Temperature and Humidity Monitoring in Hydroponic Cultivation Based on Internet of Things: Dataset Development for Smart Agriculture

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***Abstract*— This research is a continuation of the previous research, entitled "*Development of Hydroponic Application based on Web and Internet of Things for the Community to Monitor pH and Total Dissolved Solids.*" Not only pH and Total Dissolved Solids (TDS) need to be monitored, but also temperature and humidity. This research aims to produce a temperature and humidity monitoring application (in addition to pH and TDS which already exist) in hydroponic cultivation and complete the dataset that supports smart agriculture. The research method includes literature study, hardware development using NodeMCU ESP8266 microcontroller and DHT11 sensor, web-based software development with JavaScript on the Front-End side, PHP on the Back-End side, Apache as Web Server, and MySQL as database management system (DBMS), as well as the implementation stage, integration, system testing and report writing. The results of the research show that the developed system can monitor temperature and humidity in real-time with a good level of accuracy. Not only that, this system can produce a hydroponic dataset that includes temperature and humidity parameters, which can be used for data analysis and improvement of hydroponic management. Thus, this study successfully expanded the scope of the hydroponic monitoring system by adding temperature and humidity parameters. This study contributes to optimizing the hydroponic cultivation system and supporting the development of data-based smart agriculture. Further research will integrate more monitoring parameters, conduct direct hydroponic cultivation trials, and apply artificial intelligence such as machine learning and deep learning to improve efficiency and effectiveness in hydroponic cultivation.**

Keywords—Dataset, Humidity, Internet of Things, Monitoring, Temperature

I. Introduction

In the era of Industry 4.0, modern agriculture is undergoing significant transformation through the adoption of information technology to enhance efficiency and productivity. Among the most promising advancements shaping the future of farming is hydroponic cultivation [1]. This innovative method not only addresses the challenges posed by limited agricultural land, particularly in urban areas, but also provides a sustainable solution for crop production in environments where soil conditions are suboptimal for plant growth, such as vegetable farming [2].

Hydroponic cultivation plays a vital role in meeting the demand for vegetables at both local and national levels, contributing to the broader objective of strengthening food security [3]. Furthermore, this agricultural approach aligns with Sustainable Development Goal (SDG) 2 — to eradicate hunger, achieve food security, improve nutrition, and promote sustainable agricultural practices [4].

Ensuring the success of hydroponic cultivation relies heavily on the ability to continuously monitor and maintain optimal environmental parameters. Extensive researches have identified critical ranges for key variables such as pH, electrical conductivity (EC), temperature (both nutrient solution and ambient), aeration or dissolved oxygen (DO), growing media or substrates, lighting and artificial illumination, relative humidity, CO2 concentration, and plant-specific requirements [5].

This research builds upon prior research entitled "*Development of Hydroponic Application Based on Web and Internet of Things for the Community to Monitor pH and Total Dissolved Solids*" [6]. The previous research successfully developed an Internet of Things (IoT)-based system capable of monitoring pH and TDS levels. However, temperature and humidity monitoring are not included, leaving a significant gap in ensuring comprehensive environmental control. Temperature and humidity significantly influence plant growth and productivity [7]. Rapid undetected changes in temperature or humidity can lead to reduced quality of plant growth, resulting in reduced quantity and quality of crop yields.

To mitigate such risks, there is a pressing need for an accurate and real-time environmental monitoring system capable of safeguarding optimal growth conditions while generating historical datasets. These datasets not only facilitate comprehensive analysis but also serve as valuable inputs for artificial intelligence-driven agricultural innovations. In addition, the results of the review of articles in journals accredited by the Ministry of Research and Technology stated that there were no articles that specifically developed smart agriculture. [8] Thus, an accurate and real-time environmental monitoring system is needed for hydroponic cultivation to ensure that plant growth conditions remain optimal and that their history is recorded to support the realization of smart agriculture based on data.

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To address these limitations, this follow-up research seeks to develop an IoT-based monitoring system capable of tracking temperature and humidity, thereby complementing the previous study. This system is anticipated to deliver real-time data, facilitating the optimization of hydroponic management while establishing an integrated dataset to support artificial intelligence-driven analysis—an essential component as smart farming continues to evolve [9].

