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Design And Build Monitoring System Temperature And Ph Hydroponic Plants Based On Internet Of Things (Iot) Technology Using Nodemcu Esp-8266 Microcontroller

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Abstract – *Hydroponic agriculture is a soilless plant cultivation method that is becoming increasingly popular in the modern era. However, hydroponic systems require strict monitoring of environmental parameters, especially temperature and pH, to ensure optimal plant growth. This research aims to design and build a temperature and pH monitoring system for hydroponic plants based on the Internet of Things (IoT) using a NodeMCU ESP-8266 microcontroller. The developed system consists of a DS18B20 temperature sensor, a pH sensor, a NodeMCU ESP-8266 microcontroller, and the ThingSpeak IoT platform. These sensors are used to measure the temperature and pH of the hydroponic nutrient solution in real-time. The collected data is then sent to the ThingSpeak platform via the WiFi connection integrated into the NodeMCU ESP-8266. The implementation of this system is expected to assist hydroponic farmers in efficiently monitoring and controlling their plants' environmental conditions, thereby increasing productivity and harvest quality. Further research can be conducted to integrate more parameters and develop automatic control systems based on the collected data.*

Keywords: *Internet of Things*, pH Meter, Hidroponic

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1. Introduction

The technological advancements of the 21st century have brought about profound changes in various aspects of human life, ranging from methods of communication and work to socialization and learning. As a result of the rapid technological progress in the current era, automation technologies have emerged, largely replacing many tasks previously performed by humans. Automated machines are now utilized across diverse industrial sectors, including manufacturing, agriculture, and transportation. Hydroponics is a cultivation technique that grows plants without soil, relying solely on water. A critical factor in this planting method is ensuring the fulfillment of the plants' nutritional requirements. This technique requires significantly less water compared to conventional planting methods and is particularly well-suited for regions with limited water availability and land resources. Despite not using soil as a growing medium, the nutritional needs of hydroponic plants can be met from various sources, ranging from chemical fertilizers to animal manure. Hydroponics is a cultivation technique that grows plants without soil, relying solely on water. A critical factor in this planting method is ensuring the fulfillment of the plants' nutritional requirements. This technique requires significantly less water compared to conventional planting methods and is particularly well-suited for regions with limited water availability and land resources. Despite not using soil as a growing medium, the nutritional needs of hydroponic plants can be met from various sources, ranging from chemical fertilizers to animal manure. The advent of these technologies and methods represents a significant shift in how we approach agriculture and resource management, offering solutions to challenges such as water scarcity and limited arable land. This transformation exemplifies how technological innovation continues to reshape traditional practices across various sectors of human activity [1]

The rapid advancement of technology has also given rise to new innovations that assist humans in various fields, including agriculture. One of the technological developments that can be applied in this industry is the Internet of Things (IoT). IoT can be defined as the communication between devices using the internet. The progress of IoT technology can simplify various tasks, including the control of hydroponic systems. By leveraging automation technology, we can create systems that monitor humidity and water pH levels, as well as remotely control the water flow in hydroponic farms using only an internet connection. This integration of IoT and automation in hydroponics represents a significant step forward in agricultural technology. These advancements allow for more efficient and precise management of hydroponic systems, reducing the need for constant on-site monitoring and manual adjustments. The ability to control and monitor these systems remotely not only saves time and resources but also enables farmers to maintain optimal growing conditions more consistently. Furthermore, the application of IoT in hydroponics demonstrates how technology can be used to address challenges in food production, particularly in areas with limited resources or harsh environmental conditions. This technology has the potential to revolutionize urban farming and contribute to more sustainable agricultural practices [2].

By utilizing Internet of Things (IoT) technology in hydroponics, we can accurately monitor and control the plant environment in real-time. There's no need to constantly visit the hydroponic growing site. Simply by installing the necessary equipment and creating an automated system connected to the IoT, we can manage all aspects of hydroponic plant care remotely. This includes controlling the water flow through pipes or growing media, and checking the water's pH levels. Given that hydroponic cultivation doesn't use soil as a growing medium, measuring water pH becomes a crucial step. Since hydroponic plants lack soil to act as a pH buffer, we must ensure that the water used has an appropriate pH level. If the water pH is too low (acidic) or too high (alkaline), plants will struggle to absorb necessary nutrients, potentially stunting growth and reducing crop yields. The success of hydroponic plant growth is heavily dependent on the acidity or alkalinity (pH) of the water used. The correct water pH level is key to ensuring plants receive the required nutrients. This emphasis on pH control highlights the precise nature of hydroponic systems and the importance of maintaining optimal growing conditions. This integration of IoT in hydroponics demonstrates how technology can revolutionize agricultural practices, allowing for more efficient, precise, and remote management of plant growth conditions. It represents a significant advancement in sustainable farming techniques, particularly valuable in urban environments or areas with limited resources. By enabling remote monitoring and control, IoT in hydroponics not only saves time and labor but also allows for more consistent and optimal growing conditions, potentially leading to improved crop quality and yield. This technology paves the way for smarter, more sustainable agricultural practices in the future [2].

