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# IoT-Based Monitoring System for pH and Electrical Conductivity of Hydroponic Nutrient Solutions

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**Abstract**

Technological advancements in agriculture have encouraged the adoption of hydroponic systems as an efficient cultivation method for overcoming land limitations. In hydroponic cultivation, pH and Electrical Conductivity (EC) are essential parameters that influence nutrient availability and absorption by plants. However, monitoring these parameters is often performed manually, making the process inefficient and prone to measurement errors. This study aims to design and implement an Internet of Things (IoT)-based monitoring system for pH and EC in hydroponic nutrient solutions to provide real-time monitoring. The system utilizes an ESP32 microcontroller integrated with a pH sensor, EC sensor, Analog Signal Isolator, I2C LCD, and the Blynk application for data visualization. The research methodology includes hardware design, software development, system implementation, and sensor accuracy evaluation. Experimental results show that the pH sensor achieved an accuracy of 89.07%, while the EC sensor achieved an accuracy of 92.26%. The developed system successfully displayed pH and EC measurements in real time through both the I2C LCD and Blynk application, enabling remote monitoring of nutrient solution conditions. Therefore, the proposed system is suitable as an IoT-based monitoring tool to support nutrient management in hydroponic cultivation.

***Keywords**: Electrical Conductivity, Hydroponics, Internet of Things, Nutrient Monitoring, pH*

## 1. Introduction

Hydroponic cultivation has become a promising agricultural method due to its efficient use of water and ability to support plant growth in limited land areas. Along with the advancement of Internet of Things (IoT) technology, monitoring systems can be developed to provide real-time information and improve hydroponic management efficiency [1].

In hydroponic systems, pH and Electrical Conductivity (EC) are important parameters that affect nutrient availability and plant growth. Improper pH and EC values may reduce nutrient absorption and negatively impact crop productivity [2]. Several studies have implemented IoT-based monitoring systems using ESP8266, Arduino Uno, and ESP32 combined with pH and nutrient sensors to support real-time monitoring of hydroponic conditions [3], [4], [5].

However, previous studies generally focused on automatic control systems or incorporated multiple environmental parameters. Therefore, this study proposes an IoT-based monitoring system for pH and Electrical Conductivity (EC) of hydroponic nutrient solutions using ESP32 and the Blynk platform. The developed system aims to provide real-time monitoring with reliable measurement accuracy to support effective nutrient management in hydroponic cultivation.

## 2. Research Methods

This study proposes an Internet of Things (IoT)-based monitoring system for measuring the pH and Electrical Conductivity (EC) of hydroponic nutrient solutions. The research method includes system design, implementation, testing, and data analysis to evaluate the performance of the proposed system.

### 2.1. Research Methodology

This study was conducted to develop an Internet of Things (IoT)-based monitoring system for measuring the pH and Electrical Conductivity (EC) of hydroponic nutrient solutions. The research methodology included problem identification, literature review, system design, implementation, and testing.

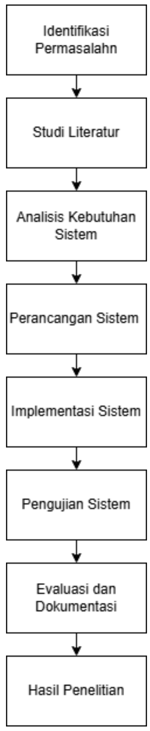


**Fig. 1:** Research methodology structure

## 2.2. Data Analysis

Data analysis was performed to evaluate the accuracy of the developed pH and EC monitoring system. Sensor measurements were compared with reference values obtained from calibration solutions and hydroponic nutrient solutions. The error value was calculated as the difference between the measured value and the reference value using Equation (1).

$$Error = X_{\text{measured}} - X_{refernce} \quad (1)$$

The absolute error was then determined using Equation (2).

$$Absolute\ Error = |Error| \quad (2)$$

To evaluate the overall performance of the sensors, the Mean Absolute Percentage Error (MAPE) was calculated using Equation (3).

$$MAPE = \frac{1}{n}\sum_{i=1}^{n}\frac{|X_{\text{measured}} - X_{Reference}|}{X_{Reference}} \times 100\% \quad (3)$$

Where $n$ represents the total number of observations. Finally, the sensor accuracy was calculated based on the MAPE value using Equation (4).

$$Accuracy = 100\% - MAPE \quad (4)$$

The calculated accuracy values were used to assess the reliability of the proposed monitoring system in measuring pH and EC parameters.

