COMPLETE
Journal of Computer, Electronic, and Telecommunication
ISSN 2723-4371, E-ISSN 2723-5912

Implementation and Evaluation of an IoT-Based Nutrient Monitoring and Pump Control System for Pakcoy Hydroponics

Dodik Ariyanto[1], Dily Monica[2], Refael Tresia Sibarani[3], Andhika Satriatama[4], Bintang Hamizan Elka[5], Yehezkiel Junifer Reyno Oppier[6], Muhammad Rifqi Annaufal[7], Muhammad Dzaky Az-zshahir[8], Ghazy Hassan[9]

[1,2,3,4,5,6,7,8,9] Computer Engineering Technology, Vocational School, IPB University, Bogor, Indonesia
*Correspondence: dodikariyanto@apps.ipb.ac.id

Received: 10 June 2026; Revised: 14 June 2026; Accepted: 8 July 2026; Published: 20 July 2026.

Abstract: The advancement of Internet of Things (IoT) technology provides opportunities to improve the efficiency and reliability of hydroponic nutrient management. This study implements and evaluates an IoT-based nutrient monitoring and automatic pump control system for pakcoy hydroponics using an ESP32 microcontroller integrated with pH, Total Dissolved Solids (TDS), DS18B20 temperature, and water level sensors. The system displays local data on an LCD and transmits monitoring data to a web-based dashboard for remote observation. A hystesis-based control strategy was applied to the nutrient pump, where the pump was activated when the TDS values was below 1000 ppm and deactivated when the TDS value reached 1400 ppm. Sensor accuracy testing showd average errors of 0.36% for the TDS sensor and 0.39% for the pH sensor. During a five-day functional evaluation, the system was able to monitor pH, TDS, and temperature conditions and provide automatic pump responses according to the predefined control logic. The results indicate that the proposed system is feasible for real-time hydroponic monitoring and initial nutrient control otomation. However, longer cultivation trials and additional network performance evaluation are required to assess its long-term agronomic impact and operational reliability.

Keywords: Internet of Things, hydroponics, pakcoy, ESP32, TDS, monitoring.

---

1. Introduction

The advancement of modern agricultural technology in recent years has shown very rapid development, especially through the implementation of Internet of Things (IoT) and intelligent automation systems that contribute to improving production efficiency and agricultural sustainability [1]. In the context of urban agriculture and limited land availability, hydroponics has emerged as an effective soilless cultivation method, enabling better water-use efficiency and maximizing crop yields without depending on soil quality [2]. Hydroponics is no longer merely an alternative cultivation method, but has transformed into a precision agriculture platform that integrates sensors, actuators, and real-time monitoring systems to create a controlled and ideal growing environment [3]. Along with the increasing global food demand and decreasing agricultural land area, IoT-based hydroponics provides significant opportunities for improving production systems by reducing manual intervention and increasing the accuracy of environmental control [4]. Despite its many advantages, manual nutrient solution management remains a major challenge in the widespread implementation of hydroponics. Important parameters such as pH and Total

Dissolved Solids (TDS) or Electrical Conductivity (EC) require continuous monitoring and adjustment, as environmental changes and nutrient absorption by plants can occur rapidly and directly affect plant growth [1], [5].

Manual methods that rely on routine inspections tend to be less efficient, time-consuming, and prone to human error and delays in responding to nutrient parameter changes [6]. Various studies indicate that ideal nutrient management—including pH, EC, and TDS regulation—remains a major challenge for hydroponic practitioners, thus requiring continuous monitoring systems with adaptive control mechanisms to prevent nutrient imbalances [7]. Comparative studies also show that automatic control systems can significantly improve plant height and biomass compared to manual systems, while also demonstrating high sensor accuracy in supporting closed-loop control systems [8], [9]. The integration of IoT in hydroponic systems offers a more comprehensive solution through real-time sensor monitoring and responsive automatic control based on changing conditions [9].

IoT-based hydroponic systems generally use microcontrollers such as ESP32 or NodeMCU connected to pH, TDS, temperature, humidity, and light sensors, as well as actuators such as peristaltic pumps or relays to adjust nutrient solutions based on threshold logic or specific algorithms [1], [10]. The closed-loop control concept allows the system to automatically adjust nutrients when parameters deviate from the ideal range, with various studies showing improved system stability and better plant growth [8]. Recent advancements have even integrated machine learning techniques such as Random Forest to classify plant health conditions and predict potential nutrient deficiencies based on sensor data, connected to automatic nutrient control systems and cloud-based backends, indicating the evolution toward more intelligent and integrated automation systems [2]. The implementation of MQTT-based automatic nutrient distribution system prototypes has also demonstrated success in establishing independent end-to-end monitoring and control architectures [11].

In addition, the use of adaptive algorithms and machine learning for dynamic dosage recommendations has been reported to improve resource utilization efficiency and plant productivity [7]. To support user interaction, modern IoT hydroponic systems are equipped with real-time web dashboards that display sensor data directly and enable remote monitoring and manual control when necessary [12]. Various cloud platforms and specialized backends have been utilized to present real-time data on pH, TDS, temperature, humidity, light intensity, and pump status to support data-driven decision making [1]. The integration of full-stack technologies, including MQTT brokers, backend servers, real-time databases, and modern frontend systems, has proven effective in providing data visualization, alarm systems, remote actuator control, and AI analysis integration within a unified dashboard [2].