The Internet of Things (IoT) presents significant potential to enhance the efficiency and accuracy of monitoring and data collection processes. In this study, temperature and humidity sensors will be integrated with a microcontroller to capture and transmit data in real-time to a web application. The collected data will be systematically stored in a structured database, forming the foundation for a dataset to be further analyzed.

The development of this system not only addresses the demand for more comprehensive environmental monitoring but also represents a critical step toward building a data-driven smart hydroponic framework. This framework will possess the adaptability to respond to environmental changes, contributing to the advancement of intelligent and sustainable agricultural practices. Thus, this research brings new innovations in IoT-based hydroponic management, by expanding the scope of monitoring, developing a dataset-based system, and paving the way for the application of artificial intelligence in hydroponics. This research not only improves the efficiency and effectiveness of hydroponic farming, but also becomes a strategic step towards a more sustainable and technology-based smart agriculture.

II. RESEARCH METHOD

This research method consists of six phases: literature study, assembly of hardware, application development, implementation and integration, testing, and finally report writing, as shown in Figure 1.

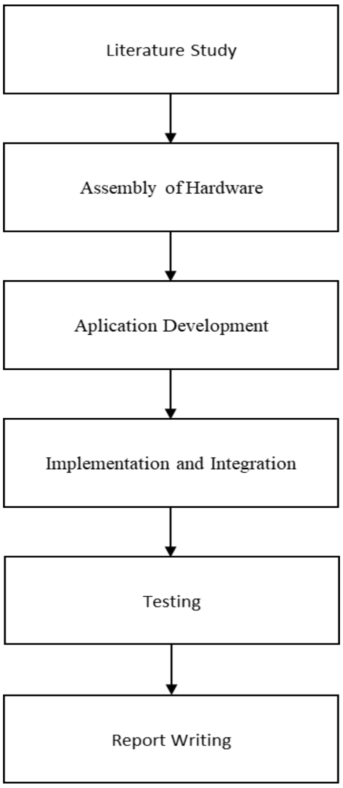

Fig. 1. Research method phases

A. Literature Study

Conducting a literature study to understand the basic principles of hydroponic farming, temperature and humidity measurement, Internet of Things (IoT), previous related studies, and application development.

B. Assembly of Hardware

The hardware used includes the DHT11 sensor (Figure 2) and the NodeMCU ESP8266 microcontroller (Figure 3). The DHT11 sensor is useful for measuring air temperature and humidity. DHT11 is chosen because it is inexpensive and sufficiently accurate, in addition to being readily available and widely used.

Fig. 2. DHT11 sensor

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Fig. 3. NodeMCU version 1 ESP8266

The NodeMCU ESP8266 microcontroller is used to connect to Wireless Fidelity (Wi-Fi), enabling internet connectivity as part of the Internet of Things (IoT). It communicates with the sensor and the web server. The NodeMCU ESP8266 is chosen because it is affordable, easily obtainable, and meets the needs of this research.

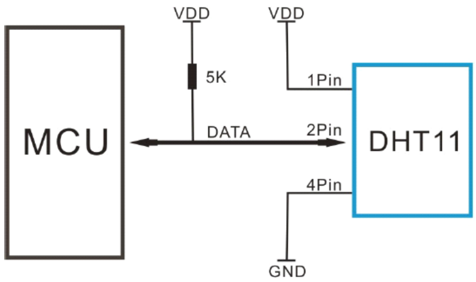

Fig. 4. Typical Application [10]

In Figure 4, the method of connecting the DHT11 sensor to the Micro-computer Unit (MCU) or single-chip computer is shown. The DHT11 sensor is connected to the NodeMCU, and a program is created to facilitate communication between the DHT11 sensor and the web server. The microcontroller collects data from the DHT11 sensor and sends it to the web server where the web application resides.

The program is developed using the Arduino IDE and written in the C++ programming language. It is subsequently embedded into the ESP8266 microcontroller, which then executes the instructions as specified within the program.

