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Improving Mushroom Cultivation Efficiency through Mobile App-based Data Visualization

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Abstract. *The increasing global population has spurred a greater need for agricultural products, particularly mushrooms, which are valued for their exceptional nutritional content and rapid growth rates. To optimize mushroom cultivation, it's vital to monitor environmental factors like temperature and humidity for ideal growth conditions. This study introduces an Internet of Things (IoT)-based mobile app for ongoing monitoring of temperature and humidity within mushroom cultivation structures, using sensor, microcontroller, LCD display, and mobile apps. The setup involves strategic placement of system components to efficiently gather data. The mobile app boasts a user-friendly interface for easy navigation and access to critical insights. The assessment of data transmission gives efficient information flow, less than 2% missclicks and 96% effectivity score, with minimal delays. Notably, the mobile app's features exhibit high accuracy and efficacy in delivering real-time updates on cultivation conditions. Furthermore, a survey using a Likert scale garnered positive user feedback, affirming the app's potential value in mushroom farming. This innovative system holds promise in elevating sustainability and profitability in the mushroom cultivation sector.*

Keywords: *IoT, monitoring system, mushroom cultivation, mobile application*

1. Introduction

The escalating global population has spurred a concomitant increase in the demand for horticultural products. This surge in demand is particularly pronounced in the realm of mushrooms, renowned for their rich nutritional composition (Dimopoulou et al., 2022; Rahmawati & Marbudi, 2021; Raman et al., 2018). The popularity of mushrooms for food is increasing rapidly due to their delicious taste, sufficient protein content, and high and delicious health value (Assemie & Abaya, 2022; Das et al., 2021; You et al., 2022). As a result, mushrooms have gained immense popularity as a sought-after culinary ingredient and a preferred choice for individuals seeking to enhance their dietary intake with nutrient-dense options.

In recent times, the cultivation of mushrooms has garnered significant attention in terms of comprehending the intricacies of the environment and the essential factors that contribute to optimal mushroom growth. Among these factors, climatic conditions play a crucial role and necessitate meticulous adjustment to cater to the specific requirements of different mushroom species (Klinlek et al., 2020; Procházka et al., 2023). Key parameters that demand careful consideration encompass temperature, air quality, humidity levels, and adequate lighting conditions, each tailored to meet the demands of the cultivated mushroom variety (Bellettini et al., 2019; Chen et al., 2022; Kavaliauskas et al., 2022).

Within the realm of mushroom cultivation, maintaining an ideal temperature range spanning from 20 to 30°C, alongside a relative

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humidity (RH) range of 60 to 90% (Ariffin et al., 2020; Chong et al., 2023; Najmurrokhman et al., 2019; Sihombing et al., 2018), assumes paramount importance. Consequently, geographical locations endowed with high-altitude attributes have emerged as favourable settings for mushroom cultivation owing to their inherent advantages of appropriate humidity levels and ambient air temperature (Diez et al., 2020; Gu et al., 2019; Herrero et al., 2019; Istiyanti et al., 2020).

However, mushroom cultivation often encounters challenges in practice, particularly related to inadequate monitoring of the cultivation environment, which can negatively impact the quality of mushroom yields (Chen et al., 2022; Rahman et al., 2022). Furthermore, farmers frequently face crop failures when environmental conditions are not adequately monitored (Moxley et al., 2022; Setiawati et al., 2021; Sher et al., 2010). With the rapid advancements in technology, the Internet of Things (IoT) presents an opportunity to develop an efficient and reliable monitoring system for mushroom cultivation facilities (Bramantara et al., 2020; Chong et al., 2023; Rahman et al., 2022; Thapwiroch et al., 2021).

2. Literature Review/ Hypotheses Development

In prior studies, Bounnady et al. introduced an IoT system based on NodeMCU ESP8266, incorporating sensors and cloud computing, which outperformed traditional farming with a 41.2% growth rate increase and a 70% boost in productivity. Additionally, water savings exceeded conventional methods by 20.9% (Bounnady et al., 2019). Mahmud et al. developed a mushroom cultivation environmental monitoring system using DHT11 temperature humidity sensors and MQ135 CO_2 sensors linked to an ESP8266 WiFi module. This system autonomously controlled irrigation to maintain optimal temperature (Mahmud et al., 2018). Nasution et al. applied IoT and wireless sensor network (WSN) technology for agricultural purposes, achieving successful temperature control and improved oyster mushroom cultivation compared to uncontrolled conditions (Nasution et al., 2019). Thus, the integration of technology that can continuously monitor the environmental conditions of the mushroom growing medium, ensuring it aligns with the natural habitat, becomes imperative.

Besides that, there is a demand that the system and application that is made must be easy to use by mushroom farmers as the user (Arifin & Maharani, 2021; Khokhar et al., 2014; Santoso et al., 2018). However, there have not been many studies related to the development of IoT systems in agriculture that are accompanied by adaptability to farming communities. For this reason, a series of assessments is needed about the usability of the applications and systems that are made, according to what the user needs and expects.

This article aims to explore the development of an IoT-based system for monitoring temperature and relative humidity within mushroom cultivation facilities, especially in Indonesia, and assessing its adaptability in farming communities. This system incorporates sensors and wireless communication system to collect and transmit real-time environmental data. The gathered data can be conveniently accessed remotely through a user-friendly mobile application, enabling growers to effectively monitor and control the environmental conditions. The hope is that optimal crop yield, quality and uniformity will be obtained through precise monitoring of vital variables, especially temperature and relative humidity. By implementing this system, there is a prospective reduction in labour expenses and a decrease in the vulnerability to crop failure arising from environmental influences. As a result, the mushroom cultivation industry stands to benefit from improved sustainability and increased profitability.

