

An IoT-based approach for microclimate surveillance in greenhouse environments

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ABSTRACT

As the demand for efficient and cost-effective greenhouse microclimate surveillance has increased, we developed a microclimate surveillance system using microcontroller technology that automatically collects temperature and relative humidity data and transmits it to a cloud server for remote surveillance and data analysis. 1971 microclimate data points were acquired over a 20-day evaluation period, providing insights into greenhouse environmental conditions with a negative linear regression between air temperature and relative humidity within the greenhouse and an R-squared of 0.73. This illustrates the system's ability to record and quantify environmental conditions data. Additionally, we derived a predictive model to manage microclimate conditions using the regression formula $y = -6.12X + 238.33$, where X represents the air temperature and y represents the relative humidity. All the results show that the acquired data can be used to make decisions to optimize plant growth. The prototype we developed can be an alternative option for small and medium-sized farms that need a greenhouse surveillance system to improve operational efficiency and reduce surveillance costs. The system can be further developed by implementing additional sensors to monitor light intensity, wind speed, or soil moisture and further data analysis models to optimize greenhouse management.

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1. INTRODUCTION

Information technology in the agricultural sector has become an essential part of modern agriculture, especially the application of information technology and computers in greenhouses to control environmental conditions and ensure that harvests can last throughout the year. The climate variables that are important for farmers and essential for plant growth include temperature, relative humidity and light intensity, which are [1], [2]. The application of information technology has emerged in the agricultural sector because conventional agriculture generally involves manual management, so it is prone to management errors and requires considerable labor. Moreover, agricultural management errors can increase operational costs and disrupt plant growth. Therefore, information and computer technology (ICT) based on a practical approach is needed by farmers as a greenhouse management method [3].

ICT based agriculture can overcome the challenges faced by conventional agriculture by applying the latest technologies, such as sensor technology and the internet of things (IoT), to pave the way for the

development of intelligent greenhouse management systems [4]. ICT-based agriculture uses a sensor network to collect data regarding environmental parameters in the greenhouse, such as temperature, relative humidity, and light intensity; then, the obtained data are sent via the internet to a server for data analysis to make crucial decisions that influence plant growth. The hope is to increase plant productivity. Although the development of intelligent systems in agriculture has various benefits, such as improving operational efficiency or minimizing errors, its application is still limited, especially among agricultural groups that have small- and medium-scale agricultural land [5]. This is an opportunity to develop information technology-based systems that can be applied in farming.

The main objective of this research is to construct an easy-to-use and low-cost microclimate condition surveillance system for small- and medium-sized greenhouses and test the system's functionality in the surveillance, transmission and storage of microclimate conditions such as the temperature and relative humidity of air, followed by measuring how well the system performs. Work so that the suitability of the acquired data can be illustrated according to the needs of the plant. This solution is expected to provide greenhouse environmental management technology that is easily accessible to agricultural users. Our proposed system will use affordable hardware and software components in greenhouse environmental parameter surveillance systems. The temperature and relative humidity data obtained from the acquisition will be sent in real time to the cloud computing system via a wireless connection for remote analysis. The device is built modularly to facilitate future system development by adding sensors measuring other environmental parameters, such as light intensity, wind speed, soil moisture or carbon dioxide levels.

The novelty of this research lies in its approach to providing farmers access to modern agricultural technology. The system is designed to be low-cost and has an easy-to-use interface to minimize difficulties for farmers in implementing surveillance systems in greenhouses. In addition, this research contributes to providing practical solutions for managing microclimatic conditions, resulting in more efficient and sustainable greenhouse operations. The system also makes it easy for farmers to make the right decisions based on real-time data so that farmers can provide fast and precise responses to optimize plant growth and increase yields, thereby producing significant economic benefits.

Research conducted by [6] shows that greenhouse automation can significantly increase productivity and profitability for farmers. Meanwhile, other research conducted by [7] states that the development of a microclimate surveillance system that is low-cost and easy to use is a significant advance in agricultural technology. This research can potentially address the specific needs of small- and medium-scale greenhouse farming operations and improve efficiency, sustainability, and food security.

