

AUTOMATED NUTRIENT CONTROL AND MONITORING SYSTEM FOR INTERNET OF THINGS (IOT)-BASED HYDROPONIC TOWERS

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Keywords:

Hydroponics, Internet of Things, Precision Agriculture, Automation,

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Abstrak. Penelitian ini bertujuan untuk merancang dan mengimplementasikan sistem kontrol dan monitoring nutrisi berbasis *Internet of Things* (IoT) pada sistem Hidroponik Tower, sebagai solusi terhadap keterbatasan lahan dan tantangan pemantauan manual. Sistem ini memanfaatkan sensor suhu DS18B20 dan sensor TDS Meter V1.0 KS0429 untuk akuisisi data presisi, serta aktuator berupa pompa Yamano WP-103 dan solenoid valve DC 2W-160-15 yang dikendalikan oleh mikrokontroler ESP32-DevKitC-1. Data dari sensor dikirim secara *real-time* ke dasbor melalui protokol MQTT, memungkinkan pemantauan dan kontrol otomatis. Sistem ini berhasil menjaga parameter lingkungan seperti pH, suhu, dan PPM dalam rentang stabil yang berkorelasi positif dengan pertumbuhan tanaman. Keberhasilan ini tervalidasi dengan total panen 10,569kg dan rata-rata 58,3gram per tanaman. Kesimpulannya, sistem ini mampu mengoptimalkan efisiensi budidaya hidroponik tower, menawarkan solusi adaptif untuk pertanian presisi di lingkungan perkotaan yang padat.



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Abstract. This research aims to design and implement an *Internet of Things* (IoT)-based nutrient control and monitoring system in the Hydroponic Tower system, as a solution to land limitations and manual monitoring challenges. The system utilizes a DS18B20 Temperature Sensor and a TDS Meter V1.0 KS0429 sensor for precision data acquisition, as well as an actuator in the form of a Yamano WP-103 pump and a DC 2W-160-15 Solenoid Valve controlled by an ESP32-DevKitC-1 Microcontroller. Data from the sensors is sent in real-time to the dashboard via the MQTT protocol, enabling automatic monitoring and control. This system successfully keeps environmental parameters such as pH, Temperature, and ppm in a stable range that is positively correlated with plant growth. This success was validated with a total harvest of 10,569kg and an average of 58.3grams per plant. In conclusion, the system is able to optimize the efficiency of tower hydroponic cultivation, offering an adaptive solution for precision farming in dense urban environments.

1. INTRODUCTION

The demand for food security in this modern era encourages innovation in the agricultural sector. Conventional methods that rely on large areas of land and non-renewable

water resources are increasingly inefficient, especially amid rapid urbanization and climate change[1]. In response to this challenge, hydroponic cultivation offers a promising solution, where plants are grown without soil media, but rather in nutrient-rich water

solutions[2]. The advantages of hydroponics lie in its ability to save water use and significantly improve land efficiency, making it an ideal choice for densely populated urban areas[3], [4], [2]. However, conventional hydroponic systems such as Nutrient Film Technique (NFT) are often energy-intensive because the pump must continue to operate for nutrient circulation[5], [6].

To overcome land limitations, especially in urban environments, vertical hydroponic systems or known as hydroponic towers are a relevant innovation. This system allows for space optimization by stacking crops vertically, maximizing yield per unit area[7]. Nonetheless, hydroponic cultivation requires strict and continuous monitoring of environmental parameters to ensure optimal plant growth[8]. These important parameters include temperature and nutrient concentration, which are generally measured in Parts Per Million (PPM) or Total Dissolved Solids (TDS)[2]. Manual control of these parameters is certainly very time-consuming and prone to errors, which can be fatal to the plant, such as withering or even crop failure due to improper nutrient delivery[7], [8].