3. Methodology

The research was conducted in a mushroom cultivation house owned by a private small-scale cultivator in Cangkringan District, Sleman Regency, Yogyakarta Special Region Province, Indonesia. The specific location was carefully chosen based on its suitability for implementing the monitoring concept under investigation. The system design involved the integration of a sensor network comprising microcontrollers, modules, and their corresponding network connections. Additionally, a mobile application was developed to facilitate the visualization of sensor readings. System and application development is carried out in a user-centric manner, where the mushroom farming community provides feedback on our system development. Once the system development phase was completed, the implemented tool was installed in a mushroom house. The tool was strategically positioned on a pole at the periphery of the cultivation room to optimize data collection. Reliability testing was conducted by continuously sampling data over the span of one month in the designated location. This extended testing period allowed for the evaluation of the system's performance under varying environmental conditions.

Usability testing of the mobile application was carried out to assess its practical application among mushroom farmers. This testing phase aimed to measure the user-friendliness and effectiveness of the application in providing relevant information and facilitating necessary control actions for the cultivation process. A short survey was also conducted, with mushroom farmers as respondents, to evaluate the performance of the application and farmers' opinions regarding this application. Subsequently, the collected data, along with the obtained results, were subjected to thorough statistical analysis, specifically using the method of calculating the average (mean) and standard deviation (standard deviation). This analysis provided insights into the system's performance, including its reliability and usability aspects. The result from the statistical analysis will be the inputs for further refinement and development of the monitoring and control system for mushroom cultivation.

System Architecture

The architecture of our system comprises several components for the design, implementation, and performance evaluation of an IoT-based mobile application aimed at monitoring systems in mushroom cultivation houses.

The IoT architecture under consideration comprises four fundamental layers, each serving a distinct purpose. At the foundation, the sensor/perception layer is responsible for gathering environmental data, including parameters like temperature and humidity, from various monitoring locations. Above that, the network layer facilitates the seamless transmission of this collected data to the cloud infrastructure, ensuring reliable connectivity throughout the process. Subsequently, the middleware layer takes charge of data processing and management within the cloud environment, encompassing tasks such as data storage, analysis, and eventual delivery to applications. Finally, the application layer serves as the user-facing interface, granting access to real-time data through mobile applications, typically designed for Android-based platforms. Mushroom farmers as users will be behind the application layer, and utilize this system interface for monitoring functions.

The hardware components utilized in our system include the NodeMCU ESP8266 microcontroller and UART WiFi Module, the DHT11 sensor, the LCD I2C display, the micro-USB for power circuitry, and an adapter. The DHT11 sensor is responsible for continuously measuring the environmental temperature and humidity at specified intervals. This sensor was chosen because it is easy to interface with a microcontroller due to its single-wire communication protocol, very affordable, low power consumption, and sufficient for environmental monitoring such as in a mushroom house where precise conditions are less critical compared to other applications. Apart from that, the ESP8266 microcontroller module was chosen because it is simple for IoT communications, allows data transmission to the cloud, at an affordable price.

The sensor readings are then displayed in real-time on the LCD I2C screen located within the mushroom house. Simultaneously, the measured data is transmitted to the cloud network through a WiFi connection previously established with the system. From the cloud, the data is further sent to a web server and subsequently displayed in a mobile application based on the Android platform. The working scheme of this system is shown in the block diagram in Figure 1.

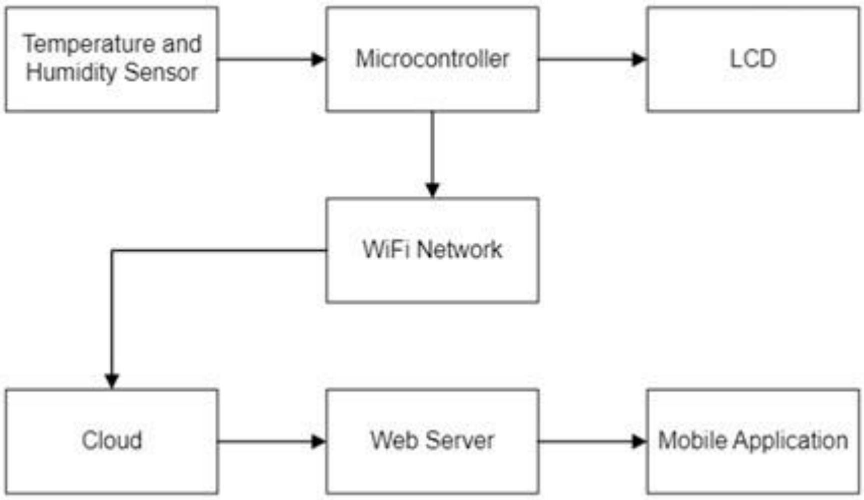

Figure 1.
Block Diagram of The Proposed Monitoring System.

To implement the system, the NodeMCU microcontroller is programmed using the Arduino IDE, which provides a convenient and user-friendly development environment for IoT applications. The Android-based mobile application is created using Android Studio, a widely-used integrated development environment (IDE) specifically designed for Android app development. By leveraging the Arduino IDE and Android Studio, we are able to seamlessly integrate the functionalities of the NodeMCU microcontroller and the mobile application, respectively. This integration enables the collection, transmission, and visualization of real-time environmental data from the mushroom cultivation houses, providing a comprehensive monitoring solution for the farmers. The architecture of our system showcases the synergy between hardware and software components, facilitating efficient data acquisition, seamless connectivity, and user-friendly data visualization.