Based on the aforementioned discussion, the author intends to develop an automated monitoring system for hydroponic plants that can provide real-time information on temperature and pH levels. This system will harness Internet of Things (IoT) technology, with the NodeMCU ESP-8266 microcontroller serving as its primary component. The implementation of this IoT-based monitoring system is expected to enhance the efficiency and effectiveness of hydroponic plant cultivation. It aims to facilitate remote monitoring and optimize plant growth through improved control of key parameters such as temperature and pH. Consequently, this research will focus on the design and construction of an IoT-based temperature and pH monitoring system for hydroponic plants, utilizing the NodeMCU ESP-8266 microcontroller. This approach represents a fusion of advanced technology with agricultural practices, potentially revolutionizing the way hydroponic farming is managed.

2. Research Methodology

The research object in this study is the development of a hydroponic plant monitoring system comprising several key components. The first component consists of sensors used to measure environmental parameters of hydroponic plants, including temperature sensors to measure thermal conditions, humidity sensors to gauge air moisture levels, and pH sensors to determine the acidity or alkalinity of the plant nutrient solution. The second primary component is the Arduino microcontroller, which serves as the brain of this system. This microcontroller processes data received from the sensors and transmits it to an Internet of Things (IoT) platform via an integrated wireless communication module. The IoT platform forms the third component of the monitoring system. This platform acts as a storage and display medium for the data transmitted by the microcontroller. Users can access this data in real-time through internet-connected devices such as smartphones, tablets, or computers. The entire system is designed and constructed with the aim of monitoring the environmental conditions of hydroponic plants automatically, efficiently, and sustainably. It is expected to provide accurate and timely data on temperature, humidity, and pH levels, thereby assisting hydroponic farmers or plant owners in optimizing growth conditions and increasing productivity. For this particular system, the author is developing a monitoring solution for a small-scale, home-based hydroponic setup located in the author's yard. This focus on a residential application demonstrates the scalability and accessibility of IoT-based hydroponic monitoring systems, potentially making advanced agricultural techniques more accessible to hobbyists and small-scale growers. This research object encapsulates the integration of sensor technology, microcontroller programming, and IoT connectivity to create a comprehensive monitoring solution for hydroponic cultivation. It represents a practical application of cutting-edge technology to enhance agricultural practices at various scales.

2.1 Tools and Materials

2.1.1 Microcontroller: NodeMCU

Microdevices, including NodeMCU, are essential components in learning about the Internet of Things (IoT). NodeMCU's open-source nature has led to its widespread production and development by various manufacturers. Currently, several product types are available, such as Amica, DOIT, and Lolin/WeMos, with board variants

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including V1, V2, and V3. Another microdevice frequently used in IoT applications is the ESP32. While similar to the NodeMCU ESP8266, the ESP32 distinguishes itself by offering more GPIO pins and supporting Bluetooth Low Energy technology [3].

Figure 1Microcontroller NodeMCU ESP-8266

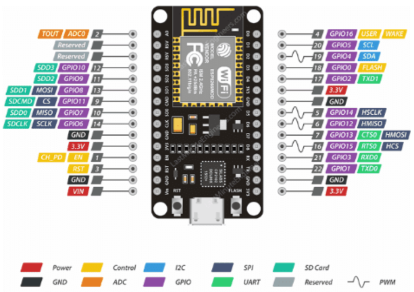

Figure 2 PINOUT from Microcontroller Nodemcu ESP-8266

2.1.2 Temperature Sensor: DS18B20

The DS18B20 temperature sensor is a highly popular and versatile digital temperature measuring device. Manufactured by Dallas Semiconductor, this sensor offers a unique combination of high accuracy, durability, and ease of use. The DS18B20 utilizes the 1-Wire communication protocol, allowing it to transmit data through a single data wire, thus simplifying installation and reducing wiring complexity. This sensor can measure temperatures across a wide range, from -55°C to +125°C, with an accuracy of ±0.5°C within the -10°C to +85°C range. Other advantages include digital output that minimizes electrical interference, programmable resolution from 9 to 12 bits, and customizable temperature alarm features. In applications such as IoT-based hydroponic systems, the DS18B20 can be easily integrated with various types of microcontrollers, providing accurate and real-time temperature monitoring for optimizing plant growth [4].