NodeMCU-based systems with web interfaces are also capable of displaying multiple hydroponic variables simultaneously while providing flexible monitoring capabilities through validated testing scenarios [13]. The presence of such dashboards not only improves operational transparency but also expands accessibility for monitoring the system from anywhere.

Although IoT-based hydroponic monitoring systems have been widely reported, many existing studies mainly emphasize sensor integration and dashboard visualization, while fewer studies provide a complete validation of sensor accuracy, threshold-based nutrient pump control, and safety interlock mechanisms in one deployable prototype. Therefore, the novelty of this study lies in the integration of pH, TDS, temperature, and water level monitoring with automatic nutrient pump control using a hysteresis-based TDS threshold and a water-level safety restriction. The proposed system also combines local LCD monitoring and a web-based dashboard to support both on-site and remote observation. The main contribution of this study is not the development of a new control algorithm, but the implementation and functional validation of a low-cost IoT architecture that can be practically deployed for small-scale pakcoy hydroponic cultivation.

Based on these considerations, this study aims to implement and evaluate an automatic nutrient pump control and water nutrient monitoring system for IoT-based hydroponics integrated with a real-time web dashboard, focusing on real-time pH monitoring and automatic nutrient pump control based on TDS values through a reliable and validated architecture.

The contributions of this research include: (1) the development of an IoT-based hydroponic monitoring system using pH, TDS, temperature, and water level sensors integrated with automatic nutrient pump control based on TDS measurements; (2) the design of a real-time web dashboard that supports historical data visualization, live monitoring, and remote access through an intuitive interface; (3) the validation of system performance through sensor testing and control response evaluation under operational conditions; and (4) an analysis of system efficiency in reducing manual intervention and improving nutrient management stability compared to conventional methods.

Therefore, this research is expected to provide practical contributions to the development of more reliable, adaptive, and easily implementable automatic hydroponic systems for both commercial and household scales. As shown in Table 1, the comparison of related IoT-based hydroponic monitoring systems is presented.

Table 1. Comparison of related IoT-based hydroponic monitoring systems

Study	Platform	Parameters Monitored	Control Method	Dashboard/Connectivity	Evaluation	Limitation	Contribution of This Study
Zaid et al. [1]	IoT-based NFT hydroponic system for lettuce; microcontroller-based system integrated with the Favoriot IoT platform	Light intensity, environmental temperature, humidity, TDS level, and pH value	Environmental and nutrient monitoring with IoT-based remote observation; automatic control mechanism is not clearly detailed in the accessible abstract	Favoriot IoT platform for remote monitoring	System implementation for lettuce NFT hydroponics and remote monitoring of key environmental and nutrient parameters	Focused on lettuce cultivation and remote monitoring; sensor accuracy, pump response, and safety interlock evaluation are not clearly emphasized	The proposed study adds sensor accuracy testing, TDS-based nutrient pump control, and a water-level safety restriction in a pakcoy hydroponic system
Aisyah et al. [8]	Arduino UNO with ESP8266-based IoT	TDS/nutrient concentration, pH, and	Closed-loop control for nutrient, pH, and water level	Smartphone-based IoT monitoring,	TDS sensor accuracy up to 99.3%, pH sensor accuracy up	More focused on closed-loop nutrient and pH control;	The proposed study provides functional

Study	Platform	Parameters Monitored	Control Method	Dashboard/Connectivity	Evaluation	Limitation	Contribution of This Study
	system for pakcoy NFT hydroponics	water level using TDS, pH, and JSN-04 ultrasonic sensors	adjustment using peristaltic pumps based on predefined set points	supported by LCD display	to 99.35%, JSN-04 ultrasonic sensor accuracy up to 100%, and better plant height increase under the control system	web dashboard, historical data visualization, and safety restriction based on low reservoir water level are not the main focus	validation on a real pakcoy hydroponic installation using ESP32, web dashboard monitoring, and TDS-based nutrient pump control with water-level safety restriction
Singh et al. [11]	IoT-based automatic nutrient delivery hydroponic system based on self-monitoring parameters	Self-monitoring hydroponic parameters for automatic nutrient delivery; detailed sensor list is not explicitly reported in the accessible source	Automatic nutrient delivery based on monitored hydroponic parameters	IoT-based communication; detailed dashboard or application interface is not explicitly reported in the accessible source	Prototype implementation of automatic nutrient delivery for hydroponic cultivation	Detailed sensor specifications, calibration procedure, dashboard performance, and response-time metrics are not clearly available from the accessible source	The proposed study presents a low-cost ESP32 implementation with pH, TDS, temperature, and water level sensors, LCD display, web dashboard, and five-day functional testing
Proposed system	ESP32-based IoT hydroponic monitoring and control system	pH, TDS, nutrient solution temperature, and water level	Hysteresis-based TDS threshold control; nutrient pump turns on when TDS is below 1000 ppm and turns off	LCD display and web-based dashboard using PHP, HTML, CSS, JavaScrip	TDS sensor average error of 0.36%, pH sensor average error of 0.39%, automatic nutrient	Short-term functional test only; communication delay, data transmission success rate, dashboard refresh time,	Practical deployable prototype for pakcoy hydroponics integrating sensor accuracy testing, automatic