Mobile Application Design

The mobile app design aims to provide users with a seamless and intuitive user experience, ensuring straightforward navigation and easy access to critical information. The interface prioritizes visual appeal and user-friendliness, allowing mushroom farmers to effortlessly monitor and control environmental conditions within their cultivation facilities. The mobile application's user interface design is shown in Figure 2.

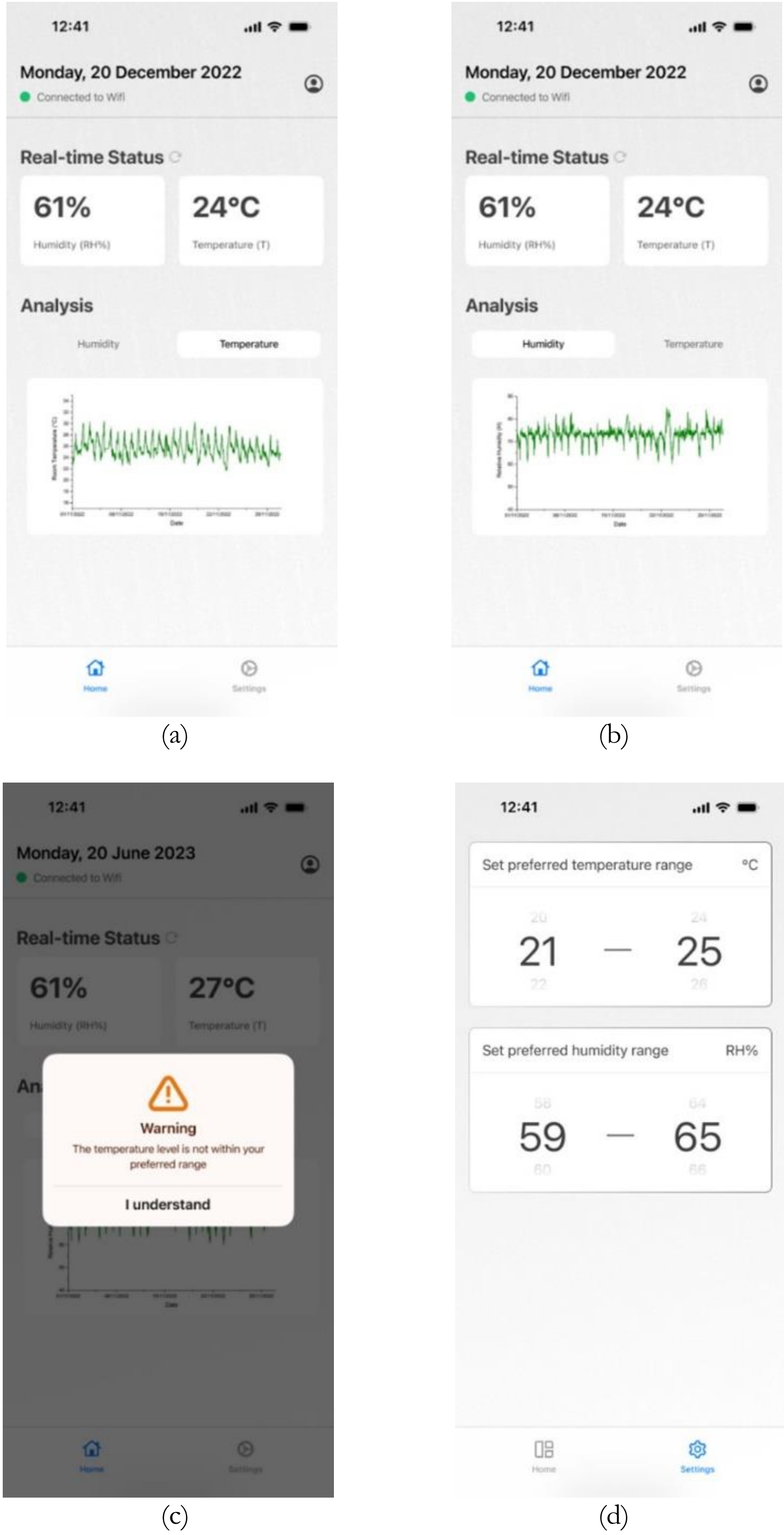

Figure 2.
Mobile application's user interface design (a) on a page that displays room temperature, (b) on a page that displays room relative humidity, (c) a pop-up notification when the measured temperature value is outside the specified range, and (d) setting page to set the preferred temperature and humidity range.

Upon launching the application, users are presented with a visually engaging homepage that offers a clear and concise overview of essential information. At the top of the page, the date is prominently displayed, enabling users to quickly orient themselves and stay updated with the latest data.

The design incorporates a connection status indicator, providing real-time feedback on the app's connectivity with the monitoring system. This objective feature ensures users are informed about the reliability of the displayed data, enhancing their confidence in the accuracy and timeliness of the information. The homepage prominently displays key environmental variables, such as humidity level and temperature, in a format that is easily comprehensible and recognizable. The humidity level is expressed as a percentage, while the temperature is presented in either Celsius or Fahrenheit, depending on the user's preference.
To facilitate a comprehensive understanding of environmental trends, interactive charts are integrated into the homepage. These charts visually depict the historical data for humidity and temperature over the past seven days. Users can efficiently grasp fluctuations and patterns, enabling data-driven decision-making regarding cultivation practices. The interface allows users to seamlessly zoom in or out on specific time frames, providing a detailed view of the data within a scientific and objective framework. Through intuitive design choices and easy access to customization options, the interface empowers users to objectively monitor and control their mushroom cultivation environments, optimizing practices and mitigating the risk of crop failure.