This study is divided into five sections. Chapter 1 summarizes the research, including the investigation's context, issue statement, aims, range, and importance. Chapter 2 reviews prior studies on microclimate surveillance systems and their usage in the farming sector. Chapter 3 explains the suggested microclimate surveillance system, comprising the hardware and software elements and the information flow. Chapter 4 highlights the outcomes and analysis of the testing and assessment of the system's efficiency and success. Chapter 5 summarizes the research, including the fundamental discoveries, contributions, and subsequent steps.

2. RELATED WORKS

Technological developments in greenhouse microclimate surveillance systems have developed due to the emergence of affordable microcontrollers and microcomputers. Many researchers use this technology to research how to increase agricultural productivity. Several published studies have investigated various combinations of sensors, microcontrollers, single board computer (SBCs) and wired and wireless communication technologies to monitor and control environmental parameters that influence plant growth. However, there is still a gap in the development of exceptionally low-cost and easy-to-use systems for small- to medium-scale greenhouse operations. This chapter will explore and compare previous studies, highlight the diversity of technologies and methodologies used, and emphasize the research gap this research aims to bridge.

The summary of related research in Table 1 describes the diverse landscape of greenhouse surveillance technologies. For example, [8] conducted a study by introducing a low-cost surveillance device prototype that utilizes ZigBee to monitor air temperature and relative humidity using wireless communication. This prototype offers a real-time environmental surveillance system that can be accessed remotely via a web-based interface, demonstrating the potential of using wireless technology to simplify greenhouse management. Another study by [9] implemented a surveillance system using several technologies, such as ThingSpeak, GSM, and Blynk, to facilitate soil temperature and moisture surveillance, showing the versatility of IoT applications in agricultural environments.

Further exploration of related research shows that many studies are trending toward integrating a broader spectrum of environmental parameters. For example, the Hydroponic IoT project developed by [10] by utilizing Wi-Fi and UBIDOTS-based cloud services using the ESP32 microcontroller shows the system's feasibility in optimizing hydroponic systems in greenhouses through remote surveillance. Moreover, [11] presented a multisensor wireless node device that combines atmospheric and soil parameters, offering a comprehensive picture of greenhouse conditions through an easy-to-understand interface. The implementation of a wireless sensor network (WSN) based on Eigen Solutions in this research shows the potential of advanced analysis techniques to improve data accuracy and reliability.

Although various studies have published technological advances in agriculture, what emerges from these studies is their focus on technological innovation without considering the practicality of its application in small- or medium-scale agriculture. Although effective, systems developed by previous researchers often require substantial investment and technical expertise, limiting their accessibility for small- and medium-sized greenhouse hardware. In addition, much of the research that has been conducted has focused on the hardware and software aspects of surveillance systems and only briefly explains the need for easy-to-use interfaces and cost-effective system implementation strategies.

This research gap can be seen in the limited exploration of integrated system solutions implementing greenhouse environmental condition surveillance capabilities with ease of use and low cost. Although studies such as those carried out by [12], [13] have used web applications such as BLYNK or Android-based platforms to access data, display information and control in real time, research on developing systems that meet the specific needs of small-scale greenhouses is rare. Intermediate, thus emphasizing the need for research that prioritizes simplicity, cost efficiency, and user engagement.

This chapter highlights studies with innovative technologies and diverse approaches to the surveillance of greenhouse microclimate conditions. However, the focus is more on technological development than its practical application, which shows a research gap, so there is a need to overcome the challenges of implementing surveillance systems in small- and medium-scale agriculture by emphasizing easy-to-use interfaces, affordability, and reliable surveillance solutions. Comprehensive. This study aims to bridge this gap by developing a microclimate surveillance system that is not only technologically advanced but also accessible and practical for a broader range of greenhouse operators, thus enhancing agricultural productivity and sustainability.

