Research Article

Hydroponic Herb Plant Monitoring System based on IoT Technology.

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Abstract: *This project aims to develop a Hydroponic Herb Plant Monitoring System based on IoT Technology, focusing on basil (Ocimum basilicum) and shallots (Allium ascalonicum). The system addresses the limitations of manual monitoring for critical factors such as temperature, air humidity, pH level of the hydroponic solution, and electrical conductivity (EC). By leveraging IoT technology, the system employs devices like Arduino UNO R3 and NodeMCU ESP8266 as main microcontrollers, integrated with DHT22 sensors for air humidity, waterproof temperature sensors, pH sensors, and EC sensors to monitor hydroponic parameters. Data collected are processed, recorded, and displayed on a web platform, to enable users to monitor their plants conveniently and proactively. User also receive alert notifications via the Telegram application when sensor data show inconsistency. The project employs the prototyping methodology, which includes several phases: the Initial Requirements Phase for analysing user and system needs, the Prototype Design Phase to build a basic model of the system, the Prototype Development Phase to implement core functionalities, the Evaluation and Refinement Phase to identify and address system weaknesses, and the Testing Phase, where user feedback ensures the system fully meets its requirements. This system is expected to improve the effectiveness and quality of herb cultivation by reducing reliance on manual monitoring. In the future, it can be expanded to accommodate more plant types and incorporate automated control functions to enhance the efficiency of plant management.*

Keywords: IoT technology, hydroponic monitoring, Arduino UNO R3, NodeMCU ESP8266, DHT22 sensor, pH sensor, EC sensor, temperature sensor, liquid level sensor, Telegram alerts, prototyping methodology, web platform.

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1. INTRODUCTION

In the era of digitalization and the Fourth Industrial Revolution, Internet of Things (IoT) technology is gaining increasing attention across various sectors, including agriculture. IoT offers innovative methods to improve efficiency and productivity through automated systems and real-time data monitoring. In the agricultural sector, IoT plays a vital role in overcoming resource management

challenges and improving crop yields. This system enables the collection of data such as temperature, humidity, water pH, and other environmental factors, which can be accessed remotely by users. With the growing demand for more efficient farming methods, the use of IoT in hydroponic systems is becoming a key focus among modern agricultural entrepreneurs.

According to an article from *Berita Harian Online* (Tayep, 2024), titled *Pertanian Hidroponik Sumber Pendapatan Lumayan*, hydroponic farming has become a profitable source of income for many local farmers. The article highlights that this method not only helps farmers increase production yields but also generates higher income compared to conventional methods. With the rising demand for fresh and high-quality vegetables, hydroponic methods allow farmers to efficiently meet this need.

Hydroponics is a farming technique that uses water and nutrients to grow plants without soil. This method offers various advantages such as water conservation, environmental control, and the ability to grow crops in limited spaces. However, continuous management of environmental parameters is essential to ensure optimal plant growth. Through this monitoring system, farmers can respond quickly to any changes in parameters that may affect the growth of herb plants.

This study focuses on the application of IoT technology in monitoring herb plants such as basil (*Ocimum basilicum*) and shallots (*Allium ascalonicum*) grown hydroponically. The main objective is to develop a monitoring system that can provide real-time data and automatic alerts to users when critical parameters exceed predefined ranges. This system is expected to improve the quality and yield of herb crops and assist in making more accurate decisions based on the collected data. The study also evaluates the potential of IoT technology in enhancing the management of hydroponically grown herb plants, thereby contributing to more efficient and effective agricultural practices.

1.2 Objectives

To achieve the goals of this project, several key objectives have been identified. These objectives aim to address the challenges users face in monitoring hydroponic herb cultivation and to ensure optimal plant growth. The planned objectives are as follows:

a. To design a herb plant monitoring system using IoT devices and hardware.

b. To develop a hydroponic herb monitoring system based on IoT technology.

c. To test the system to ensure sensor data accuracy, reliability of alert notifications, and the ability to store and display critical data for real-time monitoring and analysis.

2. METHOD & MATERIAL

Methodology plays a crucial role in ensuring that the system produced is of high quality and meets user requirements more efficiently. In the context of this system development, a well-planned methodology not only helps accelerate the process but also enhances the organization and systematic structure in building the system (Guia & Marques, 2023).

Selecting the right methodology is a critical aspect of system development as it provides guidance for the entire development process, from planning to implementation. Among the commonly used development methodologies are Waterfall, Spiral, and Prototype, each offering its own approach and structure that can be adapted to project needs. Choosing the appropriate methodology can significantly influence the effectiveness and quality of the system developed (Ahmed, 2021).

2.1 Methodology Used

In the system development process, various methodologies can be chosen to ensure smooth and structured progress. For the development of the IoT-Based Herb Plant Monitoring Application using Hydroponics, the prototype methodology was selected as the main approach. This method is considered the most suitable as it allows gradual system development while gathering user feedback at each phase.

The prototype methodology consists of several key phases: initial requirements, design, prototype construction, evaluation and improvement, final development, testing, and maintenance. This flexible approach allows changes to be made based on feedback at every stage, helping to produce a system that better fits user needs. Figure 2.1 shows the prototype model, outlining each phase involved in the process.