4. Findings and Discussion

System Installation
The installation took place in a specific mushroom cultivation house situated in Cangkringan District, Sleman Regency, within the Yogyakarta Special Region Province of Indonesia. This installation was tested only in one of the mushroom cultivation rooms, specifically for oyster mushroom cultivation (*Pleurotus ostreatus*). It is worth noting that Sleman Regency holds significant importance in the mushroom production industry, being recognized as the largest mushroom-producing area in the region (Rahmawati & Marbudi, 2021). The selected mushroom house for this installation belongs to a small-scale private cultivator and is positioned on a pole at the periphery of the cultivation room. In the installation, the sensor is placed on one of the pillars in the mushroom cultivation room, as shown in Figure 3, while the results of the installation are shown in Figure 4.

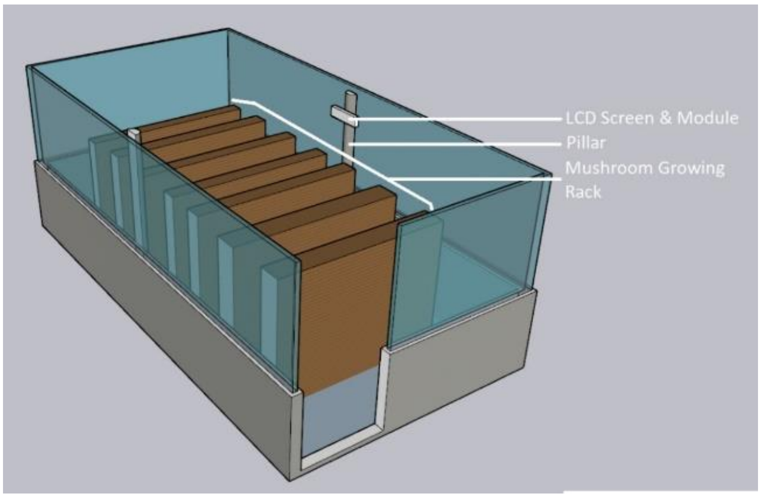

Figure 3.
Placement of sensors and modules in mushroom cultivation houses.

Figure 4.
System Installation in Mushroom Cultivation House.

The installation process involved strategically placing the components of the system to ensure optimal functionality and data collection. The NodeMCU ESP8266 microcontroller, along with the UART WiFi Module, was positioned within the mushroom house to facilitate proximity to the DHT11 sensor, which is responsible for monitoring the temperature and humidity levels. The LCD I2C display was integrated into the structure of the mushroom house, enabling real-time visualization of the sensor readings. Power circuitry, including a micro-USB and adapter, was established to ensure a stable power supply to the entire system. Furthermore, a WiFi network was set up to enable the seamless transmission of data from the NodeMCU microcontroller to the cloud.

The chosen location for the system installation offers several advantages. By installing the monitoring tool within the mushroom house, it allows for direct and accurate data collection in close proximity to the mushroom cultivation environment. The placement on a pole at the edge of the cultivation room ensures minimal interference with the cultivation activities while still capturing crucial environmental data. This installation approach provides convenience for the cultivator, allowing them to easily monitor the temperature and humidity conditions in real-time without disrupting their routine operations. Ultimately, the carefully planned and executed system installation ensures reliable data acquisition and sets the foundation for efficient monitoring of mushroom cultivation houses.

Data Measurement

In this study, the data measurement was conducted to monitor the environmental conditions inside the mushroom cultivation houses during the entire month of November 2022. The measurements were taken round the clock, with a 24-hour interval, and each measurement was recorded at 10-minute intervals. The purpose of this measurement was to gather comprehensive information regarding the temperature and humidity levels within the cultivation houses, which are crucial factors for the successful growth of mushrooms. The measured data is shown in Figure 5 (room temperature) and Figure 6 (relative humidity). While the maximum-minimum, average, and standard deviation values of these measurements are shown in Table 1.

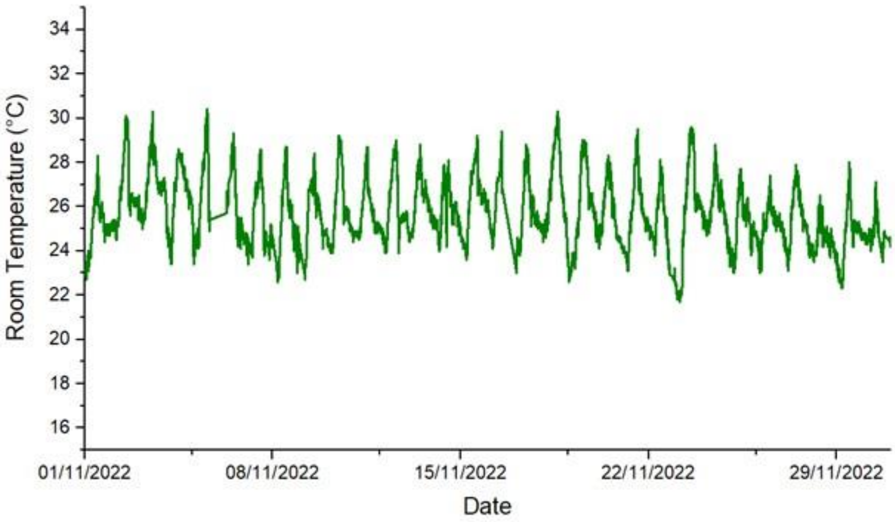

Figure 5.
Measured Temperature in Mushroom Cultivation For One Full Month.