Table 1. Comparative analysis of prior research on greenhouse microclimate surveillance systems

Authors	Sensors used	Connections	Description of works
Pisanu <i>et al.</i> [8]	Temperature and humidity	ZigBee	The prototype low-cost platform uses sensors and a wired/wireless network to monitor the greenhouse environment in real-time and offers a web app for a convenient consultation.
Aafreen <i>et al.</i> [9]	Temperature and soil moisture	GSM, ThingSpeak	ThingSpeak, GSM, and Blynk app enable real-time greenhouse surveillance and control.
Harikrishna <i>et al.</i> [10]	Temperature, humidity and luminosity	Wi-Fi, UBIDOTS	The Hydroponics IoT project optimizes greenhouse conditions and enables remote surveillance with the UBIDOTS cloud, ESP32 microcontroller, and sensors.
Lata <i>et al.</i> [11]	Temperature, humidity, luminosity and soil moisture	Eigen Solutionsbased WSN	This study proposes a multisensor wireless node with a GUI for greenhouse surveillance, which measures atmospheric and soil parameters based on Eigen Solutions.
Chakraborty <i>et al.</i> [12]	Temperature, humidity, and soil moisture	BLYNK, Wi-Fi	BLYNK app provides real-time data and control for IoT-based smart irrigation and environmental surveillance.
Guntur <i>et al.</i> [13]	Temperature and soil moisture	GSM, Android	An innovative irrigation system uses Arduino, sensors, and an Android app based on GSM Modules and IoT to automate and control irrigation, which saves time and money.

3. RESEARCH METHOD

Through technological developments, today's farmers can manipulate environmental conditions for plant growth by using greenhouses to grow crops optimally, consistently maintain microclimate conditions, and obtain maximum harvest results. Various studies have also been carried out to develop modern, user-friendly agricultural systems using the latest technology so that plant growth is optimal, especially in greenhouses, because the microclimate conditions in houses in tropical areas generally differ from those in fields, so they can have a significant impact on plant growth and productivity [14]. In its application, farmers must be able to monitor and control temperature, humidity, light intensity and carbon dioxide concentration within a specific range to ensure optimal plant growth and yields [15].

The development of greenhouse microclimate surveillance systems in recent years has led to the adoption of various technologies, such as WSNs, where WSN-based systems use wireless communication to send information from sensors to a hub or server [16], [17]. The advantages of the WSN system are its ease

of installation, scalability and remote access. However, the costs that need to be incurred to use this WSN system are more significant than those that still use cables because the system requires battery power [18]. On the other hand, cable-based systems are more reliable in acquiring data because they are directly connected to the server via cables, so there is minimal interference. The costs incurred to build a surveillance system using cables are more affordable than those incurred for WSN-based systems; however, in large-scale greenhouses, the expenses incurred to install the system can be more expensive [15], [19], [20]. In this research, we propose a microclimate surveillance system that can measure the temperature and humidity of a greenhouse and send this information to a cloud service for remote supervision, with Figure 1 depicts the system architecture.

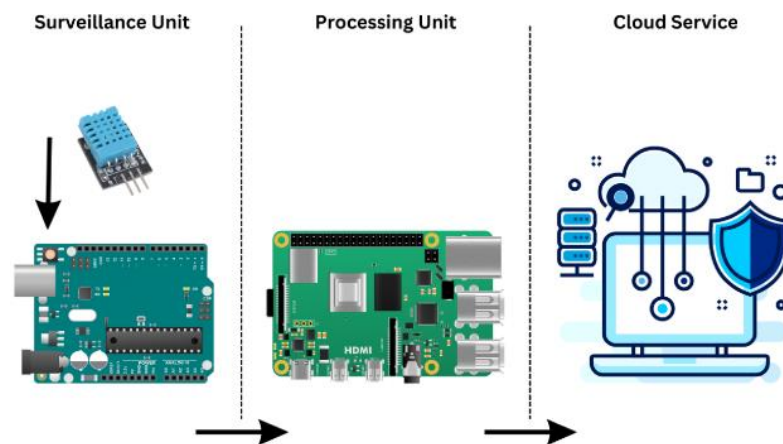


Figure 1. Architecture of the constructed system

3.1. Surveillance unit

Researchers generally use ready-to-use sensor modules to measure temperature and humidity using a microcontroller. One sensor module capable of measuring both simultaneously and is available on the market is the DHT11, an inexpensive digital-type sensor with good measurement accuracy. DHT11 is composed of a thermistor and air humidity sensor, and its digital output makes it easy to read measurement results where the temperature is in Celsius units and humidity is in percent units; it also makes it easy to connect to a microcontroller such as an Arduino UNO based on the ATmega328P or a Raspberry Pi SBC, which has a System on Chip Broadcom BCM2835 [21], [22]. In locations with tropical climates, the DHT11 sensor can be used to accurately detect the temperature and relative humidity of the air in greenhouses. Nevertheless, its accuracy can decrease at low temperatures [23].