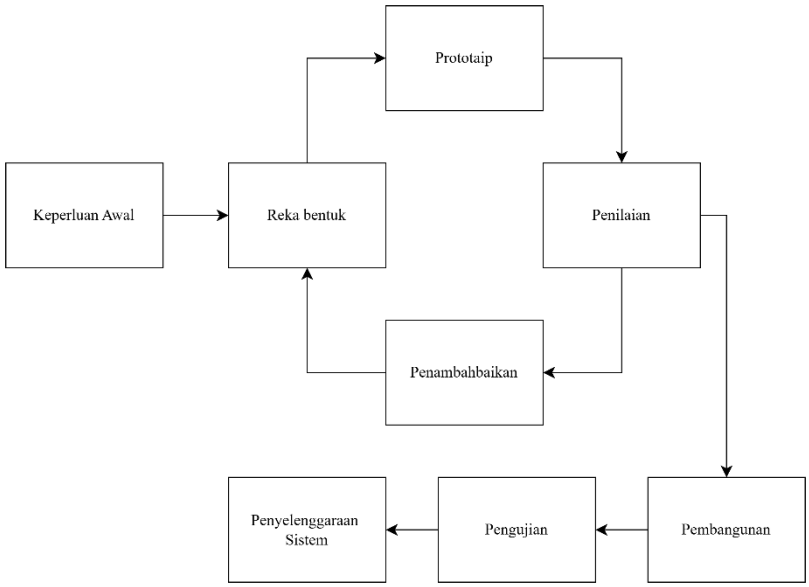


Figure 2.1 Prototype Model for the IoT-Based Herb Plant Monitoring System

The Initial Requirements Phase is the first step. In this phase, information related to the system is collected. Three similar studies were selected and compared to understand differences in system types, objectives, user access, concepts, hydroponic types, and system advantages. A detailed analysis is conducted to define system requirements and determine the necessary hardware before development begins.

The second phase is the Design Phase, where the initial design of the IoT-based hydroponic monitoring system is created. Critical elements are planned, including a user-friendly web interface to display real-time data such as temperature, humidity, and pH levels. A well-structured database is also designed to store sensor data systematically, ensuring easy access and analysis. This phase sets the foundation for the next stage, where these design elements are combined into a functional system.

The third phase is Prototype Development. Here, the actual prototype system is built based on prior research. This includes assembling hardware like the Arduino UNO R3 and integrating the system. The prototype then undergoes evaluation to ensure it meets user expectations.

The fourth phase is Evaluation and Improvement. In this phase, the prototype is reviewed with users to confirm their needs are addressed. If needed, enhancements are made. This evaluation can

involve collaboration with the Centre for Entrepreneurial Development and Innovation, National Defence University of Malaysia (UPNM), which has developed solar and IoT programs. This phase is crucial for ensuring the system's effectiveness.

The final phase, Development, Testing, and Maintenance, involves key steps. After evaluation, system development continues, followed by testing before implementation. Once implemented, the system undergoes regular maintenance to ensure it remains effective and meets user requirements.

2.1.1 Initial Requirement Phase

Based on Figure 2.1, this phase outlines the project's objectives, scope, problem statement, and significance. It serves as the foundation to finalize the system title and collect relevant data and information to meet user needs.

This phase focuses on identifying the system requirements. Previous studies by Chowdhury et al. (2020), Hafid Hardyanto & Ciptadi (2019), and Munandar et al. (2018) were reviewed to compare and determine the most suitable hardware,.

These comparisons help identify improvements over existing systems, even if they perform well. Evaluating similar systems is essential to enhance the efficiency and accuracy of this project. An in-depth study on hydroponic herb cultivation systems was also conducted. This includes selecting appropriate software and databases to display data from the sensors. With IoT integration, the system aims to simplify user tasks and stay up to date with current technologies.

2.1.2 Design Phase

After system analysis, the Design Phase begins. This phase involves planning and sketching the system based on the data gathered earlier.

Initial designs, including both physical and virtual components, are created to visualize the system. A prototype framework is built first for testing purposes. User interface (UI) and database designs are also prepared to streamline development.

The UI must be user-friendly and include proper security measures, especially in the database. Admin and user access hierarchy, along with data dictionaries, The output interface is also designed to make data display clear and easy to understand. This helps avoid confusion and ensures users can interact effectively with the system.

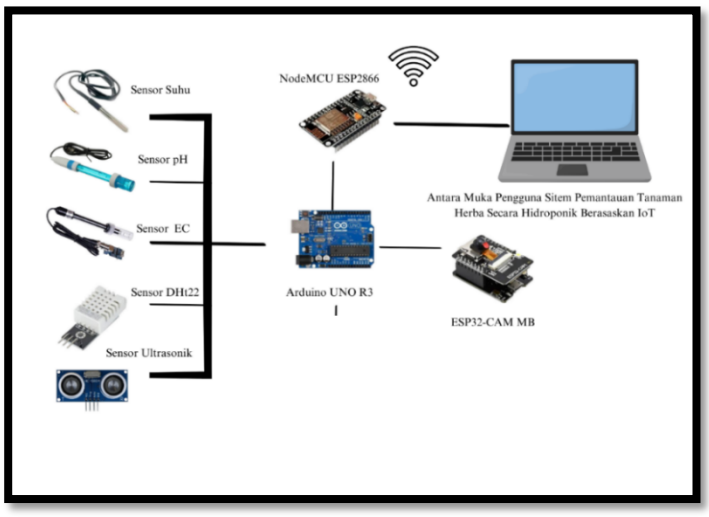


Figure 2.2 Schematic Diagram of the Hydroponic Herb Monitoring System

The hydroponic herb plant monitoring system illustrated in the schematic diagram utilizes Internet of Things (IoT) technology to enable efficient and real-time environmental monitoring. At the core of the system is the Arduino UNO R3, which interfaces with a range of sensors including temperature, pH, electrical conductivity (EC), humidity and temperature (DHT22), and ultrasonic sensors. These sensors collect critical data required to maintain optimal growing conditions for hydroponic herbs, such as nutrient balance, ambient temperature, and water levels.