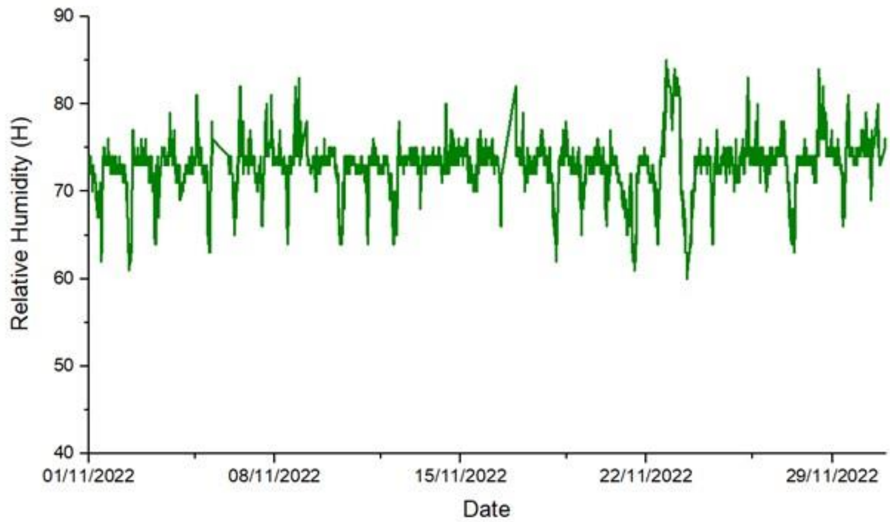

Figure 6.
Measured Humidity in Mushroom Cultivation For One Full Month.

Table 1.
Measured Values of Temperature and Humidity In The Mushroom Cultivation Room.

Parameters	Maximum Value	Minimum Value	Average	Standard Deviation
Temperature (°C)	30.40	21.70	25.726	1.497
Humidity ($\%_{RH}$)	85.00	60.00	72.769	2.946

The temperature readings obtained from the sensors ranged from a minimum of 21.70°C to a maximum of 30.40°C, with an average temperature of 25.73°C. These measurements provide valuable insights into the thermal conditions experienced within the cultivation houses throughout the month. Such temperature fluctuations could be attributed to various factors, including external climatic conditions, ventilation systems, and the heat generated by the growing mushrooms themselves.

Additionally, the humidity levels recorded during this period ranged from a minimum of 60.00% to a maximum of 85.00%, with an average humidity of 72.77%. These measurements offer crucial information about the moisture content within the cultivation houses. Maintaining the appropriate humidity level is essential for the growth and development of mushrooms, as it directly affects their ability to absorb nutrients and prevents the formation of mold or other undesirable fungal growth (Diez et al., 2020; Gu et al., 2019; Herrero et al., 2019; Istiyanti et al., 2020).

Latency Percentage of Data Sent

Latency and percentage of data sent are analysed in this study. Latency average refers to the time it takes for a data packet to travel from the source to the destination and back again. On average, the latency was recorded as -0.0067094386 seconds, with a standard deviation of 0.08089274 seconds. This indicates that the data packets generally travelled back and forth within a very short timeframe, as evidenced by the negative value of the average latency.

The percentage of data sent measures the efficiency of data transmission, specifically the ratio of successfully sent data packets to the total number of attempted data packets. The average percentage of data sent was calculated to be 96.88%, with a standard deviation of 0.213066835. This suggests that the data transmission was highly successful, with almost 97% of the attempted data packets reaching their intended destination. These findings are presented in the following Table 2.

Table 2.
Latency And Percentage of Data Sent of System Tested.

Parameters	Average	Standard Deviation
Latency	-0.00671 s	0.08090
Data Sent	96.88%	0.21307

The negative average latency value may be due to the presence of measurement errors or noise in the data. However, it is important to note that this value is within a very small range, indicating a consistently low latency throughout the data transmission process. The high average percentage of data sent indicates a robust and reliable data transmission system. The low standard deviation for both parameters further strengthens the validity of the results, suggesting that the data points are closely clustered around the average values.

Mobile Application Usability

In testing the usability of this system, testing is focused on getting an overview of the user's assessment of this application. The app includes various features such as the dashboard, data chart, setting, and notification. The assessment parameters given focus on the assessment for the number of missclicks, effectiveness in carrying out tasks, user duration in using features, and how time efficient the user is in using the features. The results of this usability test are summarized in Table 3.

Table 3.
Results Of Usability Testing for Various Features In The Mobile App Designed.

Features	Missclicks	Effectivity	Duration	Time Efficiency
Dashboard Feature	2	96%	4 s	0.10 task/s
Data Chart Feature	4	94%	5 s	0.12 task/s
Setting Feature	8	83%	11 s	0.07 task/s
Notification Feature	5	88%	8 s	0.08 task/s

The dashboard feature demonstrated high accuracy with 2% missclicks and a remarkable 96% effectivity score. It efficiently displayed real-time status for humidity and temperature in 4 seconds with a time efficiency of 0.10 tasks per second. The data chart feature had 4% missclicks and a 94% effectivity score, enabling users to interpret data charts effectively in 5 seconds with a time efficiency of 0.12 tasks per second.

Conversely, the setting feature had 8% missclicks, indicating potential challenges in user interaction accuracy. Its 83% effectivity score suggested difficulties in configuring preferred temperature and humidity settings, requiring user interface optimization. The 11-second duration and 0.07 tasks per second time efficiency emphasized the need for enhancements to offer valuable customization options for users. The notification feature achieved moderate accuracy with 5% missclicks and an 88% effectivity score. Users efficiently received notifications within 8 seconds with a time efficiency of 0.08 tasks per second, enabling timely response and intervention in cultivation.