The use of Internet of Things (IoT) technology is present as a solution to automate and simplify the monitoring and control process in hydroponic systems. With IoT, devices such as sensors and microcontrollers can connect and transmit data in real-time to users, enabling remote monitoring[9]. Previous research has implemented IoT to monitor temperature, humidity, and nutrient levels[10], and can control irrigation systems and nutrients automatically[7]. Other research shows the application of IoT in smart home control systems[11] and load control and battery power monitoring[12], confirming the ability of IoT to monitor and control various devices in real-time[13]. This integration not only improves operational efficiency, but also reduces human involvement, so that the quality and quantity of crops can be better guaranteed[9].

Although there have been many studies examining IoT applications in hydroponics, the majority still focus on horizontal systems or NFTs[5], [6], [10]. There is a specific research gap regarding integrated systems designed for hydroponic towers, where control and nutrition are carried out precisely with IoT. Several

studies have shown success in automating nutrition based on PPM values[2],[7], but the system can still be further optimized for vertical applications. This research aims to fill this gap by designing and implementing an IoT-based nutrient control and monitoring system, which is specifically applied to hydroponic towers to monitor temperature and PPM values, as well as manage nutrient delivery accurately, in order to achieve optimal plant growth.

2. LITERATURE REVIEW

2.1 Basic Concept of Hydroponics

Hydroponics is a method of cultivating plants without using soil media, but by utilizing nutrient mineral solutions dissolved in water. This technique allows for higher water and land use efficiency, as well as more precise nutrient control than conventional methods[5]. According to [7], the quality of the plants produced by the hydroponic method is very good and does not require a large amount of land. However, this demands strict and continuous monitoring of environmental parameters, including nutrient concentrations (PPM or TDS), solution temperature, and pH levels[3]. Inappropriate pH levels can affect the nutrient absorption of plants, while improper PPM levels can damage the roots[1]. Ideal nutrient control is essential for optimal plant growth[4].

2.2 Hydroponic Tower

To overcome land limitations, especially in urban environments, vertical hydroponic systems or known as hydroponic towers are a relevant innovation. The system is arranged vertically, allowing for space optimization by stacking plants, maximizing yield per unit area[1]. Despite this, the system still requires strict and continuous monitoring of environmental parameters[3].

2.3 Internet Of Things

The Internet of Things (IoT) is a concept in which physical devices are connected and can exchange data over an internet network, enabling Machine-to-Machine (M2M) interaction without human intervention[14], [15]. In this study, the application of IoT is focused on two main functions, remote monitoring and automated control systems.

2.3.1 Remote Monitoring

Based on relevant journals, IoT enables real-time monitoring of environmental conditions remotely. According to [16], IoT-based systems can monitor vegetation and field conditions by reading data from sensors (temperature, humidity, light) and sending it to the cloud for farmers to access from anywhere. A similar concept was also demonstrated in the study [17], where soil temperature, humidity, and moisture data were sent to the Blynk app for real-time monitoring.

From a technical point of view, this monitoring process relies heavily on microcontrollers. According to [18], the ESP32 microcontroller can be integrated with a variety of sensors for real-time data acquisition and efficient wireless transmission. This study confirms the importance of lightweight communication protocols, such as MQTT, that can transmit sensor data with low latency and minimal bandwidth consumption.

2.3.2 Automatic Control System

In addition to monitoring, IoT allows devices to respond to detected conditions automatically, triggering the actuator to perform specific actions. According to [11], [12] IoT applications provide concrete examples of this application in the realm of smart homes. Both studies used relays and other modules to control devices (lights, doors) automatically based on commands from the application.

In the context of agriculture, according to [17], the system designed in the study autonomously activates fans and water pumps to maintain optimal conditions for plants, proving that data from sensors can directly trigger actuators. This is very much in line with your research goal of controlling a pump or valve based on sensor data.