The NodeMCU ESP8266 module facilitates wireless communication, allowing the system to transmit sensor data to website where users can monitor conditions remotely. Additionally, the ESP32-CAM module is used to capture real-time visual images of the plants, providing a comprehensive overview of plant health and development. This integration of microcontrollers and sensors with IoT technology offers an intelligent and automated solution for managing hydroponic cultivation, promoting efficient and sustainable urban agriculture practices.

2.1.3 Prototype Phase

As shown in Figure 2.1, this is a key phase in the system development lifecycle, where the actual system is built based on the completed designs. Research findings guide the prototype development of the IoT-based herb monitoring system.

The UI for the website begins here, starting with user login to the system homepage. Special attention is given to this stage to ensure both usability and system security, which are crucial for a smooth user experience.

2.1.4 Evaluation and Improvement Phase

In this phase, the system is tested to identify any problems or bugs. Testing helps refine the system to make it more efficient and functional.

Improvements are made based on the test results and re-evaluated to minimize errors. After full testing, the final version is built and deployed for actual use.

2.2 Hardware and Software Requirements

The hardware and software used in developing the IoT-Based Hydroponic Herb Monitoring System must support real-time monitoring. Sensors are required to measure temperature, humidity, and pH levels. The Arduino UNO R3 microcontroller collects sensor data and sends it to the cloud for analysis. Table 3.1 lists all components used, with diagrams.

Table 1: Hardware and Software Used

Hardware/Software	Description
Arduino UNO R3	Microcontroller board for building electronics projects.
DHT22 Sensor	Measures air temperature and humidity.
NodeMCU ESP8266	Open-source firmware and development board.
Temperature Sensor	Measures water temperature in hydroponic solution.

pH Sensor	Measures water pH level.
EC Sensor	Measures electrical conductivity in water.
ESP32 CAM MB	Streams live video.
Ultrasonic Sensor HC-SR	Measures water level in the hydroponic system.
Jumper wires	Connect all electronic components.
Arduino IDE	Used to program the Arduino and NodeMCU.
Localhost (Xampp)	Local server for web development and testing.

3. FINDINGS

System analysis involves an in-depth study of the system to be developed to ensure a clear understanding of its functions and process flow. In this phase, a detailed initial overview of the system is discussed through elements such as the context diagram, data flow diagram, and flowchart. These diagrams provide a comprehensive view of how the system operates and interacts with other components.

Additionally, this chapter explains each operation and function required in the system, establishing a strong foundation for the subsequent development stages. This analysis process not only facilitates initial understanding but also plays a critical role in ensuring smoother system development by reducing design and implementation errors.

3.1 Analysis Phase

In the analysis phase of the IoT-Based Hydroponic Herb Monitoring System, system requirements are identified and understood to ensure the application efficiently meets monitoring objectives. This phase includes collecting necessary data such as key parameters to be monitored such as temperature, humidity, pH level, and light intensity, all of which are crucial for the growth of hydroponic crops like basil and shallots.

The planned data flow illustrates how information is processed and displayed to users via applications and websites. This helps in building a system structure that allows easy access to real-time information for users.

Furthermore, the context diagram and system flow diagrams are reviewed to ensure all components operate in line with the application's objectives. The system flowchart shows how data from IoT sensors is automatically relayed to the user. Through a structured and thorough process in this analysis phase, a clear picture of the application's functions and operations can be built, helping ensure the next development steps run smoothly while minimizing design risks.

3.2 Unified Modeling Language (UML) Diagram

To illustrate the system flow, two types of graphical representations are typically used: the Data Flow Diagram (DFD) and the Unified Modeling Language (UML) diagram. In this project, UML was chosen to represent the data flow because it offers a more intuitive approach to visualizing the processes and interactions within the system being developed. Therefore, the system flow is clearly explained using the Use Case Diagram in Figure 3.1 to facilitate an initial understanding of the system's main functions and components.