Besides that, we also conducted a survey using a Likert scale (ranging from 1 to 5) to assess users' perceptions of an IoT monitoring application designed for mushroom cultivation. The questionnaire consisted of five questions related to the application's suitability, usability, and potential benefits in managing mushroom cultivation. Participants were asked to rate their responses on a scale from 1 (strongly disagree) to 5 (strongly agree). The results from the survey indicated positive feedback from the participants regarding the application's effectiveness and usability, as shown in Table 4.

Table 4.
Questionnaire Result for Assessing the Mobile App Designed.

Question	Average Score (1-5)
1. Do you feel that this application meets your needs as a mushroom farmer?	4.72
2. Do you feel that this application will help you in managing mushroom cultivation?	4.85
3. Do you feel that this application is easy to use?	4.67
4. Do you feel that this application makes it easier for you to monitor the conditions of the mushroom cultivation room?	4.88
5. Would you use this application in your mushroom cultivation business?	4.75

The survey results showed positive feedback from users regarding the IoT monitoring application for mushroom cultivation. The application received an average score of 4.72 for meeting users' needs and 4.85 for its potential in managing mushroom cultivation. Users also praised its user-friendliness, with an average score of 4.67 for ease of use, and its efficiency in monitoring conditions, scoring 4.88. The survey further indicated users' willingness to integrate the application into their mushroom cultivation business, with an average score of 4.75. Overall, the survey provided valuable insights into the application's potential usefulness in the domain of mushroom farming.

The development of an environmental monitoring system for fungi like this has the potential to have a significant impact on management and business aspects. Managerially, this system can increase operational efficiency by enabling real-time regulation of the mushroom growth environment via a mobile application, as well as providing more accurate monitoring of environmental conditions. This can help management make more timely and data-based decisions to optimize harvest yields and control production costs. On the business side, the integration of advanced technologies such as more precise sensors and the use of artificial intelligence algorithms can improve product quality and production consistency, thereby increasing customer confidence and market share.

Mobile Application Usability

For the future development of an environmental monitoring system for this fungus, the integration of more sophisticated technology such as sensors that are more precise and sensitive to other environmental parameters that influence mushroom growth can be considered (Chong et al., 2023; Kavaliauskas et al., 2022). This expansion can lead to a more thorough and precise assessment of cultivation conditions, enabling proactive measures for optimizing yields.

Besides that, the integration of actuators into the system for regulating environmental conditions within cultivation houses should be considered. These actuators, such as fans and lights, can be controlled remotely through the application, allowing for real-time adjustments to create an ideal growth environment for mushrooms (Kour et al., 2022; Mohammed et al., 2018; Rehman et al., 2020). This level of automation can significantly enhance operational efficiency.

The use of artificial intelligence algorithms for data analysis can improve understanding of optimal environmental conditions for mushroom. The system can benefit from the implementation of adaptive learning algorithms that utilize data from sensor readings to improve system performance (Manikandan et al., 2022; Ramli et al., 2020). Integration with a wider Internet of Things (IoT) platform can also expand monitoring coverage and enable more seamless interaction with mobile applications. This development is expected to not only increase the efficiency of mushroom production, but also increase the adaptability of the system to complex and dynamic environmental variations.

Apart from that, further development is also needed to overcome several problems such as security and potential failure. In the context of security in IoT applications, data protection during transmission and storage is very important to prevent unauthorized access and data manipulation. One solution that can be implemented is to use an encryption protocol for data communication between the NodeMCU ESP8266 and the cloud server, such as HTTPS or MQTT with TLS/SSL. This ensures that data sent from the DHT11 sensor via WiFi is encrypted and cannot be read by unauthorized parties.

Additionally, on the data storage side on cloud servers, it is recommended to implement controlled access with strong authentication, such as using token-based authentication mechanisms or dynamically generated API keys. By integrating this layer of security, the system can ensure that environmental data measured for mold remains protected and accessible only to authorized parties.

Apart from that, device failure is also possible. One solution that can be implemented is to install data security, for example by sending periodic measurement data and verifying data integrity on the cloud server. Additionally, considering the use of backup sensors or redundancy in the system can ensure that measurements continue even if a failure occurs in one part of the system.

5. Conclusions

The mobile app, based on IoT technology, created for overseeing conditions in mushroom cultivation sites, demonstrated effectiveness and efficiency. The installation process smartly positioned system components to optimize their function and data collection. The app's design focused on visual attractiveness and user-friendliness, ensuring easy navigation and access to crucial details. Examination of parameters such as latency, data transmission, user errors, effectiveness, duration, and time efficiency affirmed the system's dependable performance in promptly updating the status of temperature and humidity in cultivation spaces. Survey findings further validated positive user perceptions, highlighting the app's appropriateness, ease of use, and potential advantages in managing mushroom growth. Future development is needed to obtain a more precise system and integrate it with actuators to optimize cultivation conditions, improve operational efficiency, and adapt to dynamic environmental changes while addressing security through encryption protocols and ensuring system reliability with redundancy measures.