We constructed a surveillance system for this research involving an Arduino UNO microcontroller and a DHT11 sensing unit. The DHT11 sensor module can identify microclimate conditions, and we selected it because it transmits information as digital values and has a high degree of accuracy when measuring temperatures. By integrating the DHT11 sensor module into the Arduino UNO, we enabled it to function as a surveillance device, requiring regular access to the hardware. The power source is supplied through the USB connection to the Raspberry Pi.

3.2. Processing unit

Arduino UNO and Raspberry Pi are two devices commonly used to construct surveillance systems in greenhouses because of their low cost and ease of use. Hobbyists and students often use it because it requires only basic knowledge of electronics. The Arduino UNO is a microcontroller, while the Raspberry Pi is a microcomputer or SBC [8]. The Raspberry Pi runs on the Linux operating system and has greater data processing capabilities than does the Arduino UNO, so it can be used to analyze data and apply machine learning. Analog without adjustment [14], [24].

In this research, the Raspberry Pi serves as the processing unit. We use the Raspberry Pi Model B SBC with an ARM-based processor and 512 MB of RAM. We employed Raspbian, an easy-to-use variant of Debian, for the operating system. A Wi-Fi dongle is necessary for a single-board computer to communicate through wireless networks. We chose Python3 due to its adaptability, interpreted programming language, simplicity, extensive library, and broad community support. We used MariaDB, a free and open-source MySQL fork that runs on the Linux operating system for environmental data storage. To develop a

microclimate information system, we select the PHP programming language, while we implement MySQL to store microclimate data on a cloud server. We host and build the cloud service on a cloud server using PHP and MySQL.

3.3. Device development

The Arduino UNO can monitor the local climate using the DHT11 sensor and the DHT library. The system can automatically gather information every 15 minutes and transmit it at 9600 bps through the serial interface. We use a USB cable to transmit data from the Arduino UNO to the Raspberry Pi. It also polls the microclimate data every 15 minutes and communicates with it via a serial connection. We used the MariaDB connector to input these data into the database, with the software operating in the background. The system can produce ninety-six daily microclimate data points.

Python3 and JSON-based applications allow data to be synchronized between the Raspberry Pi and the cloud service. The cloud service will generate a JSON file whenever the Raspberry Pi prompts it to provide the most recent data after receiving such a request. The system will compare the most recent data from the Raspberry Pi and the most recent data from the cloud service. The system will update the cloud service data if it discovers a disparity. The crontab program on the Raspberry Pi performs the synchronization process, which occurs once every fifteen minutes.

The cloud service presents the received data in table and line chart formats. The main page displays the two hundred most recent microclimate data points arranged from newest to oldest. The system generates Line chart web pages with the help of CanvasJS, a JavaScript-based application that transforms JSON data into charts. Additionally, the cloud service can present daily statistics on the microclimate based on the Asia/Jakarta time zone, which is 7 hours ahead of the GMT. The data from calendar-style drop-down menu return data for that day were selected as a table, and charts depicting the lowest, highest, average, and standard deviation of the data readings were generated. Cloud service is a technology that developed in the second decade of the 21st century due to the extensive use of the Internet in communications [25]. Cloud computing is used in developing a greenhouse surveillance system to store the results of greenhouse environmental data acquisition using a database and carry out data processing via the internet. This technology minimizes users' need for physical computing infrastructure, which may be expensive [26], [27].

4. RESULTS AND DISCUSSION

Table 2 summarizes the descriptive statistics for temperature (in degrees Celsius) and relative humidity (in percentages). The average or mean temperature is 27.42 °C, with a median of 27.30 °C and a mean of 27.70 °C. The standard deviation (STDev) represents how far apart the temperature values are, with an average deviation of 1.12 °C. A more minor standard deviation indicates less dispersed data. The dataset records a minimum temperature of 25.0 °C and a maximum temperature of 31.20 °C.