Study	Platform	Parameters Monitored	Control Method	Dashboard/Connectivity	Evaluation	Limitation	Contribution of This Study
			when TDS reaches 1400 ppm; pump operation is restricted when water level is insufficient	t, and MySQL through Wi-Fi connectivity	pump response based on TDS threshold, and five-day functional observation under real hydroponic conditions	and complete agronomic growth evaluation are not yet fully reported	nutrient pump control, water-level safety restriction, LCD monitoring, and web dashboard visualization

2. Materials and Methods

2.1 Materials

The materials used in this study consisted of hardware and software components to support the development of an Internet of Things (IoT)-based hydroponic nutrient monitoring and control system. The hardware components included an ESP32 microcontroller, pH sensor, TDS sensor, water level sensor, relay module, water pump, nutrient pump, LCD I2C display, and power supply. Meanwhile, the software components included Arduino IDE for programming and a web-based dashboard for real-time monitoring. WiFi connectivity was also utilized to support real-time data transmission between the ESP32 and the monitoring system [11], [12].

The hardware and software components used in this study, including their specifications and calibration methods, are shown in Table 2.

Table 1. Sensor specifications and calibration methods used in the proposed hydroponic monitoring system

Component	Model/Type	Measurement Range	Accuracy /Resolution	Operating Voltage	Calibration Method	Function
pH sensor	DFRobot Gravity Analog pH Sensor/Meter Kit V2 (SEN0161-V2) or equivalent analog laboratory-grade pH sensor	0–14 pH; operating liquid temperature 5–60°C	±0.1 pH at 25°C; response time <2 min; average error obtained in this study was 0.39% after calibration	3.3–5.5 V	Two- or three-point calibration using standard buffer solutions of pH 4.00, 7.00, and 10.00; readings were verified using a standard pH meter	Measures nutrient solution acidity
TDS sensor	DFRobot Gravity	0–1000 ppm based	±10% F.S. at 25°C; average error	3.3–5.5 V; analog	Calibration using a	Measures nutrient

Component	Model/Type	Measurement Range	Accuracy /Resolution	Operating Voltage	Calibration Method	Function
	Analog TDS Sensor/Meter (SEN0244) or equivalent analog TDS sensor	on the manufacturer specification; a higher-range TDS/EC sensor is required if the 1000–1400 ppm control threshold is retained	obtained in this study was 0.36% after calibration	output 0–2.3 V	standard TDS/EC solution, such as 707 ppm or 1413 μS/cm at 25°C, followed by verification using a standard TDS meter	concentration in the hydroponic solution
Temperature sensor	Waterproof DS18B20 digital temperature sensor	-55 to 125°C	±0.5°C from -10 to 85°C; programmable 9-bit to 12-bit resolution	3.0–5.5 V	Comparison with a calibrated digital thermometer under the same nutrient solution condition	Measures nutrient solution temperature
Water level sensor	Analog resistive water level sensor module	Threshold-based water detection; approximately 0–40 mm detection area depending on the sensor module	Analog output read by the ESP32 ADC; 12-bit raw ADC value from 0 to 4095; used for low-water threshold detection rather than precise water-depth measurement	3.0–5.0 V	Threshold test under empty, low-water, and normal-water conditions; the threshold value was stored in the ESP32 program	Detects low water condition and disables nutrient pump operation as a safety interlock

2.2 Research Method

This study employed an experimental and system engineering approach to develop and evaluate an Internet of Things (IoT)-based hydroponic nutrient monitoring and nutrient pump control system. The research was conducted at a hydroponic cultivation site to assess the performance of the developed system under actual operating conditions.

The development process consisted of several stages. The first stage was problem identification and requirement analysis, where observations were conducted to determine the main challenges in hydroponic cultivation, particularly in monitoring nutrient concentration and maintaining suitable water conditions. Based on these observations, the system requirements, hardware specifications, and monitoring parameters were determined.

The second stage involved system design, including hardware and software design. The hardware consisted of an ESP32 microcontroller, pH sensor, TDS sensor, DS18B20 temperature sensor, water level sensor, relay module, nutrient pump, LCD display, and power supply. The software was developed using Arduino IDE for data acquisition and device control, while a web-based dashboard was developed for real-time monitoring and data visualization.

The third stage was hardware and software implementation. All sensors were connected to the ESP32 microcontroller to collect data from the hydroponic reservoir. The ESP32 processed the sensor readings and transmitted the data to the web dashboard via a WiFi connection. The monitoring system continuously measured pH, TDS, temperature, and water level parameters.

The automatic control mechanism was implemented based on TDS measurements. The nutrient pump was activated when the TDS value was below 1000 ppm and deactivated when the TDS value reached or exceeded 1400 ppm. This control strategy was designed to maintain nutrient concentration within the recommended range for pakcoy cultivation. As a safety mechanism, nutrient pump operation was also restricted when the water level sensor detected insufficient water in the reservoir.

