Real-Time IoT Monitoring and Automated Control of Environmental Parameters in White Button Mushroom Farming in Zimbabwe

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Abstract

White button mushroom (Agaricus bisporus) cultivation is very sensitive to environmental changes; thus, this calls for a tight monitoring of environmental conditions, which in conventional practice is labor-intensive, inconsistent, and prone to human error. In Zimbabwe, mushroom growers predominantly rely on manual climate control, which has reduced yields, increased operational costs, and enhanced crop losses. The present study is, therefore, aimed at the design and implementation of an IoT Real-Time Monitoring and Automated Control System in enhancing the growth of white button mushrooms in Zimbabwe. The system comprises an ESP32 microcontroller interfaced with DHT22 temperature–humidity sensors, 12 V DC ventilation fans, a humidifier, relay modules, and an LCD for on-site monitoring. The complementary design of a mobile application using React allows for IoT cloud connectivity, enabling remote real-time viewing of data. Prototype testing showed that the system could measure environmental parameters like temperature, humidity, and ventilation accurately and was able to automatically actuate them to maintain optimum growing conditions within the crop canopy (22–25 °C and 70–90% humidity). Experimental results revealed that with deviations, the prototype responded effectively by turning on ventilation at 26 °C and initiating correction in humidity at 69%. The results confirm that the system could improve crop uniformity, reduce labor use, and enhance efficiency of production.

Keywords: Mushroom Farming, Real-Time Monitoring, IoT, White Button Mushroom, Smart Agriculture, Zimbabwe

1. Introduction

Generally, mushroom farming has emerged as one of the fastest-growing home-based agribusiness ventures in Zimbabwe, driven by low start-up costs, high nutritional value, and increasing consumer demand(Mabvongwe, 2019).Oyster mushroom production dominates the local market because it is inexpensive to grow, tolerates a wide range of temperatures, and requires minimal environmental control. On the other hand, White Button Mushroom is the most profitable variety in the country if grown properly yet remains under-produced despite its ready market and superior commercial value (Mutema et al., 2019). This mismatch is primarily brought about by the sensitivity of the species to environmental variation, hence needing strict control of temperature, humidity, moisture, and light during the production cycle(Barauskas et al., 2022). The White Button Mushroom grows well in controlled conditions, where temperature varies between 22–25°C and humidity at 70–90%(Subedi et al., 2020). Most of the small- to medium-scale farmers in Zimbabwe find it rather difficult to maintain these parameters using traditional methods. Existing methods rely on manual observation and changes, making the process labor-intensive and time-consuming and prone to human error(Higgins et al., 2020). Because of this, farmers experience fluctuating optimal growing conditions, an increased risk of contamination, low yields and crop loss. Lack of appropriate, real-time environmental monitoring systems is a contributory factor to the current persistent mismatch between local production and national market demand.

Zimbabwe's modernization drive under Vision 2030 is emphasizing the adoption of digital technologies that would enhance productivity from sectors like agriculture (Smart Zimbabwe 2030 master plan ICT transformation for a smart Zimbabwe ministry of ICT, postal and courier services, 2025). Smart farming, characterized by data-driven decision-making, automation, and real-time environmental monitoring, is now a cornerstone strategy toward sustainable food production. The rapid advancement within the Internet of Things allows transforming mushroom

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farming by enabling continuous collection of data, automation of environmental settings, and remote supervision by sensor-based systems(Raghu kumar B S et al., 2025).

Although IoT has been highly explored in general agricultural uses worldwide, the integration of IoT into mushroom growing, specifically for high-precision species like White Button Mushrooms, still has its many limitations within the Zimbabwe Agriculture sector(Zengeya et al., 2021). Most solutions address either monitoring or mobile-based data representation, not providing integrated systems that combine real-time monitoring and automated control of environmental parameters. This existing technological gap hinders climate-sensitive mushroom growers from increasing their production and bringing about consistent yields.