Table 2. Descriptive statistics summary for greenhouse microclimate surveillance data

	Mean	Median	Mode	STDev	Min	Max
Temperature (°C)	27.42	27.30	27.70	1.12	25.0	31.20
Relative humidity (%)	70.49	72.0	79.0	8.00	46.0	83.0

The results of the statistical calculations show that the mean air relative humidity is 70.49%, with a median of 72.00% and a median of 79.00%, which indicates that the relative humidity in the greenhouse is still below the lower threshold of 80% required by plants, so that the control carried out is to increase the humidity value. The standard deviation calculation represents the range between each measured air relative humidity value and its mean. The calculation of the standard deviation obtained a deviation of 8%, which indicates that the movement of air humidity data is relatively small when compared to the lowest measurement value of 46.00% and the highest measurement of 83.00%.

The calculation of temperature statistics shows consistent results for the mean, median and mode values, such that the standard deviation is only 1.12 °C. This implies that the temperature in the greenhouse moved by only 1.12 °C from the mean of 27.42 °C for 20 days of measurement. Similarly, the median (27.30 °C) and mode (27.70 °C) values coincide with the mean value, which means that the measured data are uniform. The mode is higher than the mean and median but with a smaller gap.

The mean relative humidity is 70.49%, with an 8% standard deviation, implying that the average difference between each humidity measurement and the mean value is approximately 8.0%. A more significant standard deviation suggests that the relative humidity data are more dispersed. The median relative humidity is 72.0%, which is quite close to the mean (72.0% vs. 70.49%), indicating that the

distribution of humidity data is uniform around the median value, with no substantial skewness. The mode is the most frequent value for the humidity, which is higher than the average and the median. This indicates that the data may have a mild positive skew, with more values in the higher humidity range. Nevertheless, the difference is not significant enough to definitively say that there is skewness [28].

We designed and developed a greenhouse microclimate surveillance system and subjected it to a 20-day field test to determine the effectiveness of the sensor in detecting microclimatic conditions, transmitting these data to the Raspberry Pi, and subsequently sending it to the cloud service. We conducted this evaluation by simultaneously activating the surveillance units. Users can use SSH to remotely examine sensor data on the Raspberry Pi and compare it with the database housed within the cloud service. We continuously evaluated the device's performance for 24 hours daily for 20 days.

A cloud service hosted on a cloud server is utilized for microclimatic data analysis. The service comprises two web pages with similar functions. The landing page displays two hundred rows of microclimate data points in graphs and tables. The secondary page presents microclimate data per day in graphical and table layouts based on the data selected in the date selection component. The page shows the microclimate data from the preceding day by default, offering a snapshot of the lowest and highest values, averages, and standard deviations of air temperature and humidity.

Linear regression analysis demonstrated the relationship between temperature (X , degrees Celsius) and relative humidity (y , percentage). Linear regression is a method that determines the connection between a dependent variable (y) and one or more independent variables (X) [29]. In this instance, in (1) illustrates how temperature and humidity are associated:

$$y = -6.12X + 238.33 \quad (1)$$

$$\begin{aligned} \text{if } X &= 26 \\ \text{then } y &= 79.19 \end{aligned} \quad (2)$$

where R^2 is 0.73, the slope coefficient (a) is -6.12, and the intercept (b) is 238.33. If we substitute $X = 26$ into (1), we obtain $y = 79.19$ (2).

An R^2 value of 0.73 indicates how well the linear regression model corresponds to the observed data. R-squared ranges from 0 to 1, with one being the optimal fit and zero being the poorest. An R-squared of 0.73 means that the shift in temperature will influence 73% of the variation in humidity. This demonstrates a moderately strong link between the two variables. The “ a ” value, the slope coefficient, is -6.12. This reveals how the humidity (y) changes for every one-unit increase in temperature (X). In this instance, the humidity decreases by approximately 6.12% per °C of temperature increase. The negative sign indicates that the relationship between temperature and humidity is inverse, as shown by the red line in Figure 2.

The intercept, denoted by the value b , is 238.33. This approximates the relative humidity at 0 degrees Celsius (X). In other words, the model asserts that if the temperature was zero, the moisture content would be 238.33%, which is not an accurate value in the real world. However, it is essential to remember that the intercept is not particularly meaningful because it is beyond the typical temperature range.