The final stage involved system testing and evaluation. Sensor performance was evaluated by comparing sensor readings with standard measuring instruments. The percentage error was calculated to determine sensor accuracy. In addition, nutrient pump control testing, real-time monitoring testing, and overall system integration testing were conducted to evaluate system reliability, response performance, and operational stability under real cultivation conditions.

2.3 System Design

The system was designed using a block diagram approach consisting of input, processing, and output sections. The input section included the pH sensor, TDS sensor, temperature sensor, and water level sensor. The processing section used an ESP32 microcontroller as the main control unit, while the output section consisted of a relay module, nutrient pump, LCD display, and web-based monitoring dashboard.

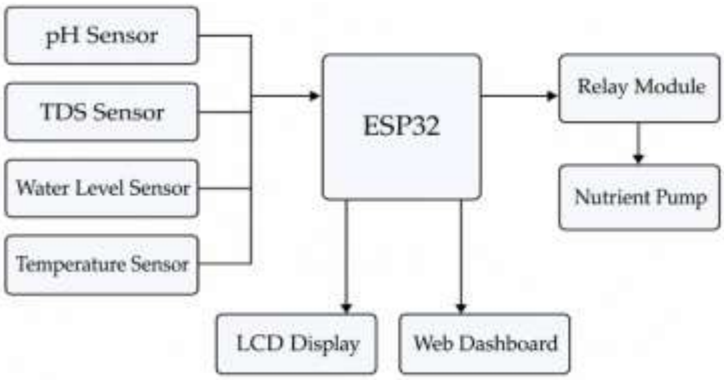

Figure 1. Block Diagram

Based on the block diagram shown in Figure 1, the ESP32 processed sensor data obtained from the pH sensor, TDS sensor, temperature sensor, and water level sensor. The pH sensor was used to monitor the acidity level of the hydroponic water, while the TDS sensor monitored nutrient concentration. The temperature sensor was used to monitor water temperature conditions, and the water level sensor functioned as a safety indicator to detect low water conditions in the reservoir.

The nutrient pump was automatically controlled through the relay module based on TDS readings. If the TDS value was below the predefined threshold, the ESP32 activated the nutrient pump automatically to increase nutrient concentration. In this prototype, automatic control was limited to the nutrient pump, while the circulation water pump was operated continuously/manual depending on the hydroponic installation setup. Monitoring data from all sensors were displayed on the LCD and transmitted to the web dashboard through a WiFi connection for real-time monitoring

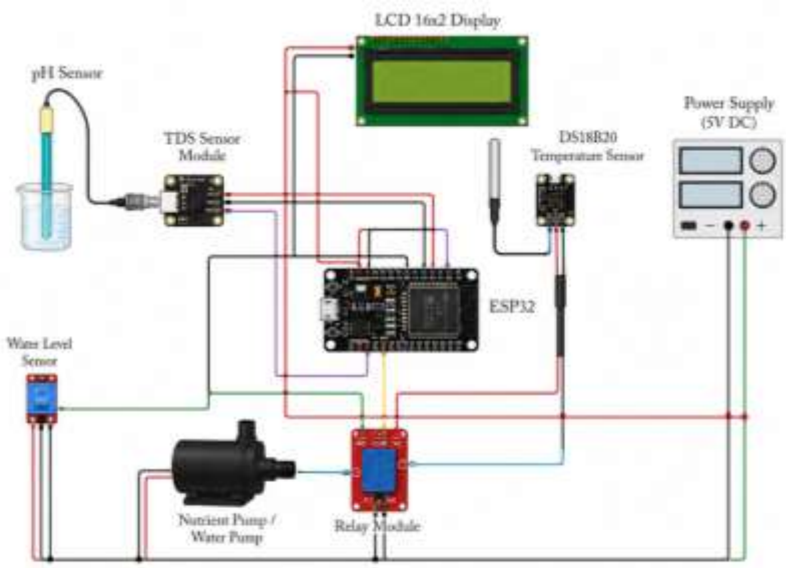

Figure 2. Circuit Schematic

The circuit schematic of the developed system is shown in Figure 2. The pH sensor, TDS sensor, temperature sensor, and water level sensor were connected to the ESP32 input pins for data acquisition. The relay module was connected to the ESP32 digital output pin to control the nutrient pump automatically based on TDS readings. The LCD module used I2C communication to display real-time monitoring data. The system also considered voltage stability and power efficiency to ensure optimal operation of all hardware components.