2. Literature Review

Mushroom farming is one of the most environment-sensitive forms of agriculture, which requires strict regulation of temperature, humidity, moisture, and light(Munshi et al., 2018). Generally, IoT in agriculture has gained significant attention in most countries around the world due to its potential to make processes automated, thereby reducing labour and improving productivity. However, in Zimbabwe, the incorporation of IoT into mushroom cultivation remains very limited. Most of the mushroom farmers in the country still use conventional farming methods, including hand-watering, manual humidity checks, and periodic visual inspection of crop conditions. These farming practices are time-consuming, inconsistent, and prone to human error; hence, they are not that suitable for climate-sensitive mushrooms like the White Button Mushroom.

Some commercial farmers in Zimbabwe have tried to regulate the growing-room conditions using air conditioners. While these devices help regulate the temperature and humidity, they lack real-time sensors and automation that can offer data logging or even remote access, hence are not able to guarantee consistent environmental control. The limitation of such technology justifies exploring IoT-enabled systems for real-time monitoring and automated environmental regulation

Several studies conducted around the world have demonstrated the potential of IoT-based solutions in mushroom cultivation. Sudhakara H.M. et al. developed an IoT-Based Real-Time Monitoring and Control System for Milky Mushroom farming in India. Their system focuses on optimal temperature between 25–30°C and humidity between 85–90% for efficient cultivation("A Review: IOT Based Real Time Monitoring and Control System for Mushroom Farm," 2023). Using a GSM module connected to an Arduino microcontroller, environmental data is transmitted to the farmer's mobile phone through an application. The changes in the environment can be observed from long distances, and some of the environmental parameters can be manually controlled remotely by farmers. However, one of the critical limitations of this system is that it is not fully automated with real-time corrective control mechanisms. It is highly dependent on the farmer's manual intervention, and the GSM-based communications result in slower data transmission, limited scalability, and have no cloud integration for long-term data storage.

Latha P. H. et al. implemented a mushroom climatic control system, powered by solar energy, in 2022 in India. The sensor suite included the DHT11 for temperature and humidity, the MQ135 for carbon dioxide monitoring, and other soil moisture sensors. Environmental data was transmitted through the ESP32 microcontroller to the Blynk IoT platform, with real-time monitoring and mobile notifications generated if environmental conditions exceeded threshold levels(H & H, 2015). While the solar-powered feature improved energy efficiency and enhanced environmental monitoring, the system was without automated actuation mechanisms. Specifically, the environmental parameters could not be controlled by switching on ventilation or humidification systems automatically. Instead, it would only alert users, who had to manually act upon receiving notifications. This provided major limitations with respect to offering consistent environmental control in a completely automated manner.

Other IoT applications have been explored in agriculture. Chimana and colleagues of Zimbabwe Open University presented the design of an IoT-Based Automated and Remote Monitored Greenhouse Irrigation System for a local university farm(IJCS2024_1paper3, 2024). The system incorporates an ESP32 module, soil moisture sensors, and a DHT22 temperature and humidity sensor for the cultivation of horticulture crops such as vegetables and tomatoes. While this system was indeed able to demonstrate both remote monitoring and automated irrigation, the design was not targeted at sensitive or climate-sensitive crops such as mushrooms. Such a crop requires more sophisticated control of humidity, airflow, and light. Moreover, the challenges of environmental stability in mushroom-growing environments, where even slight changes can mean contamination or loss of crops(Mushroom : The Fascinating Fungi, 2022), do not occur in this greenhouse irrigation system.

Other studies have pointed out other deficiencies in the IoT applications in agriculture. For instance, Douglas Allswell Kelechi et al (Kelechi et al., 2023)have determined that many of the existing solutions merely monitor environmental conditions without providing automatic feedback mechanisms to stabilize those conditions. Muharagi (Jacob et al., 2025) pointed out that manual adjustment of mushroom house parameters leads to inconsistency, resulting in low yield and quality. On the other hand, Weraikat D stressed that there is a need for real-time data-driven decisions in reducing crop losses(Weraikat et al., 2024).