2.4 Sensors and Actuators

2.4.1 Sensor

A sensor is a device that converts a physical quantity into an electrical quantity or digital signal that can be processed by a microcontroller. In the context of this study, sensors have a crucial role to monitor environmental conditions automatically.

a. Sensor PPM/TDS

It is used to measure nutrient concentrations (total dissolved solids) in parts per million (ppm) [2], [6]. This measurement is very important because each type and age of the plant has different nutritional needs. Inappropriate PPM levels can affect nutrient absorption and even damage plant roots [5]. TDS sensors, such as those used in the study by [6], have good accuracy and can work over a wide range of measurements. According to [8], TDS sensors, along with pH sensors, are used to monitor nutrient levels in hydroponic plants.

b. Temperature Sensor

Used to measure the temperature of a solution or environment. Suboptimal temperatures can inhibit plant growth. DS18B20 temperature sensors are digital sensors that are known for their accuracy and ability to measure temperature over a wide range. Although it does not use a DHT22 temperature sensor to monitor the ambient temperature around the plant [2], the principle of use remains the same, which is as input for the system to determine next actions. If the temperature is below the specified threshold ($<25^{\circ}\text{C}$ for spinach plants), the system can automatically turn on the lights to raise the temperature. Other studies have also used temperature sensors as part of hydroponic automation systems to monitor the condition of nutrient solutions [12].

2.4.2 Actuator

An actuator is a device that functions as a "muscle" of the system, receiving commands from the microcontroller to perform physical actions. In this study, an actuator was used to control the flow of water and nutrients automatically.

a. Nutrition Pump

It serves to drain nutrient solutions from the tank to the plant. The use of these pumps is very common in automated hydroponic systems. In the study [5] it was explained that pumps are used for filling raw water, circulating, and stirring solutions. Meanwhile, the study [6] implemented a "mini pump" to drain nutrient fluids when needed. The pump is controlled by a microcontroller based on data from sensors.

b. Solenoid Valve

It is an electrically controlled valve, serving as an automatic switch to regulate the

flow of fluids. According to [8], the solenoid valve functions as a regulator of nutrients that are channeled to plants. This valve will open or close according to the command of the microcontroller, which has processed the data from the pH and TDS sensors. The study [5] also used solenoid valves as automatic faucets to drain water and nutrients from the tank to the mixing container.

2.5 Microcontroller

A microcontroller is a small computer in a single chip designed to control electronic devices. In this study, the microcontroller serves as the "brain" of the system, which processes data from sensors and controls the actuator.

The microcontroller used in this study is the ESP32 Dev-Kit C1. This module was chosen because it offers a combination of advantages, namely low cost, efficient power consumption, and has integrated dual-mode Wi-Fi and Bluetooth capabilities. This feature is crucial in Internet of Things (IoT) applications because it allows the ESP32 to communicate wirelessly with the internet or other devices [16].

In this study, ESP32 functions as a control center for the hydroponic tower system. The ESP32 processes data from TDS sensors and temperature sensors to monitor nutrient levels and water temperature. Based on the processed data, these microcontrollers control the solenoid actuator and nutrient mixer pump to regulate nutrients and ensure optimal temperatures for plants [17], [18].

The data from the sensors is then published to the cloud server via the MQTT (Message Queuing Telemetry Transport) protocol. The protocol is ideal for resource-constrained IoT devices, as it uses a publish/subscribe architecture that ensures fast and reliable data transmission in real-time [14], [17].

3. RESEARCH METHODS

3.1 Research Design

This research adopts an experimental approach and system development to design and implement a prototype of an Internet of Things (IoT)-based control system. The main focus of the research is the automation of

monitoring and regulating nutrient levels and temperature in the hydroponic tower system to optimize the growth of Pakcoy plants. This approach was chosen to comprehensively validate the functionality of the system and analyze its impact on plant growth parameters.

3.2 Research Flow

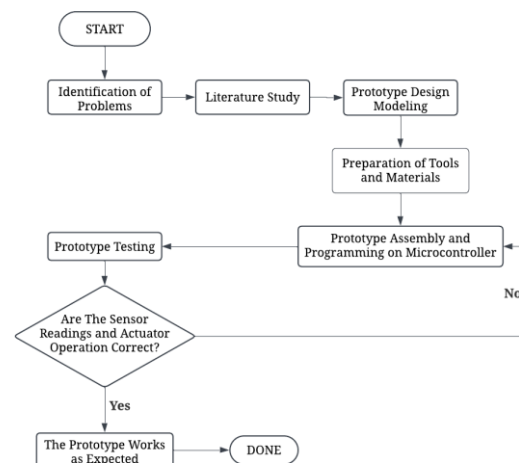


Figure 1 Research Flowchart

This research begins with a comprehensive identification of the problem, followed by an in-depth literature study to build a theoretical foundation and determine the relevance of the research.