Figure 3 Temperature Sensor DS18B20

2.1.3 pH Meter Sensor

A pH sensor is an instrument used to accurately and precisely measure the acidity or alkalinity (pH) of a solution. The working principle of a pH sensor is based on the electrical potential difference generated by the chemical reaction between the measured solution and the measurement electrode and reference electrode in the sensor. A pH sensor typically consists of a measurement electrode made of special glass with a surface sensitive to hydrogen ions, and a reference electrode. The electrical potential difference between these two electrodes is directly proportional to the pH value of the measured solution. The greater the potential difference, the more acidic the solution. pH sensors are available in various types and measurement ranges, such as 0 to 14 pH for measuring acidic to basic solutions. The accuracy of high-quality pH sensors can reach ±0.01 pH, while simpler sensors have an accuracy of about ±0.1 pH. The measurement resolution of pH sensors is typically 0.01 pH [5].

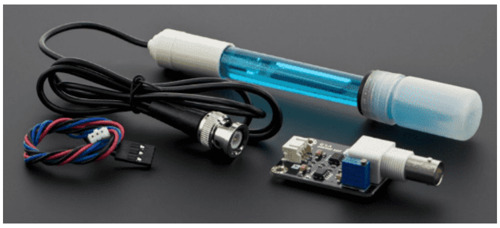

Figure 4 pH Meter Sensor

2.1.4 Breadboard

A breadboard is a versatile tool for electronics experimentation, featuring a plastic board with numerous small holes interconnected by metal strips beneath the surface. This design allows for the easy insertion and connection of electronic components without soldering, making it ideal for rapid prototyping and iterative design in electronics. Components such as resistors, capacitors, integrated circuits, and jumper wires can be quickly plugged in and rearranged. This flexibility is particularly valuable in educational settings and for hobbyists, as it enables swift assembly, testing, and modification of circuits without permanent connections. The structure of a breadboard typically includes two horizontal rows for power distribution (positive and negative voltage) and multiple vertical columns for component connections. These vertical columns are electrically isolated from each other, allowing for the creation of complex circuits on a single board. The key advantage of using breadboards in electronic project development is the ability to easily correct errors or implement design changes by simply unplugging and repositioning components. This feature significantly speeds up the prototyping process and encourages experimentation, making breadboards an essential tool for learning and developing electronic circuits.

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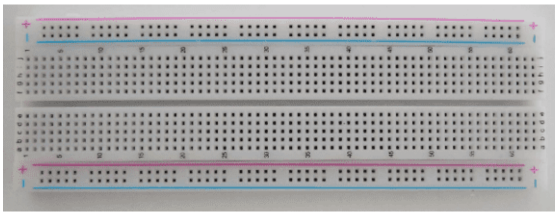

Figure 5 Electronic Circuit Board atau Breadboard

2.1.5 Jumper Wires

Jumper wires are essential tools in breadboard-based electronics, serving as flexible, temporary connectors between various components. These short wires feature small connectors at both ends, typically either straight or slightly bent, designed to fit snugly into breadboard holes. The significance of jumper wires in breadboard usage lies in their ability to create swift, adaptable connections between electronic components like resistors, capacitors, and integrated circuits. This flexibility allows for rapid circuit assembly and modification without the need for permanent soldering, which is particularly valuable in prototyping and iterative design processes. By enabling quick changes and easy reconfiguration, jumper wires significantly streamline the development of electronic projects. They allow developers to experiment with different circuit layouts and component combinations efficiently, saving considerable time and effort in the prototyping phase. In essence, jumper wires are fundamental to the breadboard's role as a tool for fast, efficient electronic circuit construction and testing. Their use greatly enhances the speed and ease of electronic project development, making them an indispensable element in the toolkit of electronics enthusiasts, students, and professionals alike.