### 2.3. System Flowchart

The system flowchart describes the operational workflow of the proposed monitoring system, including device initialization, sensor data acquisition, data processing, and real-time data transmission to the I2C LCD and Blynk platform.

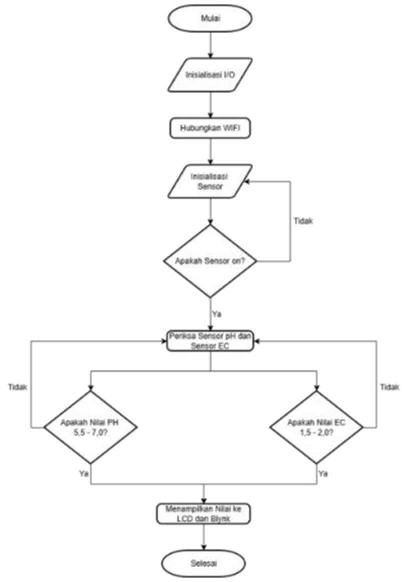


**Fig. 2:** System Flowchart

### 2.4. System Architecture

The block diagram illustrates the relationship among the hardware and software components of the proposed IoT-based monitoring system. The pH and EC sensors function as input devices to measure nutrient solution parameters. The collected data are processed by the ESP32 microcontroller and then displayed on the I2C LCD as a local monitoring interface. Furthermore, the data are transmitted through a Wi-Fi network to the Blynk platform, enabling real-time remote monitoring. The overall system architecture is presented in Figure 3.

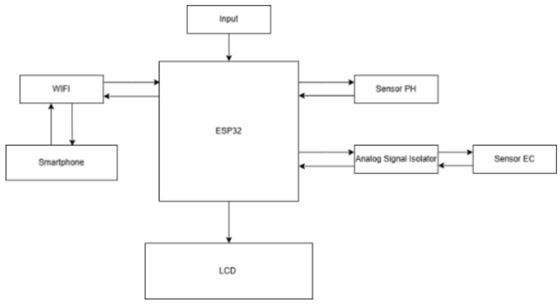


**Fig. 3:** Block diagram of the proposed monitoring system

### 2.5. Hardware Design

The hardware design was developed using an ESP32 microcontroller, pH sensor, EC sensor, Analog Signal Isolator, and I2C LCD. These components were integrated to acquire, process, and display pH and EC data from the hydroponic nutrient solution in real time.

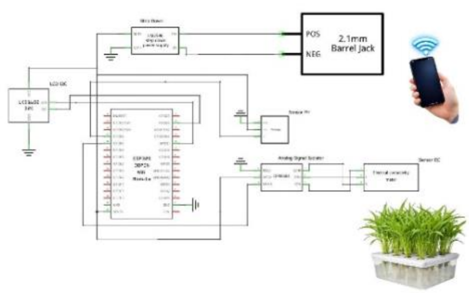


**Fig. 4:** Hardware design of the proposed monitoring system

# 3. Results and Discussion

## 3.1. Hardware Implementation

The hardware implementation was carried out by integrating all components of the proposed IoT-based monitoring system. Figure 5 shows the implemented hardware configuration used for monitoring the pH and EC of hydroponic nutrient solutions.

**Fig. 5:** Hardware Implementation

Figure 5 illustrates the hardware implementation of the proposed monitoring system. The integrated hardware consists of an ESP32 microcontroller, pH sensor, EC sensor, Analog Signal Isolator, and I2C LCD. The system successfully measured pH and EC values and transmitted the monitoring data to the Blynk platform in real time.

## 3.2. Software Implementation

The software implementation was carried out using Arduino IDE to develop and upload the program to the ESP32 microcontroller. The developed software was responsible for acquiring pH and EC sensor data, processing the measurements, displaying the results on the I2C LCD, and transmitting the data to the Blynk platform for real-time monitoring. Figure 6 shows the software development environment used in this study.