A. Prototype Design Modeling

Based on the understanding obtained, the next step is the modeling stage, where the visual and technical design of the system to be developed is prepared. This process includes creating a model to describe the overall system architecture using 3D modeling software as presented in Figure 2



Figure 2. 1 A Model Prototype from The Front.

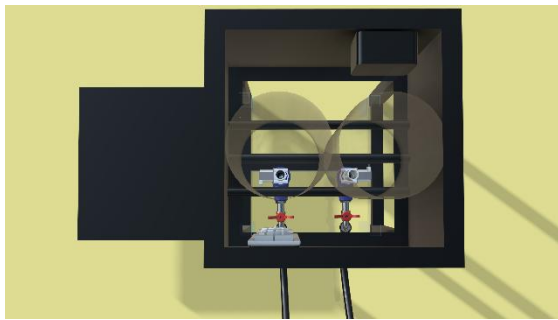


Figure 2.2 A Model Prototype from Above.

Size descriptions include: length; wide; and the height of the design presented in Figure 2, can be seen in full in Table 1.

Table 1 The Size and Material Specifications of The Prototype.

No.	Description	Size (cm)	Material Type
1.	Container Length	38	Stainless Steel
2.	Container Width	38	Stainless Steel
3.	Container Height	51	Stainless Steel
4.	Leg Height	47	Galvanized Hollow Steel
5.	Leg Width	3	Galvanized Hollow Steel

No.	Description	Size (cm)	Material Type
6.	Leg Length	3	Galvanized Hollow Steel
7.	Nutritional Buffer	38	Concrete Iron

B. Prototype Assembly and Programming on Microcontroller

This stage includes hardware implementation, namely component assembly and wiring diagramming to ensure all modules are interconnected. At the same time, software development is carried out through microcontroller programming to integrate the functionality of the system so that it can operate according to the design as shown in Figure 3

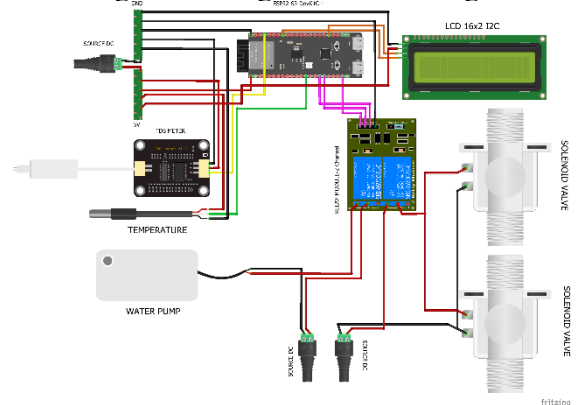


Figure 3 A Schematic of a Microcontroller.

Table 2 Pin Connections Between Devices.