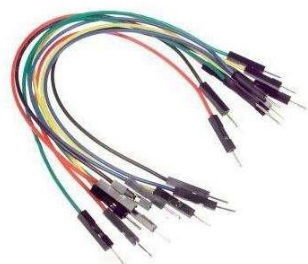

Figure 6 Jumper Wires

2.1.6 Hardware for Arduino IDE Programming

The Arduino development process requires a crucial hardware setup: a computer or laptop linked to the Arduino board through a USB connection. This computer serves as the primary interface for programming and interacting with the Arduino. Central to this setup is the Arduino IDE (Integrated Development Environment), a software tool installed on the computer. The IDE is a comprehensive platform that allows developers to write code, compile it, and transfer it directly to the Arduino board. This streamlined process facilitates efficient programming and debugging. This hardware configuration opens up a world of possibilities for electronic projects. Developers can create a wide range of applications, from basic control systems to complex robots and Internet of Things (IoT) devices. The flexibility of the Arduino platform, combined with the right supporting hardware, enables creators to bring their ideas to life, limited only by their imagination and technical skills. The synergy between the computer, Arduino board, and IDE significantly simplifies the programming process. It provides a user-friendly environment that makes Arduino development accessible to both beginners and experienced makers, fostering innovation and creativity in electronic project design.

Figure 7 Writer's Laptop

2.2 Design and Assembly of Hardware

Design becomes a very important part in creating a system because in designing this hardware, it is important to consider factors such as component compatibility, power consumption, physical size, and ease of assembly and maintenance. In addition, good documentation and implementation of best practices in electronic design are also very important to ensure the system runs smoothly and can be further developed in the future. The following overall layout or circuit can be seen in the image 2.8 below.

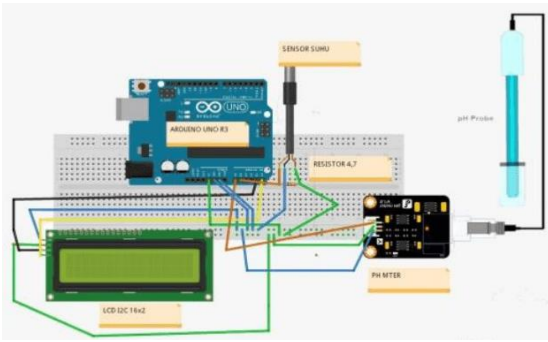

Figure 8 Schematic Design of System

The hardware integration in this system relies on a series of strategic connections made via jumper cables, linking the microcontroller to various sensors and output devices through a breadboard. These connections are organized as follows:

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- G (first slot), 3V (first slot), and D3 are connected from the microcontroller to the temperature sensor.
- A0, G (second slot), and 3V (second slot) are connected from the microcontroller to the pH meter sensor.
- VV, G (third slot), D1, and D2 are connected from the microcontroller to the LCD/Screen.

2.3 Software Design

he schematic diagram depicted in Figure 8 serves as a crucial blueprint for the researcher, providing a comprehensive overview of the system's functionality. This visual representation allows the researcher to gain a deep understanding of the system's general operation principles. This understanding is paramount as it guides the programming phase of the project. By closely aligning the code with the operational flow illustrated in the schematic, the researcher ensures that the software accurately reflects and controls the hardware components as intended. To further elucidate the system's operational logic and to provide a step-by-step visualization of the process flow, the researcher has developed a flowchart diagram. This flowchart serves as a bridge between the hardware schematic and the software implementation, offering a clear, systematic representation of the system's decision-making processes and operational sequences. The flowchart not only aids in the initial programming phase but also serves as valuable documentation for future reference, maintenance, and potential system upgrades. It encapsulates the logical structure of the system, highlighting key decision points, data flows, and operational paths within the designed system.

