (2022). IoT Powered Smart Hydroponic System for Autonomous Irrigation and Crop Monitoring. ECS Transactions.

Elnaffar, S., Amin, A., Satrya, G., and Permana, M. A. S. (2022). Remote Farming: Monitoring Hydroponic Environments using IoTs. International Conference on Electrical and Computing Technologies and Applications (ICECTA).

Fadillah, F., Buaton, R., Ramadani, S. (2023). IoT-based Hydroponic Plant Monitoring System. Journal of Artificial Intelligence and Engineering Applications (JAIEA).

Gokul, S., and Mulla, I., and Nagaraja, K., and Sakthi, P. (2021). Smart Hydroponic System Using IOT. In Proceedings of the International Conference on Innovative Computing & Communication (ICICC).

Herman, H., Surantha, N. (2019). Intelligent Monitoring and Controlling System for Hydroponics Precision Agriculture. 7th International Conference on Information and Communication Technology (ICoICT).

Hostalrich, D., Pelegrí-Sebastiá, J., Sogorb, T., Pellicer, V. (2022). Intelligent Management of Hydroponic Systems Based on IoT for Agrifood Processes. Journal of Sensors.

Jain, A. (2020). Smart Agriculture Monitoring System using IoT. In International Journal for Research in Applied Science and Engineering Technology, vol. 8, no. 7, pp. 366–372.

Khan, S., Purohit, A., and Vadsaria, N., (2020). Hydroponics: current and future state of the art in farming. In Journal of Plant Nutrition, vol. 44, no. 10, pp. 1515-1538.

Kour, V. P., & Arora, S. (2020). Recent developments of the internet of things in agriculture: a survey. IEEE Access, vol. 8, pp. 129924-129957, 2020.

Loong, F., and Yaacob, M., (2021). Facing the 4th Agricultural Revolution: Opportunities and Youth Readiness to Spur Agricultural Industry in Malaysia. In International Virtual Conference on Liberal Studies. p. 26.

Macayana, Y. L. K., Fernandez, I. C., Ung, K., Austria, I., De Leon, M. T., Densing, C. V., Santos, C., Rosales, M. (2023). Internet of things-based indoor smart hydroponics farm monitoring system. International Journal of Electrical and Computer Engineering (IJECE).

Marques, G., Aleixo D., and Pitarma, R. (2019). Enhanced hydroponic agriculture environmental monitoring: An internet of things approach. In International Conference on Computational Science: Springer, pp. 658-669.

Nagamani, P., Jahnavi, M., Raju, N. N. K. G., Shankar, A., Reddy, K. S. (2019). SMART HYDROPONICS WATER MONITORING USING IoT. Journal of Emerging Technologies and Innovative Research.

Nizetic, S., Solic, P., Gonzalez-de, D. L., and Patrono, L., (2020). Internet of Things (IoT): Opportunities, issues and challenges towards a smart and sustainable future. Journal of Cleaner Production, vol. 274, p. 122877.

Patil, N., Patil, S., Uttekar, A., and Suryawanshi, A. (2020). Monitoring of Hydroponics System using IoT Technology. In International Research Journal of Engineering and Technology (IRJET), vol. 7, no. 6, pp. 1455-1458.

Revathy, N., Guhan, T., Nandhini, S., Ramadevi, S., and Dhipthi, R. (2022). IOT based Agriculture Monitoring System using Arduino UNO. 2022.

Sekaran, K., Meqdad, M. N., Kumar, P., Rajan, S., and Kadry, S. (2020). Smart agriculture management system using internet of things. Telkomnika, vol. 18, no. 3, pp. 1275-1284, 2020.

Stevens, J., Murray, D., Diepeveen, D., Toohey, D. (2023). Development and Testing of an IoT Spectroscopic Nutrient Monitoring System for Use in Micro Indoor Smart Hydroponics. Horticulturae.

Swain, A., Chatterjee, S., and Vishwanath, M. (2021). Hydroponics in vegetable crops: A review. In The Pharma Innovation Journal, vol. 10, no. 6, pp. 629-634Vineeth, P., Ananthan,

Tambakhe, M. D., & Gulhane, V. S. (2020). A survey on techniques and technology used in hydroponics system. EasyChair PrePrint, no. 3628, 2020.

Tatas, K., Al-Zoubi, A., Christofides, N., Zannettis, C., Chrysostomou, M., Panteli, S., Antoniou, A. (2022). Reliable IoT-Based Monitoring and Control of Hydroponic Systems. Technologies

Ullah, A., Aktar, S., Sutar, N., Kabir, R., Hossain, A. (2019). Cost Effective Smart Hydroponic Monitoring and Controlling System Using IoT. Intelligent Control and Automation.

Velazquez-Gonzalez, R.S.; Garcia-Garcia, A.L.; Ventura-Zapata, E.; Barceinas-Sanchez, J.D.O.; Sosa-Savedra, J.C. (2022). A Review on Hydroponics and the Technologies Associated for Medium-and Small-Scale Operations. Agriculture. p. 646.

Vineeth, P., Ananthan, T. (2023). Automated Hydroponic System using IoT for Indoor Farming. 2023 4th International Conference on Electronics and Sustainable Communication Systems (ICESC).

Wada, T. (2019). Theory and technology to control the nutrient solution of hydroponics. In Plant Factory Using Artificial Light: Elsevier. pp. 5-14.