NO.	COMPONENT A	PIN	COMPONENT B	PIN
1.	ESP32-DevKitC-1	3V3	TDS Meter V1.0 KS0429	VCC
2.	ESP32-DevKitC-1	GND	TDS Meter V1.0 KS0429	GND
3.	ESP32-DevKitC-1	GPIO35	TDS Meter V1.0 KS0429	A
4.	ESP32-DevKitC-1	3V3	Temperature Sensor DS18B20	Power
5.	ESP32-DevKitC-1	GND	Temperature Sensor DS18B20	GND
6.	ESP32-DevKitC-1	GPIO2	Temperature Sensor DS18B20	Data
7.	ESP32-DevKitC-1	5V	LCD I2C IIC 16x2	VCC
8.	ESP32-DevKitC-1	GND	LCD I2C IIC 16x2	GND
9.	ESP32-DevKitC-1	GPIO21	LCD I2C IIC 16x2	SDA
10.	ESP32-DevKitC-1	GPIO22	LCD I2C IIC 16x2	SCL
11.	ESP32-DevKitC-1	5V	Relay Module 2 Channel 5V	VCC
12.	ESP32-DevKitC-1	GND	Relay Module 2 Channel 5V	GND
13.	ESP32-DevKitC-1	GPIO27	Relay Module 2 Channel 5V	IN1
14.	ESP32-DevKitC-1	GPIO26	Relay Module 2 Channel 5V	IN2
15.	Resources	(+)	Relay Module 2 Channel 5V	COM
16.	Relay Module 2 Channel 5V	NO	Solenoid Valve DC 2W-160-15	(+)
17.	Resources	(-)	Solenoid Valve DC 2W-160-15	(-)
18.	Resources	(+)	Relay Module 2 Channel 5V	COM

19.	Relay Module 2 Channel 5V	NO	Solenoid Valve DC 2W-160-15	(+)
20.	Resources	(-)	Solenoid Valve DC 2W-160-15	(-)
21.	Resources	(+)	Relay Module 2 Channel 5V	COM
22.	Relay Module 2 Channel 5V	NO	Yamano WP-103 Hydroponic Pump	(+)
23.	Resources	(-)	Yamano WP-103 Hydroponic Pump	(-)

Table 2 details the interpin connections of all the devices used in the prototype shown in Figure 3. Analysis of the performance of the tool as well as hydroponic plant growth and yield data will be discussed further in the Results and Discussion section below.

4. RESULTS AND DISCUSSION

4.1 System Prototype Performance

The results of the system's performance testing are presented through a monitoring dashboard, where data from each sensor can be monitored in real-time as shown in Figure 4. Meanwhile, Figure 5 shows a prototype of a hydroponic system that has been successfully realized, providing a visual overview of the hardware implementation.

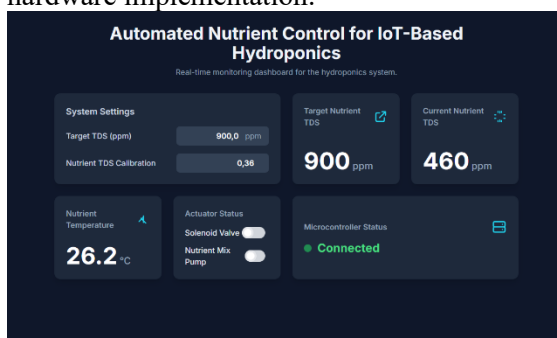


Figure 4 Hydroponic Monitoring Dashboard.

This monitoring dashboard serves as the main interface that allows users to interact with the system in real-time. The existing functions are designed to provide full control and visual monitoring of environmental conditions. Users can set the desired TDS Target value, which is a reference for the system to maintain nutrient levels. Simultaneously, the dashboard displays the Current TDS, which is the actual value of the sensor, allowing for direct comparisons and ensuring the system is working on target. Other important information, such as Nutrient Temperature, is also monitored to ensure that

the temperature of the solution is in optimal conditions for plant growth. In addition, this dashboard provides monitoring of the operational status of the Solenoid Valve and Nutrient Mix Pump, providing visual confirmation that the actuator is functioning correctly when needed. Overall, this dashboard consolidates all important data and controls, making it an effective tool for monitoring and managing hydroponic systems.



Figure 5 Automatic Nutrition System Prototype

4.2 Plant Growth Data Analysis

This analysis is based on plant growth data and environmental conditions that were successfully collected during the study period. Plant growth data, such as height and weight, are presented in Table 3 to show growth trends over time from the first day of planting on hydroponic media to harvest time.

The automatic control system successfully maintains the optimal range of environmental conditions, as illustrated in the following graphs. Figure 6, Figure 7, and Figure 8 respectively present a visualization of data on Temperature, PPM of nutrient solution, and pH during the cultivation period.