Yet, with all these developments, IoT solutions targeted at White Button Mushroom cultivation remain few in the country. Most systems developed so far address only partial aspects like monitoring, mobile alerting, or irrigation automation (“A Review: IOT Based Real Time Monitoring and Control System for Mushroom Farm,” 2023). Only a few incorporate a fully integrated approach, combining:

- Real-time data acquisition
- Automated actuation
- Cloud-based data logging
- Remote monitoring
- AI-driven environmental decision support

Given the sensitivity of White Button Mushroom farming and the fact that farming methods are traditional in Zimbabwe, there is a clear gap for a comprehensive fully automated IoT system to maintain ideal conditions for mushroom growth without constant human intervention.

3. Methodology

The methodology adopted for this study comprised two main components, the first being the design and development of the hardware and housing system, and second the creation of the mobile IoT application. The system was engineered to provide continuous monitoring and automatic regulation of key environmental parameters essential for White Button Mushroom cultivation, including temperature, relative humidity, and CO_2 concentration [19]. At the core of the setup, an ESP32 microcontroller functioned as the central processing unit, interfacing seamlessly with sensors and actuators to sustain optimal growing conditions within the mushroom chamber.

i. System Architecture Overview

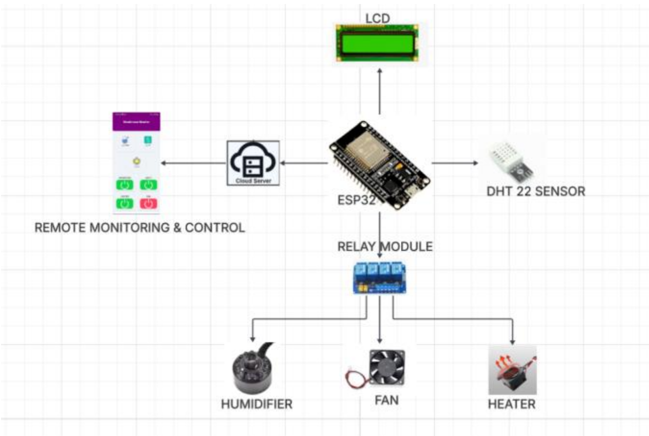

Figure 1.System Architecture Diagram

The proposed system employs an integrated architecture in which environmental data is continuously collected, locally processed by the ESP32 microcontroller, and transmitted to a cloud platform for real-time visualization and remote management. Automated actuation is achieved through relay-controlled components, including fans, a humidifier, and a heater, enabling precise environmental regulation within the cultivation chamber. Figure 1 illustrates how system components are interconnected to communicate with each other.

The overall workflow includes:

1. **Sensing**- Temperature, humidity, and ventilation conditions captured using digital sensors.
2. **Processing**- ESP32 reads sensor data, executes control algorithms, and decides actuator responses.

3. **Actuation**-Fans, humidifier, and heater activated via relay modules.
4. **Communication**- Data transmitted to the cloud and mobile app through Wi-Fi.
5. **User Interaction**: Remote monitoring and control through a mobile application

ii. Description of key components

Table 1.Key component description

Component	Functional
ESP32 Microcontroller	It functions as the central processing unit, gathering data from sensors, executing control algorithms, and operating the connected devices. At the same time, it facilitates Wi-Fi connectivity to enable seamless IoT-based communication.
DHT22 Sensor	It accurately measures temperature and relative humidity, providing dependable data for monitoring and maintaining optimal mushroom growth conditions.
12 V DC Fans (Ventilation & Exhaustion	One fan supplies fresh air to regulate CO_2 levels, while the other operates as an exhaust fan to prevent overheating and maintain proper air circulation within the chamber.
Ultrasonic Humidifier	It activates when humidity drops below the optimal range (85–95%), maintaining a moist microclimate that supports healthy mushroom growth and development.
Heater	It maintains optimal temperatures during cooler periods, preventing stunted growth and ensuring steady mushroom development.
LCD Display	It offers a real-time local display of environmental parameters, allowing on-site monitoring and supervision of growing conditions.
Relay Module	It connects the ESP32 to high-power devices such as fans, the humidifier, and the heater, allowing safe and efficient switching operations.