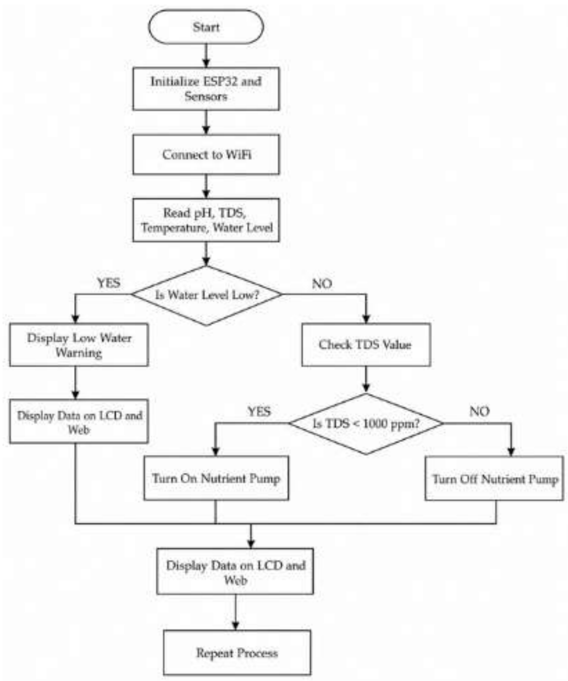

Figure 3. Flowchart of the IoT-based hydroponic monitoring and nutrient pump control system

As shown in Figure 3, the system started by initializing all hardware components and establishing a WiFi connection. The ESP32 continuously monitored water level, pH, temperature, and TDS conditions in the hydroponic reservoir. If the water level was below the predefined threshold, the nutrient pump was automatically disabled as a safety mechanism. Under normal conditions, the system monitored TDS values continuously. If the TDS value was below the specified threshold, the ESP32 activated the nutrient pump automatically through the relay module. All monitoring data were displayed on the LCD and transmitted to the web dashboard in real-time.

2.4 Software Design

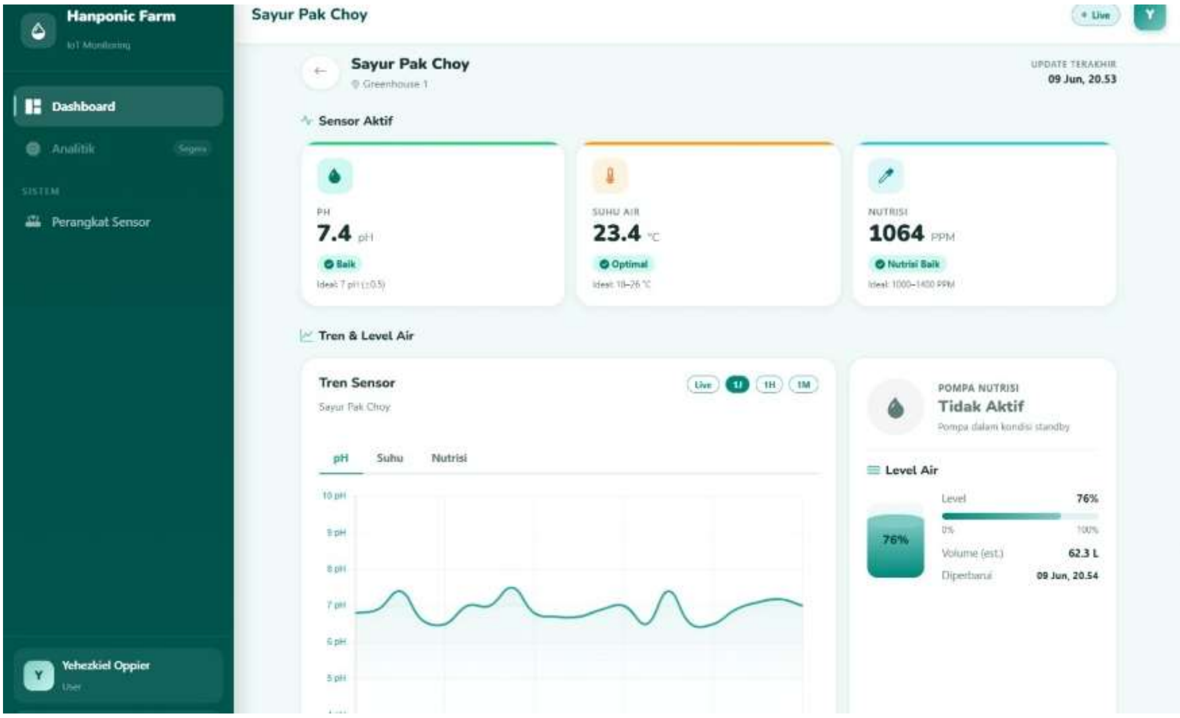

Figure 4. Web Dashboard Displaying Real-time pH, TDS, Temperature, and Water Level Data

The software consisted of two main components: the ESP32 program and a web-based monitoring application. The ESP32 program was developed using Arduino IDE with the C/C++ programming language to read pH, TDS, and temperature sensor data and transmit the collected data to the server through a WiFi network.

As shown in Figure 3, the web application was developed using native PHP, HTML, CSS, JavaScript, and MySQL. The application functioned to receive, store, and display sensor data through a real-time monitoring dashboard. Through the dashboard, users could monitor hydroponic conditions remotely using devices connected to the internet.

2.5 System Testing and Evaluation

Testing was conducted to ensure that the system operated according to the proposed design. The testing procedures included sensor accuracy testing by comparing sensor readings with standard measuring instruments, water level testing to ensure that the system could detect low water conditions, nutrient pump control testing to verify that the nutrient pump operated automatically according to TDS sensor readings, real-time monitoring testing to ensure that sensor data could be displayed on the web dashboard and LCD in real-time, and system integration testing to ensure that all components operated synchronously.