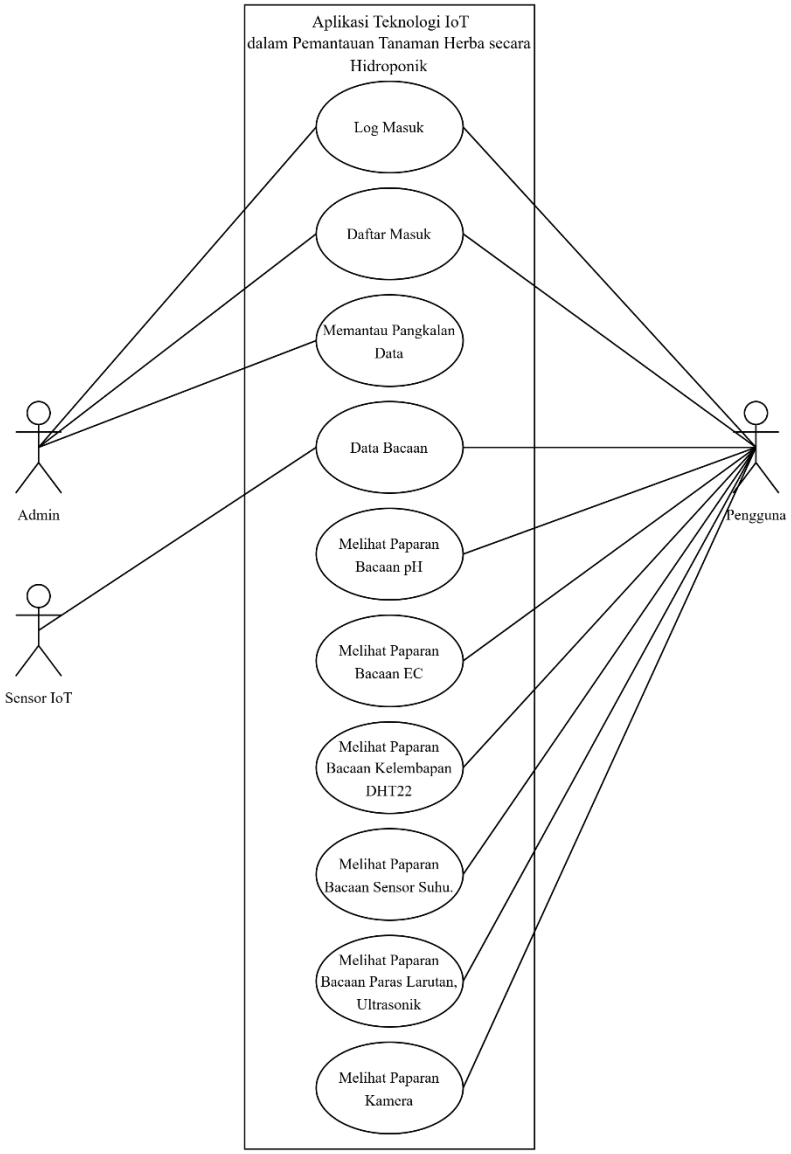


Figure 3.1 Use Case Diagram

The system begins when users log in with a username and password provided by the admin. The login data is verified against a database. If valid, access is granted. Upon successful login, users can access data from the IoT system.

IoT sensors send readings to a Data Table, which can be accessed by users. The system interaction is further detailed in the Sequence Diagram in figure 3.2, showing each interaction step between users and the system, especially during login and data access.

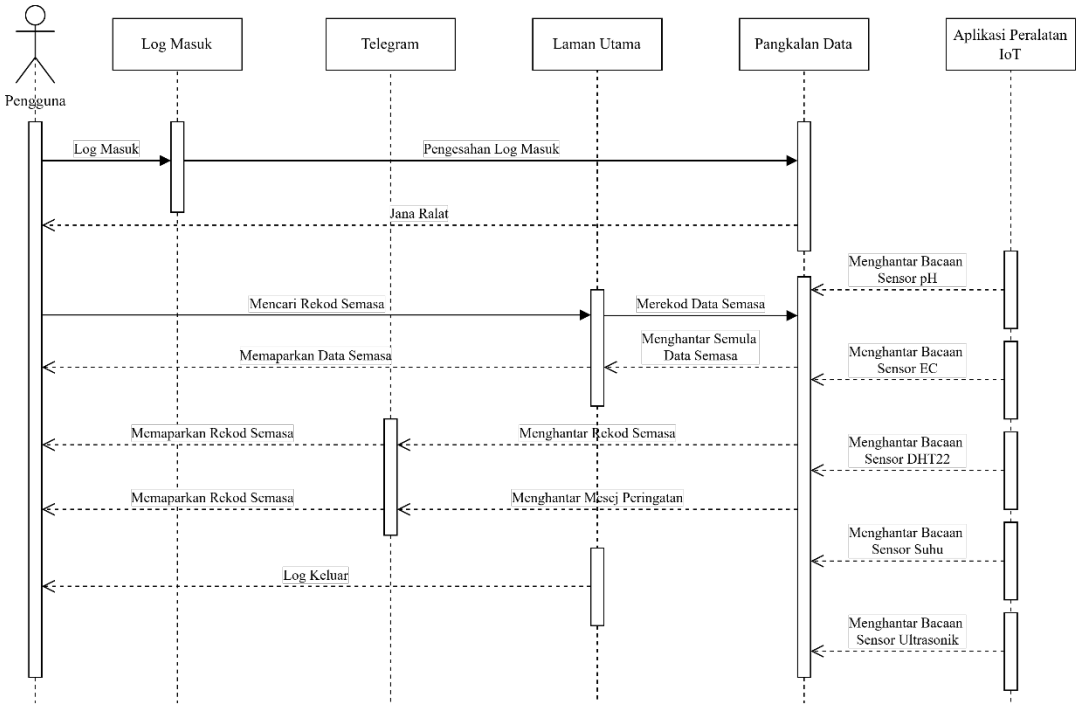


Figure 3.2 Sequence Diagram

3.3 Entity Relationship Diagram (ERD)

The Entity Relationship Diagram (ERD) is a representation of the data structure that illustrates the interactions between the Admin, Plant Data, and User in the IoT Technology Application System for Monitoring Herbal Plants Using the Hydroponic Method. In this diagram, the Admin is responsible for maintaining and ensuring the accuracy of the Plant Data, while the User accesses the Plant Data to view key parameters such as pH, humidity, temperature, and solution levels. This interaction reflects a systematic flow of data between the managing party (Admin) and the data-utilizing party (User), ensuring effective monitoring and management of hydroponic herbal plant cultivation. Figure 3.3 illustrates the entity relationships between the Admin, Plant Data, and User within the system.