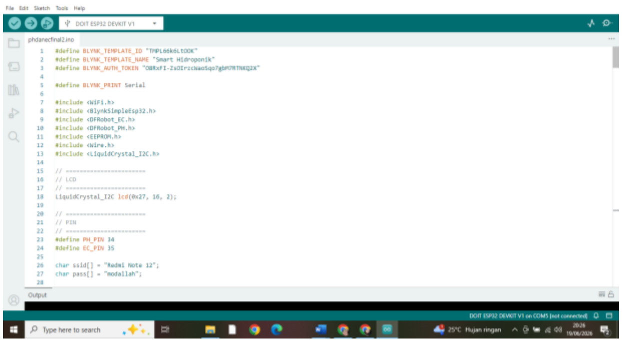

**Fig. 6** Software implementation using Arduino IDE

Figure 6 shows the software development environment used in this study. Arduino IDE was utilized to program the ESP32 for acquiring sensor data, displaying measurement results, and transmitting monitoring data to the Blynk platform in real time.

## 3.3. I2C LCD Interface

The I2C LCD was used as a local monitoring interface to display pH and EC measurements in real time. As shown in Figure 7, the LCD successfully displayed a pH value of 6.35 and an EC value of 1.80, allowing users to directly observe nutrient solution conditions without accessing the mobile application.


**Fig. 7:** I2C LCD interface

## 3.4. Blynk Dashboard Interface

The Blynk platform was utilized as a remote monitoring interface for displaying pH and EC measurements through a smartphone application. As shown in Figure 8, the dashboard successfully received and displayed sensor data transmitted by the ESP32 in real time. This functionality enables users to remotely monitor hydroponic nutrient solution conditions through an internet connection.


**Fig. 8:** Blynk Dashboard Interface

### 3.5. pH Sensor Testing

The pH sensor was tested using standard buffer solutions with reference values of pH 4.01 and pH 7.00. This testing procedure was conducted to evaluate the accuracy and reliability of the sensor before its implementation in the hydroponic nutrient monitoring system. The obtained measurement results were compared with the reference values to determine the sensor performance.

**Table 1:** pH sensor testing results

| No | Reference pH Value | Sensor Reading | Error | Absolute Error | Absolute Percentage Error (%) |
|---|---|---|---|---|---|
| 1 | 4.01 | 4.5 | 0.49 | 0.49 | 12.22 |
| 2 | 4.01 | 4.6 | 0.59 | 0.59 | 14.17 |
| 3 | 4.01 | 4.7 | 0.69 | 0.69 | 17.21 |
| 4 | 7.00 | 7.4 | 0.4 | 0.4 | 5.71 |
| 5 | 7.00 | 7.5 | 0.5 | 0.5 | 7.14 |
| 6 | 7.00 | 7.6 | 0.6 | 0.6 | 8.57 |
| Total | | | | | 65.57 |
| MAPE | | | | | 10.93% |
| Accuracy | | | | | 89.07% |

Based on the testing results, the pH sensor achieved a Mean Absolute Percentage Error (MAPE) of 10.93% and an accuracy of 89.07%. These results indicate that the sensor was capable of providing sufficiently accurate measurements for monitoring the pH of hydroponic nutrient solutions in real time.

### 3.6. EC Sensor Testing

The EC sensor was evaluated using a standard conductivity solution of 12.88 mS/cm. This testing procedure was conducted to assess the accuracy and reliability of the sensor prior to its application in the hydroponic nutrient monitoring system.