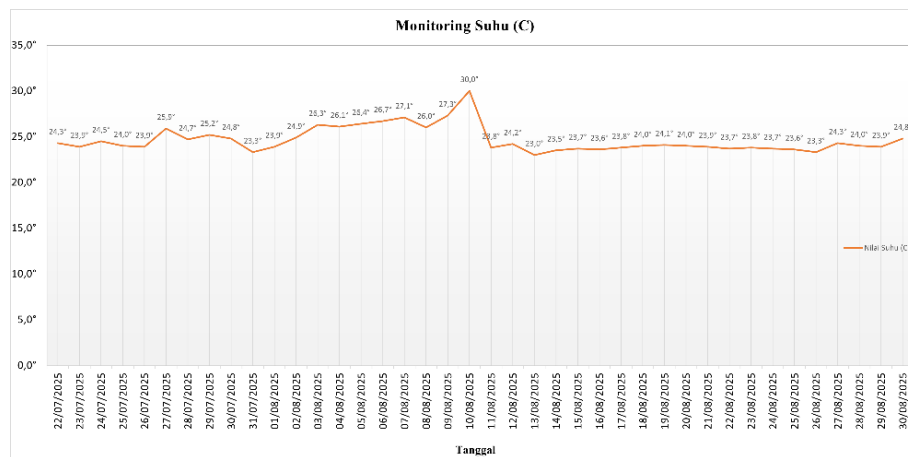


Figure 6 Graph of Temperature Monitoring Data

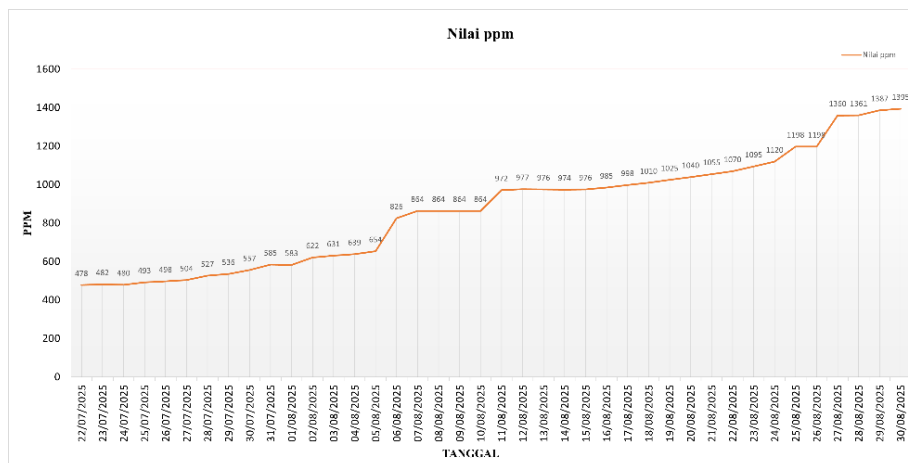


Figure 7 Graph of ppm Monitoring Data

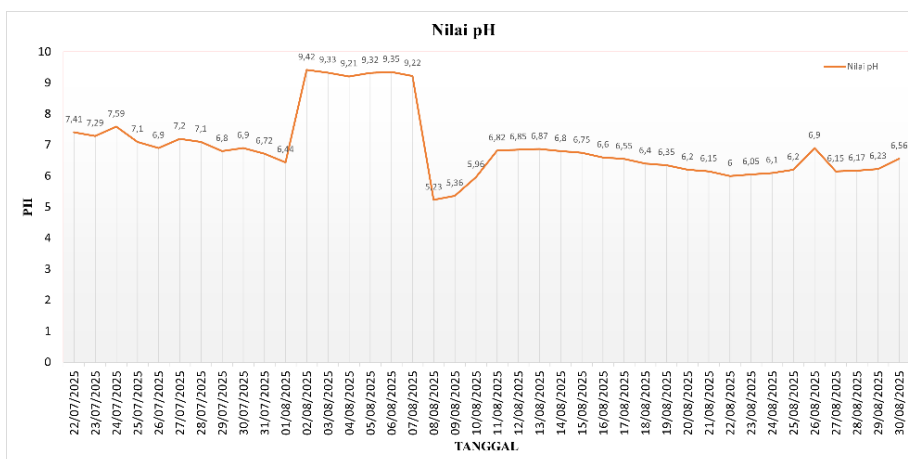


Figure 8 pH Monitoring Data Graph

Based on the data presented, correlation analysis showed a strong relationship between a consistent plant growth rate and stable environmental conditions. The stability of key parameters such as pH, Temperature, and ppm has been scientifically proven to affect nutrient