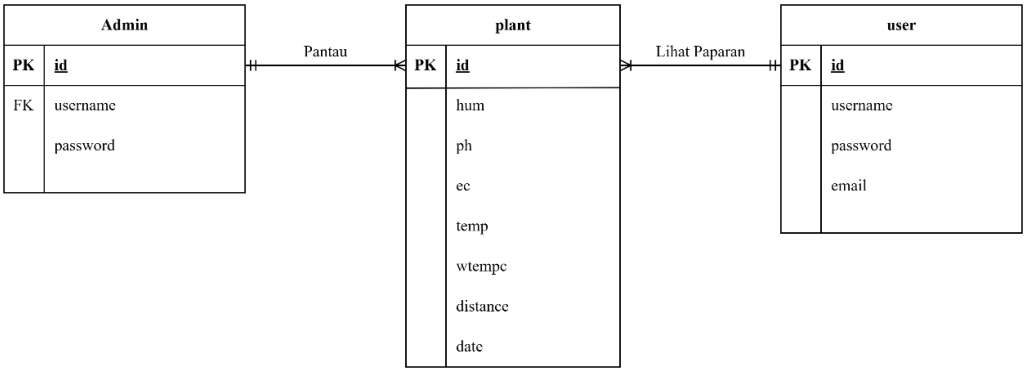


Figure 3.3 Entity Relationship Diagram

3.4 Prototype Design

This system is designed to assist users in monitoring their hydroponically grown herbal plants more efficiently. Several key factors need to be carefully considered, as these can influence the quality and yield of the herbs. Among the critical parameters being monitored are water temperature, ambient humidity and temperature, pH levels, and the electrical conductivity (EC) of the hydroponic solution.

The system is capable of automatically collecting readings and recording the data, which is then displayed on a dedicated website accessible to users. Considering user needs and expectations, this system not only simplifies remote monitoring but also encourages users to manage their plants without needing to be physically present at the cultivation site.

Figures 3.4 and 3.5 depict the system architecture of an Internet of Things (IoT)-based monitoring solution developed for hydroponic herbal plant cultivation. This system is designed to measure and track several vital parameters that directly influence plant health and growth, including water temperature, ambient temperature and humidity, electrical conductivity (EC) levels, and the pH of the nutrient solution. These values are collected in real time through a network of sensors, ensuring that users have continuous insight into the growing conditions of their plants.

The data is transmitted to a centralized web-based interface, which presents the information in an accessible and user-friendly format. This allows users to remotely monitor the system from any device with internet access. To enhance responsiveness, the system also features Telegram integration, which delivers instant alerts if any parameter falls outside of the optimal range. This proactive notification system reduces the need for constant physical supervision, making the cultivation process more efficient, reliable, and convenient for users managing their hydroponic setups from a distance.