**Table 2:** EC Sensor Testing Results

| No | Reference EC Value (mS/cm) | Sensor Reading (mS/cm) | Error | Absolute Error | Absolute Percentage Error (%) |
|---|---|---|---|---|---|
| 1 | 12.88 | 11.4 | -1.48 | 1.48 | 11.49 |
| 2 | 12.88 | 11.5 | -1.38 | 1.38 | 10.71 |
| 3 | 12.88 | 11.9 | -0.98 | 0.98 | 7.61 |
| 4 | 12.88 | 12 | -0.88 | 0.88 | 6.83 |
| 5 | 12.88 | 12.2 | -0.68 | 0.68 | 5.28 |
| 6 | 12.88 | 12.3 | -0.58 | 0.58 | 4.50 |
| Total | | | | | 46.43 |
| MAPE | | | | | 7.74% |
| Accuracy | | | | | 92.26% |

Based on the testing results, the EC sensor achieved a Mean Absolute Percentage Error (MAPE) of 7.74% and an accuracy of 92.26%. These results indicate that the sensor was capable of providing stable and reliable measurements of nutrient concentration in hydroponic solutions. Therefore, the EC sensor is suitable for real-time monitoring applications in hydroponic nutrient management.

### 3.7. Hydroponic Nutrient Monitoring Results

The monitoring system was tested using hydroponic nutrient solutions under actual operating conditions to evaluate the performance of the pH and EC sensors in real-time monitoring. Temperature data were used as supporting information and were obtained from a smartphone weather application.

**Table 3:** Hydroponic Nutrient Monitoring Results

| Day | Time | Temperature (°C) | pH | EC (mS/cm) |
|---|---|---|---|---|
| Monday | 08:00 | 25°C | 6.8 | 1.5 |
| | 12:00 | 32°C | 6.4 | 1.9 |
| | 19:00 | 29°C | 6.7 | 1.9 |
| Tuesday | 08:00 | 26°C | 6 | 1.8 |
| | 12:00 | 31°C | 6.1 | 1.8 |
| | 19:00 | 28°C | 6.6 | 1.7 |
| Wednesday | 08:00 | 26°C | 5.6 | 2 |
| | 12:00 | 31°C | 5.9 | 2.1 |
| | 19:00 | 28°C | 6.3 | 1.9 |
| Thursday | 08:00 | 25°C | 5.4 | 1.9 |
| | 12:00 | 32°C | 6.4 | 2 |
| | 19:00 | 29°C | 6.6 | 1.7 |
| Friday | 08:00 | 25°C | 5.7 | 2 |
| | 12:00 | 28°C | 6.6 | 1.9 |
| | 19:00 | 27°C | 6 | 1.8 |
| Saturday | 08:00 | 26°C | 5.8 | 1.9 |
| | 12:00 | 32°C | 6.4 | 2.1 |
| | 19:00 | 27°C | 6 | 1.8 |
| Sunday | 08:00 | 26°C | 5.6 | 2 |
| | 12:00 | 31°C | 6 | 1.9 |
| | 19:00 | 29°C | 6.6 | 1.7 |

### 3.8. Implementation of the proposed monitoring system

The monitoring system was implemented by immersing the pH and EC sensors into the hydroponic nutrient solution to acquire real-time measurements. The collected data were processed by the ESP32 microcontroller and subsequently displayed on the I2C LCD and Blynk application. Figure 8 shows the implementation of the proposed IoT-based hydroponic nutrient monitoring system.

**Fig. 9:** Implementation of the proposed monitoring system

As shown in Figure 9, the developed monitoring system was successfully implemented in a hydroponic environment. The pH and EC sensors measured nutrient solution parameters in real time, while the ESP32 processed and transmitted the data to the I2C LCD and Blynk platform. The system operated successfully and provided continuous monitoring of hydroponic nutrient solution conditions.

## 4. Conclusion

This study successfully developed an Internet of Things (IoT)-based monitoring system for measuring the pH and Electrical Conductivity (EC) of hydroponic nutrient solutions. The proposed system integrates an ESP32 microcontroller, pH sensor, EC sensor, I2C LCD, and Blynk platform to provide real-time monitoring of nutrient solution conditions. The monitoring data can be displayed locally through the I2C LCD and remotely through a smartphone connected to the internet. The testing results showed that the pH sensor achieved an accuracy of 89.07%, while the EC sensor achieved an accuracy of 92.26%. These results indicate that the developed system is capable of providing reliable real-time monitoring of hydroponic nutrient solutions and can support users in managing nutrient conditions according to plant requirements.

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