iii. Justification for hardware Components

Scalability

The ESP32 microcontroller was selected for its dual-core processing capability, multiple GPIO interfaces, and integrated Wi-Fi connectivity. These features support future system expansion, such as the integration of CO_2 sensors, camera modules, or AI-driven predictive algorithms.

Reliability

The DHT22 sensor was chosen for its high measurement accuracy (±0.5°C for temperature and ±2% RH for humidity), making it well-suited for the precise environmental control required in mushroom cultivation.

Cost-Effectiveness

All components were carefully selected to balance affordability with performance, ensuring that the system remains accessible and practical for small-scale mushroom farmers in Zimbabwe.

Energy Efficiency

The use of low-power ESP32 operations and DC fan systems minimizes electricity consumption, supporting sustainable farming practices and reducing operational costs.

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iv. Electronic Circuit design

For the mushroom environment management system, all required components were carefully selected and integrated using Proteus software. The circuit schematic was developed to define the interconnections and relationships among the various hardware components. Following schematic design, the circuit was converted into a PCB layout, where components were arranged, and conductive paths were routed across the board. Key design considerations such as component placement, trace width, and clearance were considered to ensure optimal performance, reliability, and manufacturability of the final PCB. Figure 2 shows the designed schematic circuit for the system developed using Proteus 8 Professional.

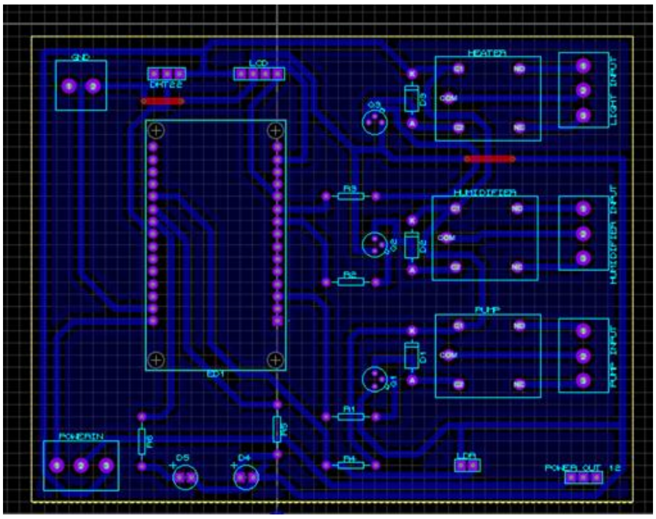

Figure 2.Designed Schematic Circuit for the system

After completing the schematic circuit design, a 3D visualization of the system was created using Proteus 8. Professional. This 3D model provided a realistic representation of the physical layout of all components, including relays, resistors, capacitors, sensors, and connectors. The visualization made it possible to identify and resolve potential design challenges such as component overlap, spacing limitations, and alignment issues before proceeding to the fabrication stage. Additionally, the 3D model offered valuable insights for refining the enclosure design, organizing wiring, and ensuring seamless hardware integration. Figure 3 shows the designed circuit in 3D, as designed in Proteus 8 Professional.