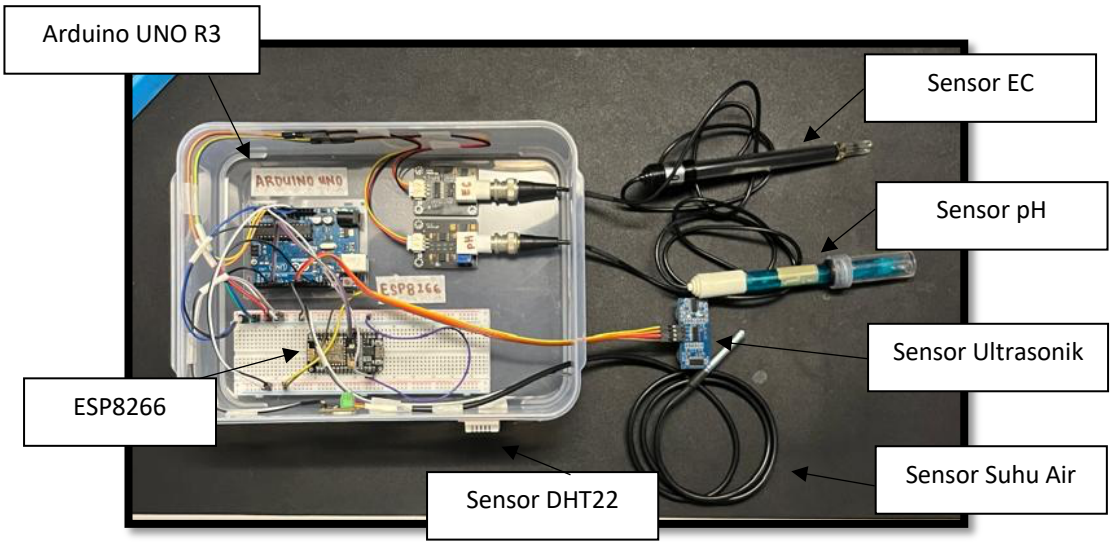


Figure 3.4 Top View of the System Design

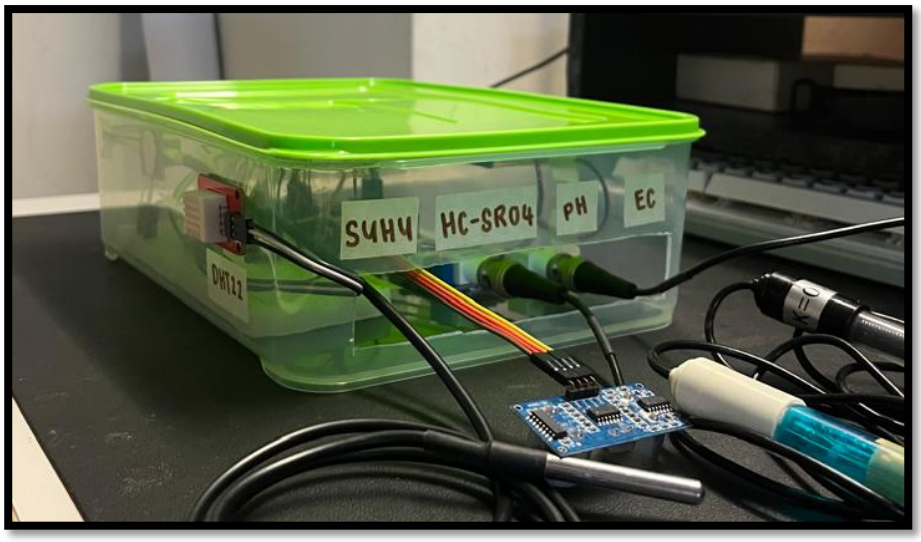


Figure 3.5 Front View of the System Design

Figure 3.6 provides a detailed view of the IoT-based monitoring system integrated with a hydroponic unit, highlighting the strategic placement of various sensors for accurate data collection. An ultrasonic sensor is mounted above the hydroponic solution container to continuously measure water levels, ensuring that the system maintains adequate nutrient solution for plant growth. The DHT22 sensor is positioned externally to monitor the ambient temperature and humidity, which are crucial for creating a stable growing environment. Inside the container, water temperature, pH, and electrical conductivity (EC) sensors are submerged to capture real-time data on the internal conditions of the nutrient solution. This arrangement allows the system to provide comprehensive monitoring of both environmental and solution-based factors, supporting optimal plant development.

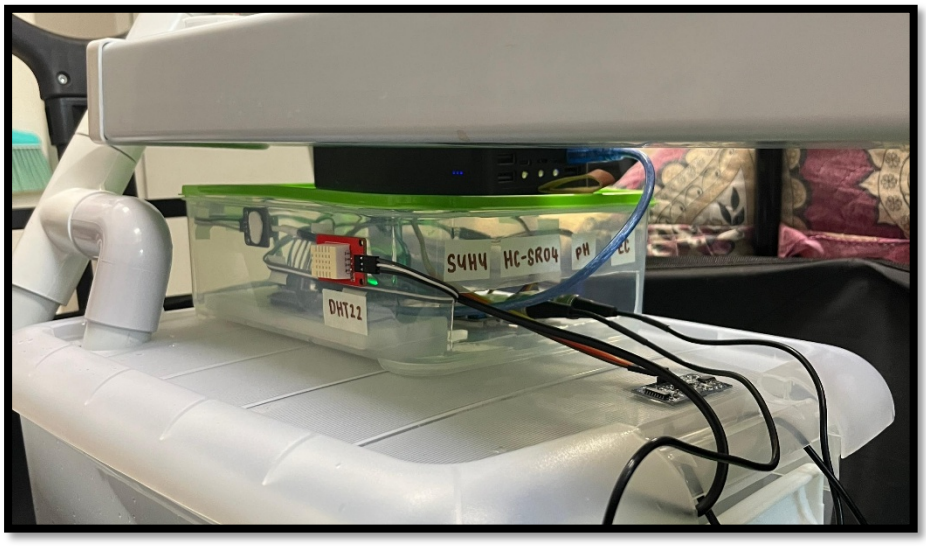


Figure 3.6 System Design Integrated Clearly with Hydroponic Setup

3.5 System Website Interface Design

The website interface developed for this system is intended to display information and data related to the user's hydroponic herbal plants. Through this interface, users can monitor data such as water temperature, ambient humidity and temperature, as well as pH and EC levels of the hydroponic solution. Users are required to analyse the data presented and make appropriate decisions if any issues are detected by the system. Figure 3.7 shows the login interface, which allows users to access the system.



Figure 3.7 User Login Interface

Figure 3.8 displays the main homepage interface that appears after a user successfully logs into the hydroponic monitoring system. Upon entry, users are greeted with a welcoming message, "*Selamat Datang ke Sistem Pemantauan Tanaman Herba Secara Hidroponik*," which sets the tone for a user-friendly experience. The homepage provides an overview of essential data through clear visualizations, including real-time graphs and numerical readings for key parameters such as water temperature, pH, EC levels, and ambient conditions. This centralized dashboard allows users to quickly assess the overall status of their hydroponic system, enabling efficient monitoring and informed decision-making at a glance.