C. Aplication Development

The application development adheres to the Patas model, as illustrated in Figure 5. This model comprises six phases: user requirements, selection of devices, modification, evaluation, implementation, and maintenance. The Patas model is selected due to its suitability for this research, which involves a small team, demands rapid completion, and is conducted on a limited scale.

The developed application is a web-based system for monitoring temperature and humidity, serving as an extension of the previous research application that monitored pH and TDS levels. This application displays sensor data and humidity measurements collected from the DHT11 sensor, which are stored in a database. The data is presented in tabular form, while summarized information, including average values, is visualized on a dashboard.

The application is composed of two sides: the Front-End and Back-End. The Front-End is developed using HTML, CSS, and JavaScript, ensuring an interactive and user-friendly interface. The Back-End is built with PHP, managing the logic and data processing. MySQL is used as the database management system (DBMS), with Apache serving as the web server. The development process encompasses database design, user interface creation, coding, and the implementation of features to monitor and record temperature and humidity data.

The application is designed to be fully responsive, allowing seamless access through web browsers on various devices, including personal computers, laptops, smartphones, and tablets, thereby ensuring flexibility and ease of use across different platforms.

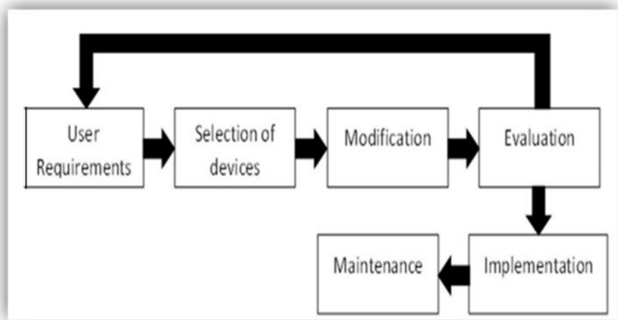

Fig. 5. Patas model [11]

The database design has been enhanced by incorporating temperature and humidity attributes into the existing schema from previous research. This expansion enables the recording of four essential parameters: pH, TDS, temperature, and humidity. In parallel, the user interface has been refined to accommodate the newly added temperature and humidity metrics, complemented by corresponding dashboard displays to ensure comprehensive data visualization.

D. Implementation and Integration

This phase involves the implementation and seamless integration of both hardware—comprising the DHT11 sensor and the NodeMCU ESP8266 microcontroller—and software, specifically the web-based monitoring application. The process adheres to the architectural framework depicted in Figure 6. The monitoring and data collection application based on web is deployed on an Apache web server and connected to a MySQL database. The NodeMCU ESP8266 is configured and establishes communication with the Apache web server over the Internet, ensuring continuous data transmission and synchronization between the hardware and software components.

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Fig. 6. Architecture for data collection and monitoring of hydroponic cultivation

E. Testing

The monitoring application, integrated with sensors and the microcontroller, undergoes rigorous testing to ensure seamless hardware-software connectivity. This testing process verifies that measurements are consistently recorded in the database at regular intervals and that temperature and humidity data are accurately presented in both tabular and dashboard formats. If a problem occurs, resolve it immediately.

Figure 7 illustrates the testing environment, where the DHT11 sensor is positioned within a hydroponic container utilizing a wick system, while the NodeMCU ESP8266 is securely enclosed. The DHT11 sensor continuously captures ambient temperature and humidity levels at the hydroponic cultivation site. The NodeMCU ESP8266 transmits the collected data via Wi-Fi to an Apache web server, where it is systematically stored in a MySQL database. Users can monitor this data in real-time through a web application accessible on various devices, including personal computers, laptops, smartphones, and tablets.

To ensure the longevity and reliability of the system, the NodeMCU ESP8266 is enclosed in a protective casing, shielding it from water, dust, heat, and other environmental factors that could compromise its functionality and disrupt the temperature and humidity monitoring process.

Fig. 7. DHT11 sensor and ESP8266 Node MCU wrapped

F. Report Writing

The research report is compiled to comprehensively document the steps undertaken, the findings obtained, and the recommendations for future development. This documentation serves as a valuable resource for understanding and replicating the research. The entire process and its outcomes are presented in the form of a scientific report and an article, which includes an introduction, research methodology, results and discussion, and conclusion.