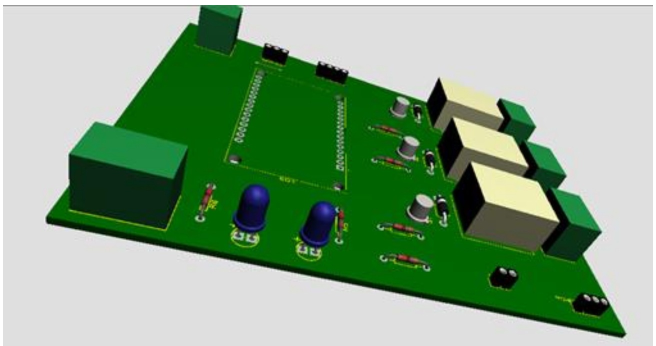

Figure 3.3D view of the designed circuit

After finalizing and validating the schematic circuit design, the next phase involved the fabrication of the Printed Circuit Board (PCB), followed by component placement and soldering. Once the PCB was produced, all essential electronic components including resistors, capacitors, relays, sensors, and connectors, were carefully mounted and soldered onto the board according to the design specifications. Precision soldering techniques were applied to ensure secure electrical connections, minimize the risk of short circuits, and maintain the overall integrity of the board.

After assembly, the PCB underwent a detailed inspection and functional testing to verify that each component performed correctly and that the system operated in full compliance with the design objectives. Figure 4 below presents the completed and fully assembled PCB for the mushroom environment management system.

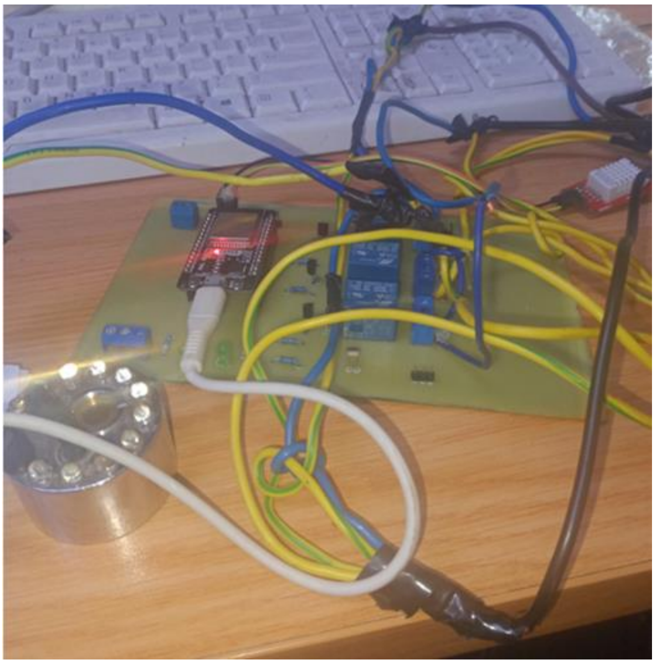

Figure 4.Assembled PCB for the System

v. Mushroom Housing Design

The mushroom housing functions as a controlled environment specifically designed to support optimal mushroom growth. It integrates environmental regulation and monitoring systems to maintain ideal conditions throughout the cultivation cycle. Key design considerations included material selection, temperature and humidity control, structural stability, ease of maintenance, and scalability to accommodate different production capacities.
For this research, a medium-scale housing unit was constructed with approximate dimensions of 0.5 m × 0.5 m × 0.5 m, providing sufficient space for experimental cultivation while ensuring effective environmental control and system testing.

vi. System Programming

The control logic for the IoT-based mushroom environment management system was implemented using the Arduino programming language within the Arduino Integrated Development Environment (IDE). This platform was chosen because of its user-friendly interface, flexibility and strong compatibility with the ESP32 microcontroller(Fezari & Al Dahoud, n.d.). Once the program was written, it was compiled and uploaded to the ESP32 board, enabling smooth communication between the sensors, actuators and control modules. During the programming phase, specific operational limits for temperature, humidity, and ventilation were established parameters that are essential for maintaining optimal conditions in White Button Mushroom cultivation. After deployment, the system operated with consistent stability and high accuracy. The sensors continuously gathered real-time environmental readings, which were analysed by the ESP32 microcontroller to determine the appropriate control responses. For example, when humidity levels dropped below the optimal range for mushroom development, the system automatically switched on the humidifier to restore favourable conditions. Likewise, if the temperature rose beyond the upper threshold, the ventilation fan was activated to dissipate excess heat and sustain the ideal microclimate within the mushroom chamber.