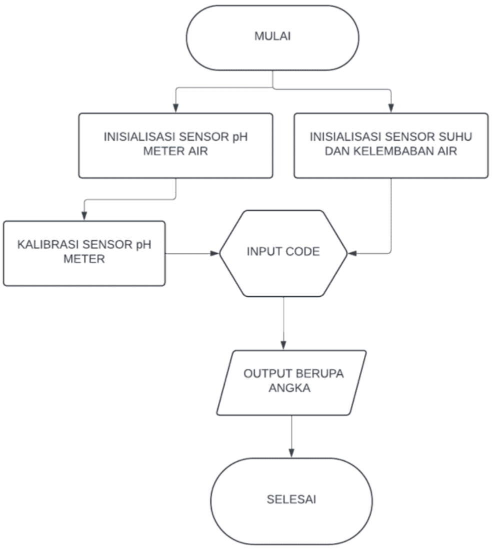

Figure 9 Flowchart Diagram

3. Results and Discussion

3.1 Analysis of Tools and Materials

The analysis of tools and materials begins with a thorough verification of all components to be used, including the Arduino IDE, NodeMCU ESP-8266 microcontroller, DS18B20 water temperature sensor, and water pH sensor. This initial step ensures each element functions according to the designed program. The process involves meticulous connection checks, linking jumper cables from each device port to the breadboard (an electric circuit board for Arduino). Comprehensive testing is conducted, starting with the temperature sensor and progressively incorporating the pH sensor. The primary objective of these tests is to confirm that the designed system circuit operates as intended. Following this, the next phase involves direct observation of the component assembly. Measurement results serve as indicators of whether the constructed system circuit functions correctly, allowing for the identification of any potential errors in the design. The physical system circuit is then assembled. Figure 9 presented below illustrates the physical manifestation of the tools and materials that have been designed and assembled, providing a visual representation of the complete system setup.

Figure 10 Required tools and materials

3.1.1 Device Operation

The initial phase of device operation centers on software development, with a focus on establishing connectivity and data transmission capabilities. The primary goal is to create a program that facilitates seamless communication between the physical device and user interfaces such as laptops or smartphones. In this context, the author has strategically selected the Blynk application as the intermediary platform. Blynk serves as a crucial bridge, effectively linking the custom-designed device system with the end-user hardware. This choice enables efficient transmission and reception of output data from the engineered device.

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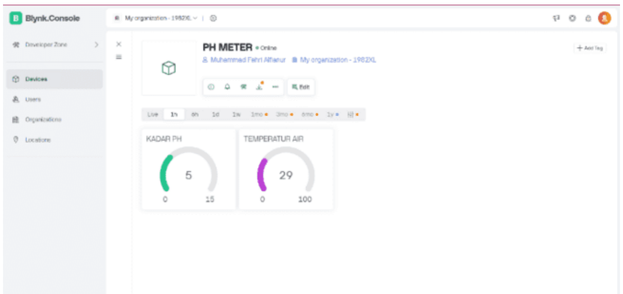

Figure 11 Application Interface Before Synchronization

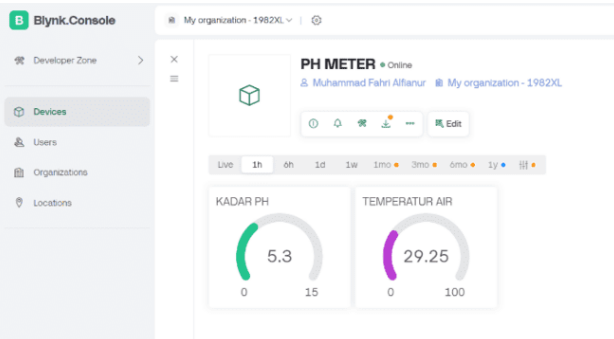

Figure 12 Application After Interface Synchronization

After the device with the hardware used to monitor the data output has been synchronized, the second step here is to calibrate the device using pure water and add the calibration powder of the pH meter to stack whether the device is running as expected. The calibrating process is done so that the output values of the water pH and water temperature can be read accurately and there are no errors in it.

Figure 13 Pure Water

Meanwhile, pH meter calibration powder is a specialized chemical mixture used to ensure the accuracy and precision of pH meter measurements. This powder is typically available in sachets or capsules containing buffer compounds with known and stable pH values. When dissolved in distilled water, the powder creates a standard solution with an exact and consistent pH, which is then used to calibrate the pH meter.

Typically, a pH meter calibration set includes various types of powders with different pH values, such as pH 4.0 (acidic), pH 7.0 (neutral), and pH 10.0 (basic). The calibration process involves measuring these standard solutions to adjust the pH meter readings to match the known values. Routine calibration using these powders is crucial for maintaining the accuracy of the pH meter, especially in applications that require precise pH measurements, such as in laboratories, industry, or scientific research [6].

Figure 14 Calibration results with pH meter powder with a pH level of 4.00

Figure 15 Calibration results with pH meter powder with a pH level of 6.86

After adding pH meter calibration powder with a pH value of 6.86, the output data showed a pH level of 6.85 with the water temperature at 29°C. This demonstrates that the designed device can read values accurately within the expected range for the calibration powder's pH levels, specifically pH 4.00 within the range of 4.00 – 4.06 and pH 6.86 within the range of 6.92 – 6.83.