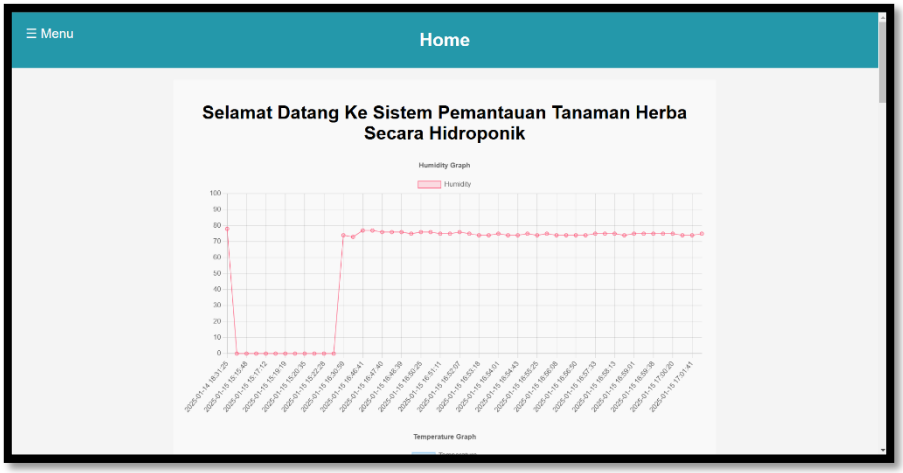


Figure 3.8 User Homepage Interface

Figure 3.9 presents both historical and current system readings in a structured table format, allowing users to easily track and review past data alongside real-time values. This tabular display enhances usability by offering a clear and organized overview of parameter trends over time. Meanwhile, Figure 3.10 illustrates real-time data through dynamic graphs specifically focused on air humidity and ambient temperature. These visual representations enable users to quickly identify fluctuations or anomalies in environmental conditions, supporting prompt decision-making and better control over the hydroponic growing environment.

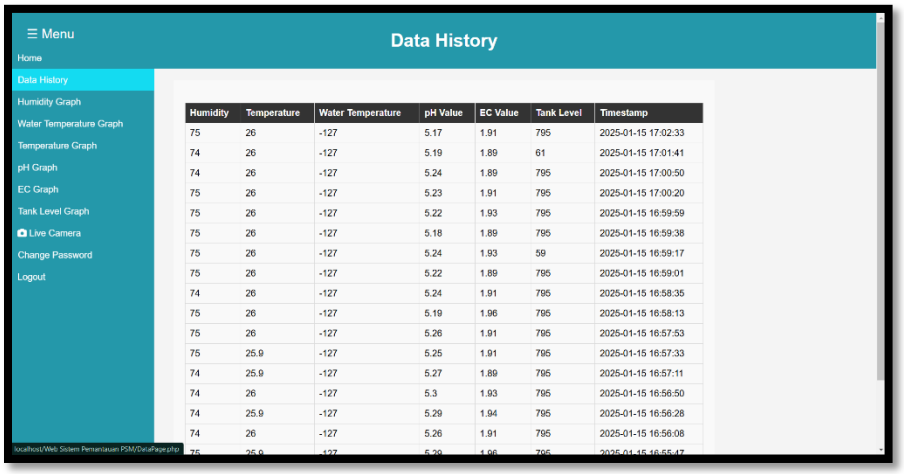


Figure 3.9 Data History Interface

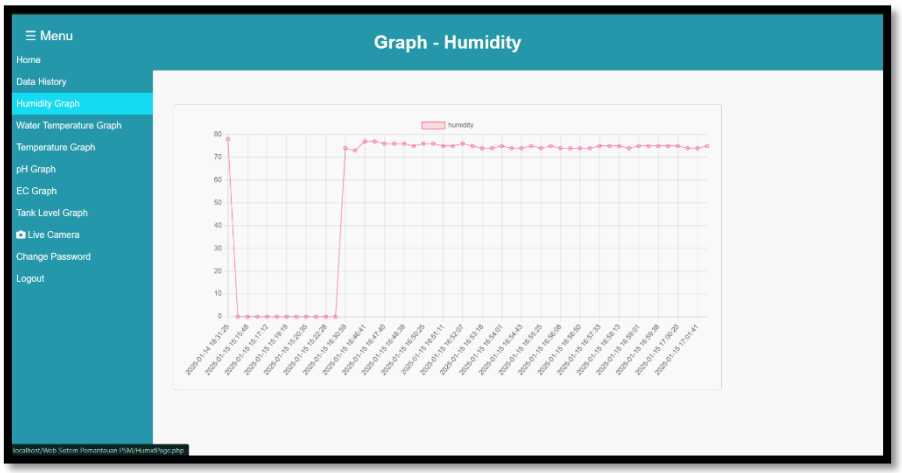


Figure 3.10 Graph Humidity Interface

4. DISCUSSION

4.1 Comparison of Equivalent Systems

The comparison of IoT-based hydroponic systems discussed in the three selected articles highlights different approaches to leveraging technology for urban farming and limited-space environments. Each study offers an innovative solution for monitoring and managing hydroponic systems, with its own strengths and limitations. This comparison focuses on four main criteria: type of system, system objective, user access, and system advantages. The goal is to provide a clearer picture of how IoT technology is applied in the increasingly growing field of agriculture. Table 5 presents a comparison of equivalent systems based on the selected studies to identify the best concepts that can be used as a reference in developing this system.