A snippet of the Arduino program used to implement these control functions is shown below.

```
#include <DHT.h>

#include <LiquidCrystal_I2C.h>

#include <WiFi.h>


#define DHTPIN 4
```

#define DHTTYPE DHT22

// Actuator pins

#define FAN_PIN 14

#define HUMIDIFIER_PIN 27

Defining HEATER_PIN 26

vii. Mobile Application Development

The mobile application for the IoT-based mushroom environment management system was developed in Visual Studio Code using React, selected for its adaptability, cross-platform functionality, and efficiency in building responsive user interfaces. Acting as a remote monitoring and control hub, the application enables farmers to view real-time environmental data directly on their smartphones. This capability allows them to oversee and adjust the growing environment from virtually any location with an internet connection, thereby minimizing the need for constant physical supervision inside the grow house. Communication between the mobile application and the ESP32 microcontroller is established through IoT protocols. The ESP32 gathers sensor data including temperature, humidity, and CO_2 levels and transmits it via Wi-Fi to a cloud server. The mobile application then retrieves this information using RESTful API requests, ensuring continuous, low-latency data updates for efficient and responsive system monitoring.

To obtain initial access to the mobile application essentially completing the user registration process users were first required to scan a QR code generated during the development phase. This QR code offered a fast and secure way to link each user's mobile device to the application.

Following this step, users proceeded to create an account, as illustrated in Figure 6. During registration, they were asked to enter key credentials such as their email address and password, which were securely stored to ensure authorized and protected access to the system. Figure 5 displays the generated QR code as rendered within the Visual Studio Code development environment.

Figure 5.Generated QR code in Visual Studio

Figure 6.Mushroom monitor signup interface

4. Discussion and results of prototype testing

The prototype of the IoT-based Real-Time Mushroom Environment Management System was evaluated in a controlled indoor environment that simulated the optimal conditions for White Button Mushroom cultivation. The testing phase was conducted to assess several key performance aspects, including sensor accuracy, actuator responsiveness, wireless communication stability, and the efficiency of the automated control algorithms.

During the experiments, the system effectively captured and displayed real-time environmental parameters such as humidity, temperature, and light intensity. This data was simultaneously presented on the LCD screen and transmitted to the mobile application via the cloud server, ensuring both local and remote accessibility.

As shown on the mobile application display in Figure 7, sample readings recorded included a humidity level of 69%, a temperature of 26°C and a light intensity of 50%, illustrating the system's capability to accurately monitor and respond to environmental fluctuations in real time.

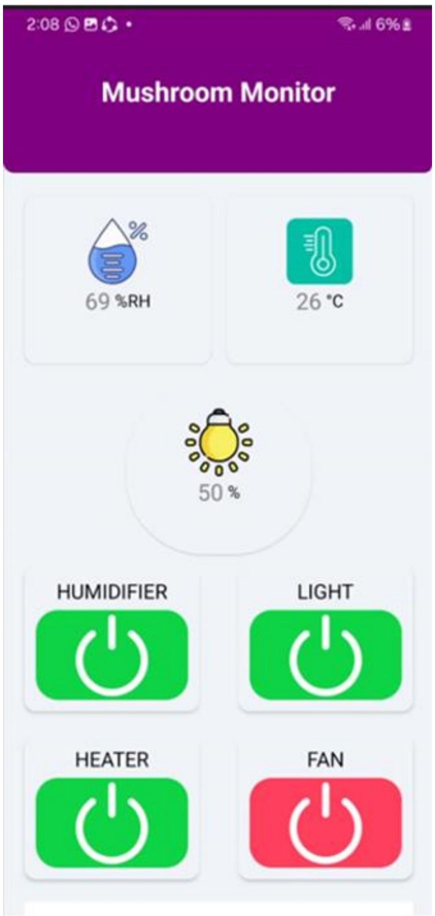

Figure 7.Mobile Application Displaying Data

To further assess system performance, a series of tests were carried out under varying environmental conditions. Data from multiple trials were collected, and average readings were computed to evaluate the overall reliability and consistency of the system. Table 2 presents the environmental parameters recorded during the initial prototype testing phase.