availability and plant metabolism. By keeping these conditions at an ideal range, the system is effective in facilitating optimal nutrient uptake, which is directly correlated positively with vegetative growth and crop quality.

Table 3 Hydroponic Plant Growth Data

Weeks	Date	Plant Height (cm)	Plant Length (cm)	Plant Width (cm)
WEEK 3	22/07/2025	2,0 to 2,5	0,5 to 0,7	0,2 to 0,3
	23/07/2025	2,0 to 2,6	0,5 to 0,8	0,2 to 0,4
	24/07/2025	2,1 to 2,6	0,6 to 0,9	0,4 to 0,5
	25/07/2025	2,5 to 2,8	0,9 to 1,5	0,7 to 0,8
	26/07/2025	2,7 to 2,8	1,0 to 1,7	0,7 to 0,9
	27/07/2025	2,9 to 3,0	1,9 to 2,0	0,8 to 0,9
	28/07/2025	3,3 to 3,9	2,1 to 2,5	0,9 to 1,0
WEEK 4	29/07/2025	4,2 to 4,8	2,5 to 2,7	1,1 to 1,5
	30/07/2025	4,7 to 5,3	2,8 to 3,0	1,1 to 1,5
	31/07/2025	5,5 to 6,0	3,0 to 4,5	1,5 to 3,0
	01/08/2025	5,5 to 6,0	3,5 to 4,5	1,5 to 3,0
	02/08/2025	7,5 to 8,5	4,0 to 4,8	2,5 to 3,2
	03/08/2025	7,5 to 10,9	4,5 to 5,0	2,5 to 3,5
	04/08/2025	8,0 to 11,5	5,0 to 5,5	2,5 to 4,0
WEEK 5	05/08/2025	8,3 to 11,7	5,2 to 5,9	2,7 to 4,2
	06/08/2025	8,6 to 11,9	5,5 to 6,3	2,8 to 4,5
	07/08/2025	7,0 to 12	5,8 to 6,5	2,8 to 4,8
	08/08/2025	10 to 14	6,8 to 7,0	4,0 to 5,0
	09/08/2025	12,5 to 15,2	7,0 to 7,5	4,5 to 5,2
	10/08/2025	15 to 16	7,0 to 8,5	4,5 to 5,5
	11/08/2025	15,5 to 16	7,5 to 8,5	5,0 to 5,5
WEEK 6	12/08/2025	15,8 to 16,1	7,6 to 8,5	5,5 to 5,9
	13/08/2025	16,3 to 17	8,7 to 9,0	6,0 to 6,4
	14/08/2025	16,5 to 17	8,4 to 9,1	5,9 to 6,1
	15/08/2025	16,9 to 17,2	8,6 to 8,9	6,0 to 6,3
	16/08/2025	17 s/ 17,4	8,7 to 9,1	5,8 to 6,1
	17/08/2025	17 to 17,5	8,9 to 9,3	6,0 to 6,3
	18/08/2025	17,6 to 17,7	8,9 to 9,2	6,0 to 6,4
WEEK 7	19/08/2025	17,3 to 17,8	8,6 to 9,0	6,1 to 6,3
	20/08/2025	17,6 to 17,9	8,9 to 9,2	5,9 to 6,1
	21/08/2025	17,8 to 17,9	8,7 to 8,9	6,0 to 6,2
	22/08/2025	18,1 to 18,3	8,9 to 9,3	6,1 to 6,5
	23/08/2025	17,9 to 18,3	9,0 to 9,3	6,4 to 6,8
	24/08/2025	18,2 to 18,4	9,2 to 9,4	6,5 to 6,8
	25/08/2025	18,1 to 18,7	9,0 to 9,5	6,8 to 7,1
WEEK 8	26/08/2025	18,5 to 21,5	9,5 to 10	7,0 to 7,5
	27/08/2025	21,3 to 22,2	10 to 10,3	7,2 to 7,5
	28/08/2025	22,4 to 24,0	10,1 to 10,6	7,3 to 7,5
	29/08/2025	22,0 to 24,0	10,0 to 10,8	7,0 to 7,6