References

Ariffin, M. A. M., Ramli, M. I., Amin, M. N. M., Ismail, M., Zainol, Z., Ahmad, N. D., & Jamil, N. (2020). Automatic Climate Control for Mushroom Cultivation using IoT Approach. *2020 IEEE 10th International Conference on System Engineering and Technology (ICSET)*, 123–128. doi: 10.1109/ICSET51301.2020.9265383

Arifin, S., & Maharani, L. (2021). Assessing User Experience of a Mobile Application Using Usability Questionnaire Method. *Applied Information System and Management (AISM)*, *4*(1), Article 1. doi: 10.15408/aism.v4i1.20265

Assemie, A., & Abaya, G. (2022). The Effect of Edible Mushroom on Health and Their Biochemistry. *International Journal of Microbiology*, *2022*, 8744788. https://doi.org/10.1155/2022/8744788

Bellettini, M. B., Fiorda, F. A., Maieves, H. A., Teixeira, G. L., Ávila, S., Hornung, P. S., Júnior, A. M., & Ribani, R. H. (2019). Factors affecting mushroom Pleurotus spp. *Saudi Journal of Biological Sciences*, *26*(4), 633–646. doi: 10.1016/j.sjbs.2016.12.005

Bounnady, K., Sibounnavong, P., Chanthavong, K., & Saypadith, S. (2019). Smart Crop Cultivation Monitoring System by Using IoT. *2019 5th International Conference on Engineering, Applied Sciences and Technology (ICEAST)*, 1–3. doi: 10.1109/ICEAST.2019.8802584

Bramantara, A. H., Wicaksono, A. S., Setiawan, M., Yuliyana, M. Q., & W, A. P. W. (2020). IoT-Based Mushroom Cultivation Monitoring Information System. *Solid State Technology*, *63*(4), Article 4.

Chen, L., Qian, L., Zhang, X., Li, J., Zhang, Z., & Chen, X. (2022). Research progress on indoor environment of mushroom factory. *International Journal of Agricultural and Biological Engineering*, *15*(1), Article 1. doi: 10.25165/ijabe.v15i1.6872

Chong, J. L., Chew, K. W., Peter, A. P., Ting, H. Y., & Show, P. L. (2023). Internet of Things (IoT)-Based Environmental Monitoring and Control System for Home-Based Mushroom Cultivation. *Biosensors*, *13*(1), Article 1. doi: 10.3390/bios13010098

Das, A. K., Nanda, P. K., Dandapat, P., Bandyopadhyay, S., Gullón, P., Sivaraman, G. K., McClements, D. J., Gullón, B., &

Lorenzo, J. M. (2021). Edible Mushrooms as Functional Ingredients for Development of Healthier and More Sustainable Muscle Foods: A Flexitarian Approach. *Molecules*, *26*(9), Article 9. doi: 10.3390/molecules26092463

Diez, J., Kauserud, H., Andrew, C., Heegaard, E., Krisai-Greilhuber, I., Senn-Irlet, B., Høiland, K., Egli, S., & Büntgen, U. (2020). Altitudinal upwards shifts in fungal fruiting in the Alps. *Proceedings of the Royal Society B: Biological Sciences*, *287*(1919), 20192348. doi: 10.1098/rspb.2019.2348

Dimopoulou, M., Kolonas, A., Mourtakos, S., Androutsos, O., & Gortzi, O. (2022). Nutritional Composition and Biological Properties of Sixteen Edible Mushroom Species. *Applied Sciences*, *12*(16), Article 16. doi: 10.3390/app12168074

Gu, X., Lai, Q., Liu, M., He, Z., Zhang, Q., & Min, Q. (2019). Sustainability Assessment of a Qingyuan Mushroom Culture System Based on Emergy. *Sustainability*, *11*(18), Article 18. doi: 10.3390/su11184863

Herrero, C., Berraondo, I., Bravo, F., Pando, V., Ordóñez, C., Olaizola, J., Martín-Pinto, P., & Oria de Rueda, J. A. (2019). Predicting Mushroom Productivity from Long-Term Field-Data Series in Mediterranean Pinus pinaster Ait. Forests in the Context of Climate Change. *Forests*, *10*(3), Article 3. doi: 10.3390/f10030206

Istiyanti, E., Fivintari, F. R., & Syaftiana, M. (2020). Potential development of oyster mushrooms in the lowlands of Bantul Regency, Special Region of Yogyakarta, Indonesia. *IOP Conference Series: Earth and Environmental Science*, *423*(1), 012037. doi: 10.1088/1755-1315/423/1/012037

Kavaliauskas, Ž., Šajev, I., Gecevičius, G., & Čapas, V. (2022). Intelligent Control of Mushroom Growing Conditions Using an Electronic System for Monitoring and Maintaining Environmental Parameters. *Applied Sciences*, *12*(24), Article 24. doi: 10.3390/app122413040

Khokhar, M. F., Ejaz, H., Asif Butt, T., Iftikhar, S., Muzaffer, U., Ilyas, A., Mustafa, F. ul, Mushtaq, A., Ahmad, U., & Asghar, U. (2014). Enhancement of Usability for Farmers: User Interface for Rural Community. In A. Marcus (Ed.), *Design, User Experience, and Usability. User Experience Design for Everyday Life Applications and Services* (pp. 574–582). Springer International Publishing. doi: 10.1007/978-3-319-07635-5_55

Klinlek, P., Samattapapong, N., & Cadenet, V. D. (2020). *Design of Temperature and Humidity Sensor in Mushroom Houses Displayed via Wi-Fi* (4641). Article 4641. https://easychair.org/publications/preprint/gtW8

Kour, K., Gupta, D., Gupta, K., Anand, D., Elkamchouchi, D. H., Pérez-Oleaga, C. M., Ibrahim, M., & Goyal, N. (2022). Monitoring Ambient Parameters in the IoT Precision Agriculture Scenario: An Approach to Sensor Selection and Hydroponic Saffron Cultivation. *Sensors*, *22*(22), Article 22. doi: 10.3390/s22228905