To evaluate sensor accuracy, the measured values obtained from the pH sensor and TDS sensor were compared with readings from standard measuring instruments. The percentage error was calculated using Equation (1):

$$Error\ (\%) = \frac{|Standard\ Value - Sensor\ Value|}{Standard\ Value} \times 100\,\%$$

The tests were performed under the same operating conditions to evaluate functional consistency of the monitoring and control system. System evaluation was based on several parameters, including sensor accuracy, system response time, system stability, automatic nutrient control performance, and the reliability of real-time monitoring for hydroponic nutrient conditions.

3. Results

This section presents the results of testing the developed Internet of Things (IoT)-based hydroponic nutrient monitoring and control system. The testing was conducted to evaluate the system's performance in monitoring pH, Total Dissolved Solids (TDS), and temperature parameters in real time through a web dashboard and LCD display. In addition, the testing aimed to assess the effectiveness of the automatic nutrient pump control based on measured TDS values.

The developed system was implemented directly at the partner's hydroponic installation under actual operating conditions. Data collected from the sensors were processed by the ESP32 microcontroller and transmitted to the server for real-time visualization on the web dashboard. The test results were then analysed to evaluate the accuracy, stability, and reliability of the system in supporting hydroponic cultivation activities.

3.1 System Implementation

The system implementation consisted of the installation of a pH sensor, TDS sensor, temperature sensor, ESP32 microcontroller, relay module, nutrient pump, LCD display, and web-based monitoring dashboard. All components were integrated to create an automatic nutrient monitoring and control system.

Figure 5. Implementation Device

Figure 5 shows the implementation of the developed device installed on the hydroponic system. The ESP32 microcontroller was connected to the pH, TDS, temperature, and water level sensors to continuously monitor nutrient solution conditions. Sensor data were processed by the ESP32 and displayed on the LCD while simultaneously being transmitted to the monitoring platform through a Wi-Fi connection. The relay module was used to control the nutrient pump automatically based on TDS measurements. The implemented system was successfully integrated with the hydroponic installation and operated according to the designed monitoring and control functions.

3.2 Sensor Accuracy Testing

Sensor accuracy testing was conducted to evaluate the performance of the pH and TDS sensors used in the developed hydroponic monitoring system. The sensor readings were compared with measurements obtained from standard measuring instruments under the same operating conditions. The percentage error was calculated using Equation (1) to determine the deviation between the sensor readings and the reference measurements.

The TDS sensor accuracy test results are presented in Table 3.

Table 2. TDS Accuracy Test Results

Test	Sensor TDS (ppm)	Standard TDS Meter	Error (%)
1	498	500	0.40%
2	748	750	0.27%
3	998	1000	0.20%
4	1245	1250	0.40%
5	1492	1500	0.53%

Based on Table 3, the TDS sensor produced measurement values close to the standard TDS meter readings. The differences between sensor values and reference values may occur due to several factors, including analog measurement noise, sensor characteristics, and solution conditions during measurement. The highest error value occurred in the fifth test with **0.53%**, while the lowest error value was obtained in the third test with **0.20%**. The average TDS sensor error was calculated as:

$$Average\ Error = \frac{0.40 + 0.27 + 0.20 + 0.40 + 0.53}{5}$$

$$Average\ Error = 0.36\%$$

The result indicates that the TDS sensor provides good accuracy and stable measurement performance. Therefore, the sensor can be effectively used for real-time monitoring of nutrient concentration in the hydroponic system.

The pH sensor accuracy test results are presented in Table 4.

Table 3. pH Accuracy Test Results

Test	Sensor pH	Standard pH Meter	Error (%)
1	6.48	6.50	0.31
2	5.96	6.00	0.67
3	5.52	5.50	0.36
4	6.18	6.20	0.32
5	6.82	6.80	0.29

The results in Table 4 show that the pH sensor generated measurement values close to the standard pH meter readings. The highest error occurred in the second test with **0.67%**, while the lowest error was obtained in the fifth test with **0.29%**. The measurement deviation was still within an acceptable range, indicating that the sensor is suitable for monitoring hydroponic water conditions. The average error of the pH sensor was calculated as:

$$Average\ Error = \frac{0.31 + 0.67 + 0.36 + 0.32 + 0.29}{5} = 0.39\%$$

$$Average\ Error = 0.39\%$$

These results show that the calibrated pH sensor is capable of providing readings with a low error rate so that it can be used to monitor hydroponic environmental conditions.

Overall, the accuracy testing results indicate that both sensors achieved low measurement errors and were able to provide consistent monitoring data. Therefore, the pH and TDS sensors can be considered suitable for real-time hydroponic monitoring applications and for supporting automatic nutrient management within the developed IoT-based system.

3.3 pH Sensor Testing

The pH sensor was tested to evaluate its capability in continuously monitoring the acidity level of the nutrient solution. Maintaining pH within the recommended range is important because it directly affects nutrient availability and plant growth. The testing was conducted for five consecutive days, and the results are presented in Table 5.