30/08/2025

22,6 to 24,1

10,3 to 10,8

7,4 to 7,6

Based on Table 3, the plant growth data shows a consistent rate of improvement from Week 3 to Week 8. Specifically, the height, length, and width of the plant experienced significant growth, where each parameter indicated a size range that increased over time. This proves that the environment controlled by the automation system successfully facilitates the sustainable growth of plants.

4.3 Discussion

The findings of this study confirm that automation of environmental parameter control is essential to achieve optimal plant growth. According to [8], maintaining pH and nutrient levels (TDS) on a regular basis is a significant challenge for supervisors. The system successfully addresses these challenges by automatically keeping pH, temperature, and PPM in a stable range, in line with the statement[4] that a control system is necessary to maintain nutrient levels. The consistency of PPM and temperature values shown in Graph 7 and Graph 8 is consistent with the findings[7] which show the success of the fuzzy logic control system in maintaining nutrient concentrations in the ideal range (1050–1400 ppm) for pakcoy plants.

The success of the system in maintaining these parameters has a direct impact on growth and crop yields. Based on the harvest data obtained, the total harvest weight was 10,569 kg, with the average weight per tower reaching 3,523 kg. The average weight per plant individually (estimated) is 58.3 grams. These results show that with stable environmental conditions, crop production can be optimized. According to [1], maintaining a constant pH can prevent negative chemical reactions in nutrient solutions, which affect the absorption of nutrients by plants. This is validated by the results of this study, where the stability of environmental conditions is strongly correlated with a consistent plant growth rate, which ultimately results in a good harvest weight. These results also confirm the theory put forward by[6] that proper nutrition at ideal PPM values is essential to optimize growth and production yields.

In implementation, this system fills in the research gaps identified in the introduction. While many previous studies have focused on horizontal systems such as NFTs[4], this study specifically integrates IoT control systems in hydroponic towers, which are an efficient solution to urban land limitations. By theoretical implications, this study reinforces the idea that the integration of IoT technology can modify conventional methods and become the foundation for the development of more advanced precision farming systems, in line with that described by[9] the use of the MQTT protocol for real-time data acquisition.

5. CONCLUSION

This study successfully demonstrated the effectiveness of IoT-based automated systems in managing critical environmental parameters in hydroponic cultivation. The integration of this technology allows for consistent monitoring and control of pH, PPM, and temperature, which has been shown to be strongly correlated with optimal plant growth. The main advantage of this system is its ability to maintain environmental conditions at the ideal range in a precise manner, which results in a significant harvest weight of 10,569 kg in total, with an average of 3,523 kg per tower, and an estimated 58.3 grams per plant. In addition, the interactive dashboard provides the advantages of real-time monitoring and control, allowing users to set nutrition targets and visually monitor operational status, overcoming the time-consuming challenges of manual monitoring.

Despite showing significant success, the system still has some shortcomings that could be the focus of future development. Reliance on specific physical conditions such as location and inclination, as well as the potential lack of nutrient stirring that can affect sensor accuracy, are challenges that need to be addressed. For further development, improve internet connectivity to speed up data acquisition without delay. In addition, the use of pH sensors and control systems capable of automatically adjusting the pH, both when the pH is too high or too low, can be implemented to maintain environmental stability in a sustainable manner.

Other potentials include the use of solar panels as a self-sustaining energy source, making them a more efficient and environmentally friendly system.

THANKS

The author would like to thank the relevant parties who have provided support to this research.

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