III. Result and Discussion

The research results demonstrate that the IoT-based monitoring system developed can effectively monitor temperature and humidity parameters in real-time. The system utilizes a DHT11 sensor connected to the NodeMCU ESP8266, which continuously transmits data via Wi-Fi to a web server hosting the monitoring application. The collected data offers a comprehensive overview of the environmental conditions (temperature and humidity) surrounding the hydroponic cultivation.

The monitoring was conducted on June 6, 2024, from 16:36:22 to 17:55:40. During this study, temperature and humidity data were recorded every 10 seconds. The temperature recordings are depicted in Figure 8, while the humidity readings are shown in Figure 9. The average temperature and humidity during this period were 23.16°C and 66.67%, respectively. These average values are also displayed on the dashboard (Figure 10). This monitoring can be performed anytime and from any location, if the device used is connected to the Internet. Various devices, such as personal computers, laptops, smartphones, and tablets, can access the monitoring application via web browsers like Google Chrome and Microsoft Edge.

By utilizing the DHT11 sensor connected to the NodeMCU ESP8266, the IoT system can generate extensive data. For instance, if the vegetable harvest period spans 25 days and data is recorded every second, it would result in 2,160,000 data points for temperature and humidity. This system not only generates large volumes of data but also facilitates remote monitoring due to its Internet connectivity.

Kode Hidroponik	Hari Catat	Tanggal Catat	Jam Catat	Suhu
PC001	Kamis	06/06/2024	16:36:22	23.00
PC001	Kamis	06/06/2024	16:36:32	23.00
PC001	Kamis	06/06/2024	16:36:42	23.00
PC001	Kamis	06/06/2024	16:37:01	23.00
PC001	Kamis	06/06/2024	16:37:11	23.00
PC001	Kamis	06/06/2024	16:37:21	23.00
PC001	Kamis	06/06/2024	16:37:31	23.00
PC001	Kamis	06/06/2024	16:37:41	23.00
PC001	Kamis	06/06/2024	16:37:51	23.00
PC001	Kamis	06/06/2024	16:38:01	23.00

Go to 1 View 10 1 2 3 4 5 [1 to 10 of 262]

Fig. 8. Temperature Monitoring Results

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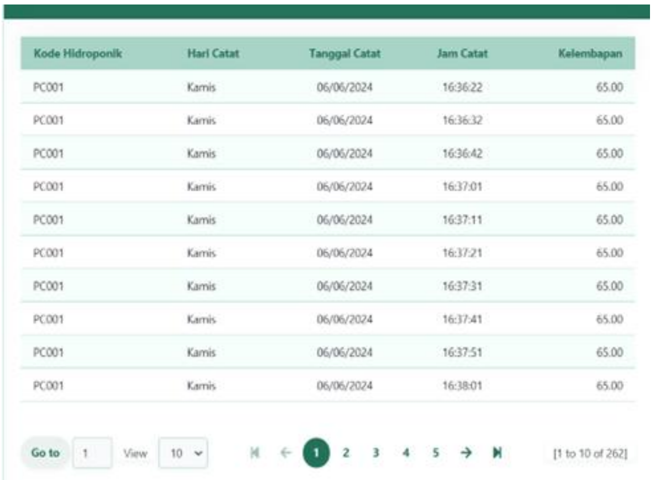

Kode Hidroponik	Hari Catat	Tanggal Catat	Jam Catat	Kelembapan
PC001	Kamis	06/06/2024	16:36:22	65.00
PC001	Kamis	06/06/2024	16:36:32	65.00
PC001	Kamis	06/06/2024	16:36:42	65.00
PC001	Kamis	06/06/2024	16:37:01	65.00
PC001	Kamis	06/06/2024	16:37:11	65.00
PC001	Kamis	06/06/2024	16:37:21	65.00
PC001	Kamis	06/06/2024	16:37:31	65.00
PC001	Kamis	06/06/2024	16:37:41	65.00
PC001	Kamis	06/06/2024	16:37:51	65.00
PC001	Kamis	06/06/2024	16:38:01	65.00