According to the linear regression equation ($y = -6.12X + 238.33$), when the temperature (X) is 26 °C, the predicted humidity (y) is 79.19%. The model suggests that temperature and relative humidity have a moderately strong negative correlation. The R-squared value, slope coefficient, and intercept inform us about the strength and direction of this correlation. The precise X and y values enable us to use the model to make predictions.

We analyzed the relationship between variable y (relative humidity) and variable X (temperature) in the greenhouse using a scatter plot, as shown in Figure 2. The dependent variable (y) measures relative humidity in conjunction with air temperature as the independent variable (X). We collected 1,971 data points for 20 days. The data distribution and the R-squared measurements show a strong relationship between the two parameters (0.73), which indicates that a rise in relative humidity will accompany a decrease in greenhouse air temperature [30].

4.1. Performance evaluation

The designed surveillance system's performance assessment depends on precision, dependability, and user-friendliness. The system uses the DHT11 sensor module to achieve precision and accurately measure temperatures. Figure 3 shows that the system can precisely detect and record microclimate conditions in the greenhouse, as evidenced by the logged data. Figure 3(a) with blue lines shows the movement of air temperature in the greenhouse for 20 days, while Figure 3(b) shows the movement of relative humidity in the greenhouse for 20 days with green lines. These two graphs reinforce our assertion

that air temperature and air relative humidity in a greenhouse are inversely proportional, a decrease in air temperature will raise the relative humidity.