3.1.2 Device Implementation

After obtaining all the calibration results and the expected values for the pH and water temperature for hydroponic plants, it is time to test the device on

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hydroponic plants growing directly at the cultivator's site. For this research, the author has chosen watercress as the subject of the study.

Figure 16 Implementation of tools to hydroponic plants

Figure 17 Testing the tool into the plant nutrition tank

Figure 18 Tool testing results

After placing the designed device into the nutrient tank of the hydroponic plants, the output was consistent on both the device's LCD display and the Blynk application synchronized with the device, showing a pH level of 5.77 and a water temperature of 32.12°C..

According to experts in hydroponics, the ideal pH range for hydroponic watercress is between 5 and 6.5. This range is considered optimal as it allows for efficient nutrient absorption by the plant roots. At this pH level, most essential nutrients are in a form that is easily absorbed by the plants, ensuring healthy growth and high productivity [7].

Meanwhile, the ideal water temperature for hydroponic watercress generally ranges from 18°C to 33°C (65°F to 91°F). This temperature range is considered optimal because it supports efficient nutrient absorption by the plant roots and promotes healthy growth. Water temperature within this range also helps maintain sufficient dissolved oxygen levels, which are crucial for root health and plant metabolism. [8].

3.2 Analysis of Test Results

The testing analysis here is conducted to determine whether the designed device and system function as expected or if there are any deficiencies when operated in real-life scenarios.

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Tabel 1 Analysis of Test Results

No	Testing	Process	Expected Results	Test Results
1	Testing of Temperature and pH Monitoring Device for Hydroponic Plants.	Connecting sensors with jumper wires to the electronic circuit board and connecting it to the power supply.	The device powers on perfectly, and all components operate according to the designed program instructions.	The device powers on, executes the program instructions, and outputs the correct data.
2	Testing All Device Components in Bottled Drinking Water.	Inserting the sensor into a popular brand of bottled drinking water commonly consumed by the public.	The pH level and water temperature meet the ideal standards required for hydroponic plants, making it a viable option for use in the designed hydroponic growing medium.	The device accurately reads the pH level and water temperature of the bottled drinking water. However, the pH level is still too high to be used for hydroponic plants.
3	Testing Sensors in Water with Added pH Meter Calibration Powder.	Adding pH meter calibration powder to the previously used water, with a pH level of 4.00.	The device can detect changes in water conditions after adding other particles.	The device can accurately measure the pH and temperature of water contaminated with pH meter calibration powder, but the resulting pH level is still too low for use in hydroponic plants.
4	Testing sensors in water with a higher concentration of pH meter calibration powder than before.	Adding more pH meter calibration powder to the previously contaminated water, reaching a pH level of 6.86.	The device can detect changes in water conditions after adding other particles and also measures the water pH accurately for hydroponic plants.	The device reads the pH and temperature accurately, showing 5.18 for pH and 25.88°C for temperature. The resulting pH level, between 5-6.5 with a temperature range of 18-26°C, is suitable for use in hydroponic plants.

4. Conclusion

Based on the testing and research conducted by the author, the conclusion is as follows: This study successfully designed and developed an Internet of Things (IoT)-based temperature and pH monitoring system for hydroponic plants using the NodeMCU ESP-8266 microcontroller. The developed system is capable of monitoring and transmitting temperature and pH data in real-time to an IoT platform, allowing for remote monitoring and more efficient data analysis. The use of the NodeMCU ESP-8266 as the main microcontroller proved effective in connecting the sensors quickly, directly, and periodically, providing a cost-effective and easy-to-implement solution.

The testing results show that this system can provide accurate temperature and pH readings, with minimal error compared to standard measurement tools. The system also demonstrated stable performance in transmitting data to the IoT platform, with a high success rate in data transmission. Implementing this system in hydroponic cultivation allows farmers or users to remotely monitor their plant conditions, facilitating quicker and more precise decision-making in plant management.

Therefore, it can be concluded that this IoT-based monitoring system significantly enhances the efficiency and effectiveness of monitoring key parameters in hydroponic cultivation. It also opens opportunities for further development in the automation and optimization of hydroponic systems, growing medium used in hydroponic plants directly and periodically.

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