Mahmud, M. S. A., Buyamin, S., Mokji, M. M., & Abidin, M. S. Z. (2018). Internet of Things based Smart Environmental Monitoring for Mushroom Cultivation. *Indonesian Journal of Electrical Engineering and Computer Science*, *10*(3), Article 3. doi: 10.11591/ijeecs.v10.i3.pp847-852

Manikandan, R., Ranganathan, G., & Bindhu, V. (2022). Deep Learning Based IoT Module for Smart Farming in Different Environmental Conditions. *Wireless Personal Communications: An International Journal*, *128*(3), 1715–1732. doi: 10.1007/s11277-022-10016-5

Mohammed, M. F., Azmi, A., Zakaria, Z., Tajuddin, M. F. N., Isa, Z. M., & Azmi, S. A. (2018). IoT based monitoring and environment control system for indoor cultivation of oyster mushroom. *Journal of Physics: Conference Series*, *1019*(1), 012053. doi: 10.1088/1742-6596/1019/1/012053

Moxley, A., Ebel, R., Cripps, C. L., Austin, C. G., Stein, M., & Winder, M. (2022). Barriers and Opportunities: Specialty Cultivated Mushroom Production in the United States. *Sustainability*, *14*(19), Article 19. doi: 10.3390/su141912591

Najmurrokhman, A., Kusnandar, Komarudin, U., Daelami, A., & Adiputra, F. (2019). Design and Implementation of Temperature and Humidity Control

System in Oyster Mushroom Cultivation using Fuzzy Logic Controller. *2019 International Conference on Computer, Control, Informatics and Its Applications (IC3INA)*, 146–150. doi: 10.1109/IC3INA48034.2019.8949573

Nasution, T. H., Yasir, M., Fahmi, & Soeharwinto, S. (2019). Designing an IoT system for monitoring and controlling temperature and humidity in mushroom cultivation fields. *2019 International Conference on Electrical Engineering and Computer Science (ICECOS)*, 326–331. doi: 10.1109/ICECOS47637.2019.8984446

Procházka, P., Soukupová, J., Tomšík, K., Mullen, K. J., & Čábelková, I. (2023). Climatic Factors Affecting Wild Mushroom Foraging in Central Europe. *Forests*, *14*(2), Article 2. doi: 10.3390/f14020382

Rahman, H., Faruq, Md. O., Abdul Hai, T. B., Rahman, W., Hossain, M. M., Hasan, M., Islam, S., Moinuddin, Md., Islam, Md. T., & Azad, M. M. (2022). IoT enabled mushroom farm automation with Machine Learning to classify toxic mushrooms in Bangladesh. *Journal of Agriculture and Food Research*, *7*, 100267. doi: 10.1016/j.jafr.2021.100267

Rahmawati, N., & Marbudi. (2021). Analysis of Oyster Mushroom Farming in Highlands (A Case Study in Sleman and Temanggung Indonesia). *E3S Web of Conferences*, *232*, 01012. doi: 10.1051/e3sconf/202123201012

Raman, J., Lee, S.-K., Im, J.-H., Oh, M.-J., Oh, Y.-L., & Jang, K.-Y. (2018). Current prospects of mushroom production and industrial growth in India. 한국버섯학회지, *16*(4), 239–249. https://www.earticle.net/Article/A348291

Ramli, M. R., Daely, P. T., Kim, D.-S., & Lee, J. M. (2020). IoT-based adaptive network mechanism for reliable smart farm system. *Computers and Electronics in Agriculture*, *170*, 105287. doi: 10.1016/j.compag.2020.105287

Rehman, A., Hussain, M., Idress, M., Munawar, A., Attique, M., Anwar, F., & Ahmad, M. (2020). E-cultivation using the IoT with Adafruit cloud. *International Journal of ADVANCED AND APPLIED SCIENCES*, *7*, 75–82. doi: 10.21833/ijaas.2020.09.012

Santoso, H. B., Delima, R., & Wahyuni. (2018). Webuse Usability Testing for Farmer and Farmer Group Data Collection System. *2018 Third International Conference on Informatics and Computing (ICIC)*, 1–6. doi: 10.1109/IAC.2018.8780465

Setiawati, D. A., Utomo, S. G., Murad, & Putra, G. M. D. (2021). Design of temperature and humidity control system on oyster mushroom plant house based on Internet of Things (IoT). *IOP Conference Series: Earth and Environmental Science*, *712*(1), 012002. doi: 10.1088/1755-1315/712/1/012002

Sher, H., Al-Yemeni, M., Bahkali, A. H. A., & Sher, H. (2010). Effect of environmental factors on the yield of selected mushroom species growing in two different agro ecological zones of Pakistan. *Saudi Journal of Biological Sciences*, *17*(4), 321–326. doi: 10.1016/j.sjbs.2010.06.004

Sihombing, P., Astuti, T. P., Herriyance, & Sitompul, D. (2018). Microcontroller based automatic temperature control for oyster mushroom plants. *Journal of Physics: Conference Series*, *978*, 012031. doi: 10.1088/1742-6596/978/1/012031

Thapwiroch, K., Kumlue, A., Saoyong, N., Taprasan, P., & Puengsungewan, S. (2021). Easy-Mushroom Mobile Application Using the Internet of Things (IoT). *Indonesian Journal of Educational Research and Technology*, *1*(1), Article 1. doi: 10.17509/ijert.v1i1.32647

You, S. W., Hoskin, R. T., Komarnytsky, S., & Moncada, M. (2022). Mushrooms as Functional and Nutritious Food Ingredients for Multiple Applications. *ACS Food Science & Technology*, *2*(8), 1184–1195. doi: 10.1021/acsfoodscitech.2c00107