Table 5 Comparison of Equivalent Systems

Criteria	Design and development of an IoT-based smart hydroponic system (Munandar et al., 2018)	Internet of Things Technology Implementation for Hydroponic Planting Culture (Hafid Hardyanto & Ciptadi, 2019)	Design, construction and testing of IoT based automated indoor vertical hydroponics farming test-bed in Qatar (Chowdhury et al., 2020)	Hydroponic Herb Plant Monitoring System based on IoT Technology
Type of System	Smart hydroponic system based on IoT	IoT-based hydroponic system	Automated vertical indoor hydroponic system	IoT-based monitoring system for herbal plant using hydroponics
System Objective	Design and test a smart hydroponic prototype for efficient monitoring	Develop an IoT hydroponic system for urban farming in limited spaces	Develop a fully automated hydroponic system suitable for desert climates with minimal user involvement	Develop an IoT-based monitoring system that provides real-time data and automatic alerts to optimize herbal plant growth
User access	Monitoring via web and Android app	Web-based monitoring	Web interface and mobile app with Short Message Service SMS alert system	Monitoring via website and Telegram app for instant notifications
System Concept	Consists of three main components: sensor nodes, RESTful API, and real-time monitoring interface	Uses sensors (light, temperature, humidity) and solar power to autonomously monitor plant conditions	Vertical NFT hydroponic system with sensors (pH, EC, temperature), dosing pumps, air conditioning control, and continuous power monitoring	IoT-based system that measures parameters such as temperature, EC, humidity, and pH level, with automatic alerts via Telegram for corrective actions
Type of Hydroponics	Nutrient Film Technique (NFT) system	Drip system	Vertical Nutrient Film Technique (NFT) system	Vertical Nutrient Film Technique (NFT) system
System Advantages	Real-time data visualization and remote monitoring;	Simple, effective, solar-powered; suitable for limited urban spaces	Fully automated with minimal user input; suitable for hot and dry areas;	Monitors and detects changes in environmental parameters

	scalable for both small and large setups		cost-effective for home and large-scale use	quickly; improves herbal plant management efficiency; supports immediate actions through notification alerts

4.2 Achievement Review

The success of this system development can be evaluated based on the objectives set out in Chapter 1, Section 1.3. These objectives were formulated to address the challenges users face when monitoring herbal plants using hydroponics, and to ensure optimal plant growth. The Herbal Plant Hydroponic Monitoring System is deemed successful as it has achieved the following goals:

a. Designed a hydroponic herbal plant monitoring system using hardware components as described in Section 3.4 and software in Section 3.5.

b. Developed a monitoring system that integrates IoT technology to simplify plant management and decision-making.

c. Tested the system to validate the accuracy of sensor data, the reliability of alert notifications, and the capability to store and display crucial data such as water temperature, ambient humidity, nutrient solution pH, and electrical conductivity (EC) in a real-time database.

The achievement of these objectives demonstrates that the system provides accurate, real-time insights and technological support to enhance the efficiency and productivity of hydroponic herbal farming.

4.3 System Advantages

The Herbal Plant Hydroponic Monitoring System has been designed with user-friendliness and efficiency in mind, allowing users to manage their plants with minimal effort. Key benefits of the system include:

a. A dedicated website interface that allows users to view recorded environmental data for easy observation and analysis.

b. Integration with Telegram for real-time alerts, enabling users to take prompt action in response to abnormal conditions.

c. A simple and intuitive user interface that facilitates ease of use, even for individuals with limited technical knowledge.

d. A structured database that stores plant growth data, allowing users to track progress and plan future actions based on historical trends.

These advantages demonstrate the system's ability to enhance user experience and streamline the process of hydroponic plant monitoring through IoT integration.

4.4 System Limitations

While the system offers significant improvements in monitoring hydroponic herbs, several limitations were identified that require further refinement:

a. Hardware components, such as water temperature sensors, require regular maintenance to ensure consistent performance and avoid system malfunctions.

b. The current version lacks a built-in feature for users to report technical issues or submit complaints directly through the platform.

c. The website interface does not support auto-refresh, requiring users to manually reload the page to update the data graphs.

d. The system does not yet generate detailed reports based on collected data, which could assist users in making informed decisions.

Addressing these limitations will enhance system reliability and user satisfaction in future implementations.

4.5 Future Recommendations

To further improve the system and meet evolving user needs, the following future enhancements are proposed:

a. Develop a mobile application for more convenient and portable monitoring of plant growth.

b. Add a reporting or feedback feature on the website, allowing users to report issues or suggest improvements.

c. Implement real-time auto-refresh functionality for the data graphs on the web interface.

d. Introduce additional hardware features to improve the depth and scope of environmental monitoring for more effective plant care.

By implementing these recommendations, the system can be further optimized to support a broader range of users and applications in modern smart agriculture.

5. CONCLUSION

The Hydroponic Herbal Plant Monitoring System developed aims to assist users in monitoring their hydroponic herbal plants more effectively. This system is expected to address various issues and challenges faced by farmers and individuals utilizing hydroponic systems. In addition, the development of this system is anticipated to simplify processes and meet user needs, especially in the rapidly advancing era of globalization. Overall, the development of this system can help improve the quality of hydroponically grown herbal plants managed by users.

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