Table 4. pH Sensor Results

Day	pH Value	Plant Condition	Description
1	6.2	Good	The plant looks fresh, leaves are bright green.
2	6.1	Good	Stable growth, no signs of nutrient deficiency.
3	5.9	Good	Leaves remain green and stems begin to increase in height.
4	5.8	Fair	pH begins to decrease, growth is still normal but requires monitoring.
5	6.0	Good	pH returns to stable, plants grow healthy and roots develop well.

The measured pH values ranged from 5.8 to 6.2 throughout the testing period, indicating relatively stable nutrient solution conditions. As shown in Table 4, the pH values remained within the recommended range for hydroponic pakcoy cultivation, which generally lies between 5.5 and 6.5. Although the pH value decreased to 5.8 on the fourth day, the plants continued to exhibit normal growth and healthy leaf development. On the fifth day, the pH value returned to 6.0, indicating improved nutrient solution stability. These results demonstrate that the pH sensor was capable of continuously monitoring acidity levels and providing reliable real-time information to support effective hydroponic nutrient management.

3.4 TDS Sensor and Automatic Nutrient Pump Testing

The TDS sensor was tested to evaluate the nutrient concentration in the hydroponic solution and the performance of the automatic nutrient pump control. The testing was conducted over five consecutive days, and the results are presented in Table 6.

Table 5. TDS Sensor Result

Day	TDS Value (ppm)	Plant Condition	Description
1	850	Fair	Nutrient concentration is still low, the nutrient pump is active to add nutrient solution.
2	980	Fair	TDS value is approaching the ideal range, plant growth is beginning to improve.
3	1120	Good	TDS is within the optimal range, plants are healthy and leaves are green.
4	1280	Good	Nutrient concentration is stable, root and leaf growth are proceeding optimally.
5	1380	Excellent	TDS is near the upper ideal limit, visual observation indicated that the plants remained in acceptable condition during the short-term test.

The testing results showed that the automatic nutrient pump operated according to the predefined control logic. When the TDS value was below 1000 ppm, the nutrient pump was activated to increase the nutrient concentration in the hydroponic reservoir. As shown in Table 5, the TDS value gradually increased from 850 ppm on the first day to 1380 ppm on the fifth day. This indicates that the nutrient addition mechanism functioned properly and was able to maintain nutrient concentration within the desired range for hydroponic cultivation. Furthermore, the observed improvement in plant condition from Fair to Excellent suggests that the nutrient levels provided by the system were sufficient to support healthy plant growth and development. These results indicate that the integration of the TDS sensor and automatic nutrient pump control has the potential to reduce manual nutrient adjustment, although a direct comparison with manual operation is required to quantify the reduction.

3.5 Temperature Sensor Testing

The temperature sensor was tested to monitor nutrient solution temperature under actual hydroponic operating conditions. Temperature stability is important because it affects nutrient uptake and plant development. The testing results are presented in Table 7.

Table 6. Temperature Sensor Result

Day	Temperature (°C)	Plant Condition	Description
1	25.8	Good	Temperature is within the ideal range, plants look fresh and healthy.
2	26.3	Good	Temperature is stable, leaf growth is proceeding normally.
3	27.1	Good	Temperature has risen slightly but still supports plant growth.
4	28.0	Fair	Temperature is approaching the upper optimal limit; further monitoring is needed.
5	26.7	Good	Temperature has stabilized again; plants show good growth.

The recorded temperature values ranged from 25.8°C to 28.0°C throughout the testing period. These values remained within the acceptable temperature range for hydroponic cultivation and were able to support normal plant growth. As shown in Table 6, the temperature increased gradually from the first to the fourth day before decreasing to 26.7°C on the fifth day. Although the temperature reached 28.0°C on the fourth day, which was close to the upper optimal limit, the plants continued to exhibit normal growth without significant signs of stress. The temperature sensor successfully detected environmental variations and continuously transmitted monitoring data to the web dashboard, enabling real-time observation of hydroponic conditions. These results indicate that the temperature monitoring system operated reliably and can assist users in maintaining suitable environmental conditions for hydroponic cultivation.

4. Discussion

The five-day evaluation showed that the developed system was able to monitor hydroponic nutrient solution parameters and operate the nutrient pump according to the predefined TDS control logic. The pH values ranged from 5.8 to 6.2, indicating that the nutrient solution remained within the generally recommended range for pakcoy hydroponic cultivation. The TDS values increased from 850 ppm to 1380 ppm during the observation period, showing that the nutrient pump control mechanism was able to increase nutrient concentration toward the target range. Meanwhile, the recorded temperature values ranged from 25.8°C to 28.0°C, indicating relatively stable nutrient solution conditions during testing.

However, the observed plant condition should be interpreted carefully because the evaluation period was limited to five days and did not cover a complete pakcoy growth cycle. In addition, plant performance was assessed based on visual observation rather than quantitative agronomic parameters such as plant height, number of leaves, fresh weight, root length, or chlorophyll content. Therefore, the results primarily demonstrate the functional feasibility of the monitoring and control system, not the final effect of the system on crop productivity. Future work should include longer cultivation trials, comparison with manual nutrient management, quantitative plant growth measurements, and network performance evaluation such as communication delay, data transmission success rate, and dashboard response time.