Table 2.Sample sensor readings during prototype operation

Parameter	Measured Value	Required Range	Status
Temperature (°C)	26°C	22–25°C	Slightly High
Humidity (%)	69%	70–90%	Slightly Low
Light Intensity (%)	50%	Low Light Preferred	Acceptable

As shown in Table 2, the prototype effectively detected and responded to environmental variations during the testing phase. The system accurately identified that the recorded temperature of 26°C was slightly above the optimal range for White Button Mushroom cultivation. Likewise, the humidity level of 69% was recognized as being below the ideal threshold, triggering the system to automatically activate the humidifier to restore appropriate moisture levels. The measured light intensity of 50% fell within acceptable limits for mushroom growth, as White Button Mushrooms thrive in low-light conditions and do not require direct illumination.
Overall, these results demonstrate the system's capability to accurately interpret environmental data and autonomously adjust conditions to maintain an optimal growing environment.

System Response Test

To assess the responsiveness of the control system, intentional environmental disturbances were introduced by reducing humidity levels and raising the temperature. The prototype consistently responded appropriately in all test scenarios, automatically activating or deactivating the actuators to restore optimal environmental conditions. The rapid response time measured at less than 3 seconds highlights the efficient processing capability of the ESP32 microcontroller and the reliable performance of the connected actuators.

Mobile Application Performance

The mobile application reliably retrieved sensor data through IoT connectivity, maintaining an average refresh rate of 1–2 seconds, which is sufficient for real-time agricultural monitoring. Remote control actions such as switching on the fan and humidifier were executed accurately, with only minor delays ranging between 2–4 seconds.

Through the application interface, users could conveniently access real-time readings, graphical trends and system status indicators, enabling efficient remote supervision of the mushroom growing environment. This functionality greatly improves flexibility for farmers, allowing them to monitor and manage conditions even when they are away from the cultivation site.

Reliability and Stability Tests

The prototype underwent continuous testing for a period of six hours, during which it demonstrated stable and reliable performance. No communication failures or sensor dropouts were observed throughout the testing phase. Power consumption remained within the anticipated range and the ESP32 microcontroller sustained a consistent and stable Wi-Fi connection for the entire duration of the test.

5. Conclusions and recommendations

The development and evaluation of the IoT-based Real-Time Monitoring and Automated Control System for White Button Mushroom cultivation demonstrated both the practicality and effectiveness of integrating smart technologies into Zimbabwe’s agricultural sector. The prototype efficiently monitored key environmental parameters temperature, humidity, and light intensity while automatically adjusting conditions to maintain optimal growth environments. Results from the prototype tests confirmed that the system could accurately detect environmental fluctuations and activate the appropriate actuators, such as the humidifier and ventilation fan, within seconds.

The mobile application enhanced system usability by enabling remote monitoring, real-time data visualization, and manual control options, thereby reducing reliance on labour-intensive manual management. Overall, the system proved to be a reliable, energy-efficient, and cost-effective solution capable of improving mushroom yield, minimizing crop losses, and promoting precision agriculture practices in Zimbabwe.

Despite these promising results, there remains significant potential for further enhancement and scalability. Future iterations of the system should incorporate additional sensors such as CO_2 concentration and ammonia detectors to enable a more comprehensive understanding of the growing environment. Moreover, the integration of machine learning algorithms could enhance predictive capabilities, allowing the system to anticipate environmental variations and adjust proactively. Finally, adopting solar-powered operation would improve sustainability and make the system more suitable for rural farmers in areas with limited or unreliable access to electricity.

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