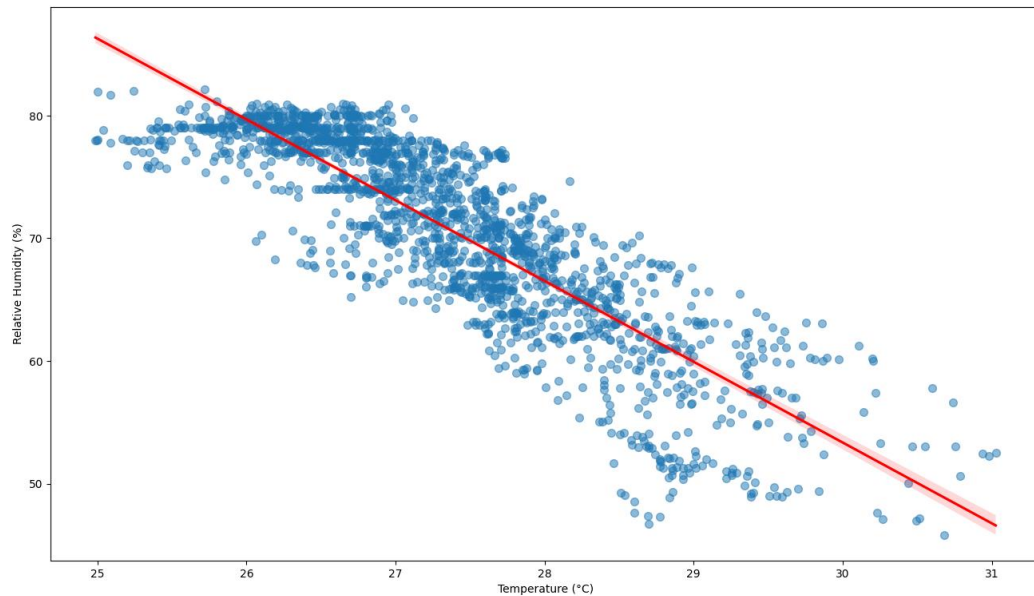


Figure 2. Relationship between temperature and humidity in greenhouses

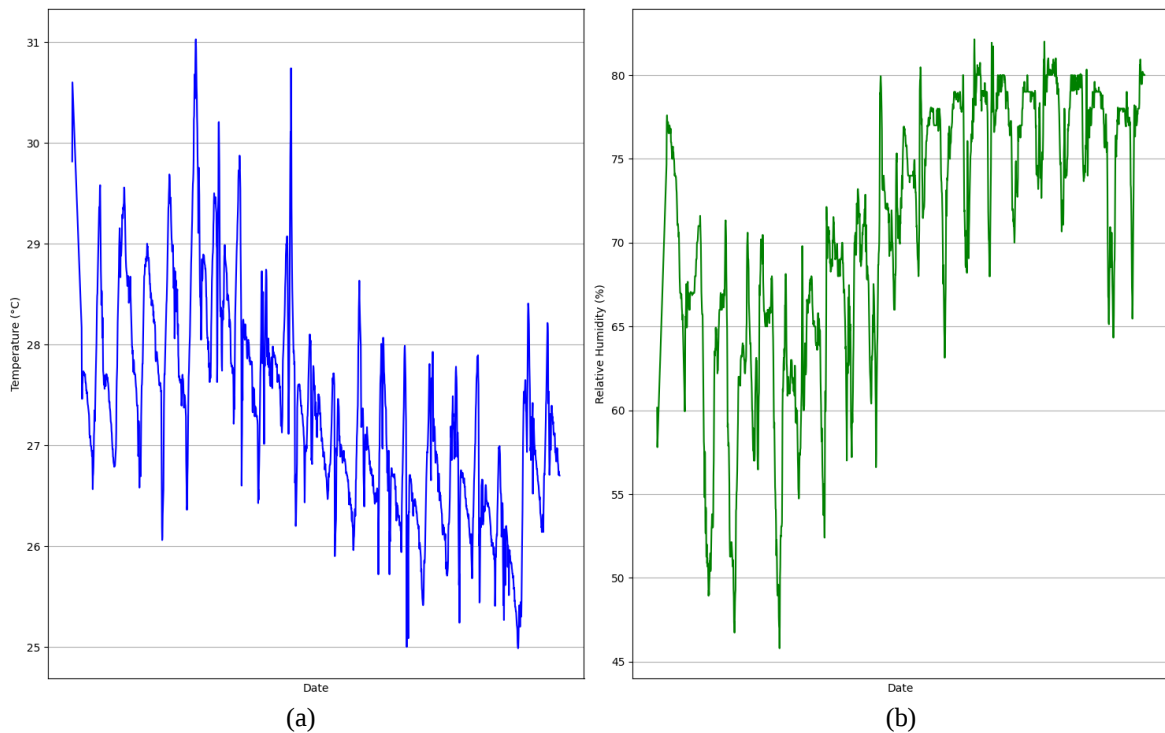


Figure 3. Greenhouse microclimate (a) temperature and (b) relative humidity data over time

Regarding dependability, we tested the system for 20 days without critical issues. When we powered down the surveillance or control units, the system stopped recording data. The system could send data to the cloud service via the internet when the Raspberry Pi had internet connectivity, and we synchronized it every fifteen minutes. We can use alternative devices or backup systems to improve dependability and prevent data loss.

Regarding user friendliness, the cloud service provides an intuitive interface that allows users to access the most recent greenhouse microclimate data and daily data for analysis and decision-making. We present the data in chart and tabular formats, simplifying user data comprehension. We can also add notifications, alerts, and automated actions based on predefined conditions to improve the system's user friendliness.

4.2. Comparison with prior works

Our proposed greenhouse microclimate surveillance system has similarities in terms of hardware with prior works primarily using Arduino UNO as the microcontroller and differences in sensors used; prior works mainly used DHT22 or BME280 sensor modules to measure temperature and humidity in greenhouses [8], [10]. Our proposed system uses Arduino UNO and DHT11 sensor modules, which provide accurate digital output measurements at tropical temperatures. Regarding the processing unit, various microcomputers, such as Raspberry Pi, Beaglebone, and NodeMCU, were utilized in prior works [9], [11], [27]. Our proposed system implements Raspberry Pi as a processing unit for optimal resource management and low power consumption. Raspberry Pi has proven dependable enough to function as a headless server.

Previous works [10], [11]. Different programming languages and libraries, such as C++, Python, and Node.js, were used. However, we propose using Python3 as the primary programming language for data communication and processing in our system. Python3 is a versatile interpreted programming language that is easy to comprehend, boasts a comprehensive library, and enjoys widespread community support. Regarding data visualization, various methods, such as web-based dashboards, mobile apps, and SMS notifications [13], [27], have been utilized in prior works. However, our proposed system employs a cloud-based web application for data visualization. This web application provides an intuitive interface for users to access the latest greenhouse microclimate data. It also displays the most recent two hundred microclimate data points in tabular and line chart formats and everyday microclimate information for a particular date.