5. Conclusions

Based on the implementation and testing results, the developed IoT-based hydroponic monitoring system successfully performed its intended functions. The system was capable of monitoring pH, TDS, and temperature parameters in real time using an ESP32 microcontroller integrated with sensors, an LCD display, and a web-based dashboard.

The sensor accuracy testing results showed that the TDS and pH sensors achieved average errors of 0.36% and 0.39%, respectively, indicating that both sensors provided reliable measurements for hydroponic monitoring applications. The automatic nutrient pump control mechanism operated according to the predefined TDS threshold, enabling the system to maintain nutrient concentration within the desired range for hydroponic cultivation.

In addition, the web dashboard successfully displayed monitoring data in real time, allowing users to remotely access and continuously observe hydroponic conditions. Overall, the integrated system operated according to the designed monitoring and control functions and showed potential to support more efficient hydroponic. Therefore, the proposed system can be considered a practical solution for implementing real-time hydroponic monitoring and automatic nutrient management through the application of Internet of Things (IoT) technology.

References

1. M. Zaid *et al.*, "IoT-based Smart Hydroponic System Using Nutrient Film Technique (NFT) for Lettuce Plant," in *2023 IEEE 12th Global Conference on Consumer Electronics (GCCE)*, IEEE, Oct. 2023, pp. 976–980. doi: 10.1109/GCCE59613.2023.10315640.
2. Prof. T. Baraskar, V. Khatri, P. Kolhe, M. Katyarmal, and S. Khedekar, "AI-powered automated hydroponic system for smart agriculture," *MethodsX*, vol. 15, p. 103579, Dec. 2025, doi: 10.1016/j.mex.2025.103579.
3. K. Bouarroudj, F. Babaa, and A. Touil, "IoT-based monitoring and control for optimized plant growth in smart greenhouses using soil and hydroponic systems," *Internet of Things*, vol. 33, p. 101710, Sep. 2025, doi: 10.1016/j.iot.2025.101710.
4. S. M S, A. S, B. S, N. H R, and S. Shivani, "IoT-Powered Hydroponics System: A Real-Time Monitoring and Control System," *Asian Journal of Convergence in Technology*, vol. 9, no. 3, pp. 82–86, Feb. 2024, doi: 10.33130/AJCT.2023v09i03.013.
5. F. Fauzan, I. Lesmana, and N. Nugraha, "Sistem Pengendalian Nutrisi Hidroponik Menggunakan Logika Fuzzy Berbasis Internet of Things," *Jurnal Algoritme*, vol. 6, no. 1, pp. 162–174, 2025, doi: 10.35957/algoritme.v5i3.11740.
6. D. Galuh Pratama, J. Maulindar, and R. Puspita Indah, "Perancangan Monitoring & Pengontrol pH Sayuran Sawi Hidroponik Berbasis IoT (Internet of Things)," *Ratna Puspita Indah INNOVATIVE: Journal Of Social Science Research*, vol. 3, pp. 4051–4060, 2023.
7. A. A. Imansyah, M. Syamsiah, and D. M. Jakaria, "Rancang Bangun Prototype Sistem Otomatis Dalam Budidaya Tanaman Hidroponik Berbasis IoT (Internet of Things) Automatic System Prototype Design In Hydroponic Cultivation Based On IoT (Internet Of Things)," 2022.
8. P. Y. Aisyah, P. I. J.A.S, Q. Ainin, and M. I. Wijayanti, "Control System for Pakcoy Hydroponic Cultivation with Nutrient Film Technique based on Internet of Things," *IPTEK The Journal of Engineering*, vol. 10, no. 3, p. 179, Dec. 2024, doi: 10.12962/j23378557.v10i3.a17931.
9. A. Salim Wardhana *et al.*, "Desain dan Prototipe Integrasi IoT dalam Pertanian Hidroponik Cerdas Berbasis Energi Terbarukan," 2025. [Online]. Available: https://journal.stmiki.ac.id
10. N. Heriyani and S. Ernawati, "Pemanfaatan Teknologi IoT Berbasis Mobile Dalam Upaya Monitoring Kualitas Air pada Tanaman Hidroponik."
11. N. K. Singh, P. Bhatt, and B. Vala, "Automatic Nutrient Delivery IoT Based Hydroponic by Self-Monitoring Parameter," *IET Conference Proceedings*, vol. 2025, no. 7, pp. 661–667, Sep. 2025, doi: 10.1049/icp.2025.1361.
12. S. Savitri, I. G. Waluyo, and Y. Permadi, "Sistem Kontrol Adaptif Untuk Optimalisasi Pertanian Hidroponik Menggunakan Internet of Things (IoT) Berbasis Web," *RIGGS: Journal of Artificial Intelligence and Digital Business*, vol. 4, no. 2, pp. 6725–6731, Jul. 2025, doi: 10.31004/riggs.v4i2.1737.
13. D. Yulianto, A. F. Nugraha, and F. F. Rahani, "Automated Hydroponics System using the Internet of Things," *Jurnal Edukasi Elektro*, vol. 8, no. 2, Nov. 2024, doi: 10.21831/jee.v8i2.76816.

© 2019 by the authors. Submitted for possible open access publication under the terms and conditions of the Creative Commons Attribution (CC BY) license (http://creativecommons.org/licenses/by/4.0/).