Fig. 9. Humidity Monitoring Results

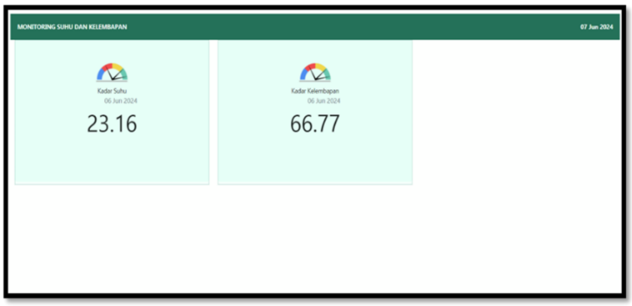

Fig. 10. Dashboard for Average Temperature and Humidity

The primary implications of this research include improved efficiency in hydroponic management through data-driven decision-making. The generated dataset not only aids in the optimization of the cultivation environment but also opens opportunities for the development of data-driven artificial intelligence models, such as neural networks, machine learning, and deep learning, which can enhance prediction, classification, and control mechanisms. In addition, the developed system has direct practical benefits for hydroponic farmers, such as real-time automatic monitoring (reducing the risk of environmental fluctuations that can affect plant growth), data-driven decision-making (allowing farmers to optimize the use of resources such as water and nutrients) and increased cultivation efficiency (ensuring consistent yields and high-quality products through precise environmental control).

Numerous previous researches related to the monitoring of temperature and humidity in various contexts have predominantly focused on non-artificial intelligence (AI) approaches [12], [13], [14]. However, some have begun to incorporate AI techniques, such as Fuzzy Logic [15], [16]. In general, prior research has remained partial and not data-oriented, meaning it has neither generated nor utilized datasets to facilitate effective and efficient smart hydroponic farming. Therefore, it is essential that, in addition to monitoring plant conditions, the system also records plant growth, creating datasets that can be employed for analysis, AI applications, or serve as a reference model for future cultivation aimed at achieving optimal harvest quality.

The research findings reveal that, within the study area, the temperature and humidity levels were approximately 23°C and 66%, respectively, in a hydroponic space of less than 1 m². For larger cultivation areas, additional DHT11 sensors would be required to ensure accurate readings across various sections. For more precise temperature and humidity measurements, the DHT11 sensor could be replaced with more advanced options such as the DHT22, SHT3x Series, or BME280 sensors. Furthermore, to accommodate broader coverage, microcontrollers like Arduino or mini-computers such as Raspberry Pi could be utilized. Additionally, careful attention must be given to power supply requirements to maintain a stable electricity flow and ensure a reliable, continuous Wi-Fi connection.

IV. CONCLUSION

This research has successfully developed a web-based and Internet of Things (IoT) real-time temperature and humidity monitoring and recording application in hydroponic cultivation. The integration of the DHT11 sensor and the NodeMCU ESP8266 microcontroller allows continuous data collection, resulting in a structured data set that supports monitoring the cultivation environment. System testing shows the efficiency and effectiveness of real-time monitoring, ensuring stable environmental conditions for hydroponic cultivation, and improving the accuracy of decision making in hydroponic management.

This research makes a significant contribution to data-driven hydroponic management and smart farming by addressing the existing research gap. Unlike previous researches that primarily focused on pH and Total Dissolved Solids (TDS) monitoring, this research extends the monitoring system by incorporating temperature and humidity tracking. This comprehensive dataset serves as a foundation for advanced Artificial Intelligence applications, enabling predictive modeling, automated environmental control, and optimized cultivation strategies.

Further more, it is essential to compare the performance of other sensors, integrate findings with previous research, and incorporate additional sensors, such as light and CO2 sensors, to broaden the scope of environmental data. Monitoring should also include visual data on plant growth to further enrich the dataset. Moreover, the development of artificial intelligence algorithms capable of providing recommendations, predictions, and classifications will become a strategic innovation, enhancing the competitiveness of IoT-based hydroponic technology in the future. Further hydroponic cultivation of plants, such as kale, celery, lettuce, and others, should be conducted to observe actual outcomes and refine dataset management practices.

This research lays the foundation for the future of smart hydroponic systems. IoT-based hydroponics will play a vital role in improving sustainability (food security), efficiency, and productivity in modern agriculture.

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