Our proposed system offers benefits such as accurate readings at tropical temperatures, reliable management of resources and power consumption, support for a programming language, and an intuitive interface compared to prior works. Users can easily add additional plant growth-related sensor systems.

5. CONCLUSION

In this research, we used Arduino UNO and Raspberry Pi to design and implement a microclimate surveillance system for a greenhouse. Integrating this hardware and the DHT11 sensor module provides the opportunity to build a system capable of real-time surveillance of greenhouse temperature and relative humidity levels. A Raspberry Pi is used as a temporary data processing and storage unit. To carry out permanent data storage and visualization, web hosting is used through a user-friendly interface that can be accessed via a web application on a desktop or mobile device. Evaluation of the system through field trials for 20 full days showed that the system could acquire and store data on microclimate conditions in the greenhouse every fifteen minutes. This computerized surveillance capability provides the advantage of faster, more precise and accurate measurements compared to manual measurements to offer farmers a more attractive and efficient alternative for obtaining updated microclimate information about their greenhouses. Based on the results of the analysis of previous research, we highlighted the need for a practical, efficient and low-cost surveillance system for farmers who have small- and medium-scale greenhouses, so we developed an alternative system that is cost-effective by utilizing hardware and components that are affordable and easy to obtain. However, this system relies on connectivity via a USB cable to connect the Arduino UNO and Raspberry Pi, which can limit the system installation location, potentially increasing costs if the greenhouse is expanded.

Future research could explore wireless communication protocols to overcome these limitations and improve scalability significantly as the number of managed greenhouses increases. Statistical analysis of the acquired data provided insight into the relationship between the temperature and relative humidity of the air in the greenhouse. Descriptively, the calculation results show that the distribution of temperature data is relatively even, with data values that coincide, while the relative humidity data show a moderate distribution. In addition, linear regression analysis highlights the inverse relationship between temperature and humidity, where the relative humidity of air decreases with increasing temperature. Understanding the relationship between temperature and air relative humidity allows farmers to proactively manage the microclimate conditions in their greenhouses. Another idea that needs to be considered in future research is to integrate additional sensors to obtain a greater quantity of data, improve data quality and expand the range of parameters monitored, including light intensity, soil moisture and carbon dioxide levels, to help farmers understand environmental conditions Greenhouse. Quality information can help farmers adjust microclimate conditions based on the crops planted to increase production. System enrichment must also be performed by

implementing more complex data analysis calculations or applying artificial intelligence (AI) to the system to provide other, more sophisticated options in further research. Implementing machine learning algorithms can also identify data patterns and trends and enable predictive analysis and automation of decision-making, making it easier for farmers to manage their greenhouses. The development of a user-friendly interface to make it easier for farmers to read information in real time is also necessary. With the help of intuitive controls and data visualization tools, greenhouse operators can make informed decisions to manage their operations efficiently. Ongoing research efforts should prioritize the scalability and affordability of surveillance systems to ensure accessibility for a wide range of greenhouse operators, including small- and medium-scale farmers. A statement that what is expected, as stated in the “INTRODUCTION” section can ultimately result in “RESULTS AND DISCUSSION” section, so there is compatibility. Moreover, it can also be added the prospect of the development of research results and application prospects of further studies into the next (based on result and discussion).

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AUTHOR CONTRIBUTIONS STATEMENT

Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Irfan Ardiansah		✓	✓		✓	✓		✓	✓				✓	
Sophia Dwiratna Nur Perwitasari		✓			✓	✓		✓	✓					
Roni Kastaman	✓			✓		✓				✓		✓		
Totok Pujianto	✓			✓		✓				✓				

C : Conceptualization

M : Methodology

So : Software

Va : Validation

Fo : Formal analysis

I : Investigation

R : Resources

D : Data Curation

O : Writing - Original Draft

E : Writing - Review & Editing

Vi : Visualization

Su : Supervision

P : Project administration

Fu : Funding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

DATA AVAILABILITY

- Derived data supporting the findings of this study are available from the corresponding author [IA] on request.
- The data that support the findings of this study are available from the corresponding author, [IA], upon reasonable request.

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